UNIVERSITY OF NAIROBI

Inaugural Lecture

From Rope-Stretchers to E-Mapping

The Story of the Discipline of Surveying

Francis W. Odhiambo Aduol

Professor of Surveying

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by

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Introductory Remarks on

Prof. Francis W. Odhiambo Aduol

When in July 1973, Francis Aduol reported to the Faculty of Engineering at the University of Nairobi as a fresher he was clear about one thing; his dream to study for a degree in Surveying was about to come true. So when during the orientation week the freshers in the Faculty were asked to make their choices about which of the four degree programmes in the Faculty they wished to study for, Aduol promptly put down Surveying as his first choice. Thus started a career in the discipline in which Francis Aduol has now been involved with for close to thirty-three years.

As a secondary school pupil, Francis Aduol had greatly been fascinated by maps and the physical structure of the world in general. The fact that one could view a part of the world all before one as represented on paper, he found most fascinating. The detail and accuracy with which maps were presented had made quite an impression on him. The mapmaker to him had to be quite a meticulous field operator who also had to be very good at calculations and drafting. He decided already as a young secondary school pupil that he wanted to be a surveyor.

Francis Aduol had his primary school education at Alungo, Runda, and Migosi primary schools at the shores of Lake Victoria in Kisumu District. In 1967 he joined Kisumu Boys High School for his secondary school education. In secondary school his favourite subjects were mathematics, physics, geography, and technical drawing. He sought to develop a career around these subjects and was early on focussed on training as a high school teacher of mathematics, physics, and geography. In 1969, he stumbled upon a copy of the 1965 calendar of the University College, Nairobi, the predecessor the University of Nairobi. This booklet totally changed his career plans.

From the calendar of the University College, Nairobi, he learnt about the existence of a Surveying degree programme at the University College and that the ideal subject combination into the programme was mathematics, physics, and geography. He promptly made up his mind to aim at joining the University College, Nairobi, to study Surveying. When he took his O-Level examinations in 1970, he applied to join to Maseno School to study mathematics, physics, and geography for his A-Levels. In 1971, he was called to Maseno School alright, but to study mathematics, physics, and chemistry.

Convinced however that geography would be more relevant in his plans for a career in Surveying he promptly sought to substitute chemistry with geography in the combination of his subjects. The school however did not offer geography in combination with mathematics and physics at the A-Levels and was not quite ready to have just one student in the entire school offer the combination. Moreover, the career master, who was also the deputy headmaster and head of chemistry Department, believed the desired combination of subjects was totally ill advised.

Eventually after much convincing about the existence of a Surveying programme at the University of Nairobi, the school authorities relented and allowed the young Aduol to offer the combination of mathematics, physics, and geography for A-Levels. However the school would not prepare a timetable for this combination of subjects for just one student, but instead he was advised to cope as best he could with the existing timetable. The consequence of this was that quite often he had to miss certain lessons, as there were regular clashes between geography and mathematics or geography and physics on the timetable.

At Maseno, Aduol decided to learn by himself about Surveying and often went to Kisumu on weekends to borrow books on Surveying at the library of the Kenya National Library Service. At the practical level, he organised a team of classmates to carry out a survey of the school and to produce a school map thereof. For the geography class, the school had some rudimentary survey equipment which he supplemented with a further set of equipment which he had constructed by himself in the school workshop. The survey of the school was successfully completed and the map of the school produced and deposited with the school administration. A most fascinating geographical phenomenon of Maseno School was that, the equator as shown on the school map went right through the Headmaster's office.

Francis Aduol graduated with the degree of Bachelor of Science in Engineering (Surveying and Photogrammetry) from the University of Nairobi in 1976. He immediately joined Survey of Kenya as a land surveyor and was posted to the Nyanza-Western provincial survey office in Kisumu. His first task at Survey of Kenya was to establish the acreage of land owned by individuals, for compensation purposes, in the planned South Nyanza Sugar Company (SONY) at Awendo. He

further carried out several cadastral surveys in Kisumu, Siaya, Kakamega, and Bungoma Districts.

After a year's stint at Survey of Kenya, on 1st August 1977, Francis Aduol joined the Department of Surveying and Photogrammetry, University of Nairobi, as a Tutorial Fellow. As a Tutorial Fellow he was expected to participate in limited teaching while pursuing studies towards the MSc degree in Surveying. In 1978 he registered for an MSc degree by research and thesis in the area of geodetic surveying. In 1981 he was awarded the MSc degree for a thesis entitled "Optimisation of a three-dimensional terrestrial geodetic network".

In 1983, he was awarded a German Academic Exchange Service (DAAD) scholarship to enable him pursue studies towards the PhD degree at the University of Stuttgart in Germany. After a six month German language course at the Goethe Institut in Freiburg, he joined the University of Stuttgart in April 1984. For the first part of his studies he took courses in Geodesy (under Prof. Erik Grafarend), Engineering Surveying (under Prof. Kurt Linkwitz), and Geophysics (under Prof. Karl Strobach). He also prepared a Diplom-Ingenieur (Dipl.Ing.) level thesis under the title: "Detection of outliers in geodetic networks using principal component analysis and bias parameter estimation".

For his doctoral studies, Francis Aduol carried out research in the area of integrated three-dimensional geodesy. His mentors for the doctoral studies were Prof. Erik Grafarend and Prof. Burkhard Schaffrin. He was awarded the degree of Doktor-Ingenieur (Dr.-Ing.) [Doctor of Engineering] in 1988 for his thesis: "Integrierte geodätische Netzanalyse mit stochastischer Vorinformation über Schwerefeld und Referenzellipsoid" ["Integrated geodetic network analysis with stochastic prior information about the gravity field and reference ellipsoid"].

Francis Aduol was appointed on promotion to the positions of Lecturer in 1981, Senior Lecturer in 1988, and Associate Professor in 1994. He was appointed to the position of Full Professor in the Department of Surveying with effect from 19th May 2001. He is only the third person to occupy the position of Professor of Surveying in the University of Nairobi. Previous occupants of the position are Professor Lawrence Pentecost Adams (1971-1973) and Professor Raouf Shawky Rostom (1976-1993).

Prof. Aduol's area of specialisation within the broad field of Surveying is geodesy, which is the study of the geometry of the Earth including its gravity field as well as the precise determination of points within geo-space. In the period that he has been in the Department of Surveying, he has taught in diverse areas of specialisation including: geodesy and geodynamics, adjustment theory and computations, satellite positioning and navigation, astronomy and celestial mechanics, mathematical cartography and map projections, engineering surveying and surveying techniques, and general surveying and mapping.

Prof. Aduol's research has focused mainly in the areas of geodetic positioning within the frameworks of integrated three- and four-dimensional geodesy, application of robust statistical techniques in geodesy and detection of outliers in geodetic networks, application of geodetic techniques in Earth and engineering deformation analysis, and geodetic computations. He has published widely in these areas and has also written papers on surveying education and the development of the surveying profession. He has also supervised a number of postgraduate theses in his areas of research.

Prof. Aduol has served in various capacities in University administration at the University of Nairobi. In the period 1989-91 he was hall warden to Mamlaka Hall. From 1991 to 1995 he was Chairman of Department of Surveying. In 1995 he was elected Dean of the Faculty of Engineering and served in this position up to 1999. Since 1999 he has been the Principal of the College of Architecture and Engineering. Within the framework of University administration, he has been involved in numerous important University and national committees either as Chairman or member of committee.

Some of the technical work carried out by Francis Aduol in University administration has been developed into high quality research papers that have been published in international journals and conferences. These include the work on Full Time Student Equivalent (FTSE) and student unit cost that have been published in the *Higher Education Policy* journal and versions of which have also been presented at conferences.

Prof. Aduol is an associate member of the International Association of Geodesy (IAG) and has previously served as a corresponding member of the Special Study Group of IAG in mathematical statistics. Early this year, he was elected an honorary member of the Institution of Surveyors of Kenya in recognition of his distinguished and outstanding contribution to the Surveying profession in this country.

Prof. Aduol has been a visiting Professor at the University of Karlsruhe in Germany. He has also served as external examiner at the University of Dar-es-Salaam, Makerere University, Jomo Kenyatta University of Agriculture and Technology, and Maseno University. He is founder and founding Chairman of the Kenya DAAD Scholars Association.

Francis Aduol is married to Margaret and God has blessed them with three children; Joshua, Mark, and Timothy.

Table of Contents

"From His true dominion it follows that the true God is a living, intelligent, and powerful Being; and from His other perfections, that He is supreme, or most perfect. He is eternal and infinite, omnipotent and omniscient; that is, His duration reaches from eternity to eternity; His presence from infinity to infinity; He governs all things, and knows all things that are or can be. He is not eternity and infinity, but eternal and infinite; He is not duration or space, but He endures and is present. He endures forever, and is everywhere present; and by existing always and everywhere, He constitutes *duration* and *space*. Since every particle of space is *always*, and every indivisible moment of duration is *everywhere*, certainly the maker and Lord of all things can not be *never* and *nowhere*."

Isaac Newton

1

Introduction

1.1 Introductory Remarks

A Professorial inaugural lecture has three main objectives: (i) to act as a ceremonial occasion to formally install the new Professor into the office of Professor, (ii) to act as an indication by the new Professor that he has accepted the office of Professor in the respective University, and (iii) to provide an opportunity for the new Professor to indicate to the University community and the public in general his area of specialisation; which he then intends to represent within the University on the occupation of the Professorial Chair.

In respect of the third objective, the University of Nairobi guidelines for the Professorial Inaugural Lectures states that: "An Inaugural Lecture is supposed to be broad based but with a definite focus on the discipline one is professing, giving its philosophical foundation, its development over the years and how you see it developing in the University in your Department". This obviously presents quite a challenge in terms of how the lecture must be pegged. Most importantly, this guideline assumes that the Professorial Chair on which the inaugural lecture is being given is already well stated with clearly defined scope.

Normally, in this University, on appointment to the position of Professor, one's letter of appointment reads something to the effect that: "you have been appointed to the position of Professor in the Department ..." The letter of appointment usually would not state directly the Professorship to which one would have been appointed nor would the scope of the Professorship be stated. In this situation it often becomes quite a challenge for the newly appointed Professor to establish exactly how one should describe one's self; i.e. as Professor of what. Under these circumstances, the description of the Professorship that one is to occupy would be left largely to the whims of the newly appointed Professor.

I am trained in the broad area of Surveying but my specialisation is Geodesy, which is the study of the geometry of the earth including its gravity field and the precise determination of positions within geo-space. On my appointment to the position of Full Professor then, my immediate dilemma was how to describe myself: should I go by the title "Professor of Geodesy" or "Professor of Surveying"? I considered however that in view of the fact that the Department of Surveying had only one formal Professorial position, it would only be appropriate if the position carried the title "Professor of Surveying".

Following my appointment as Full Professor in the University of Nairobi, I set for myself the task of delivering my inaugural lecture as soon as possible. In accordance with the University of Nairobi guidelines for inaugural lectures, I interpreted that I was expected to present a broad based lecture on my discipline, covering its philosophical foundations, its development over the years, its future directions, and its position in the University of Nairobi. With this background, after much consideration, and in view of the fact that I had assumed the title "Professor of Surveying", I settled for a lecture covering the broad scope of the discipline of Surveying.

It happens that, in many universities, the discipline of Surveying is usually not one of those glamorously represented, at least in terms of numbers of students and physical size. Often, one would find Surveying represented as one of the minor disciplines in a Faculty of Engineering. Because of this minority status, the discipline is usually seen as one of those belonging in the class of the 'exotic' disciplines within the University. Many people though have an idea about what Surveying is supposed to be about. The common view is that it is concerned with the measurement of land and the making of maps. That indeed is correct, if however only to some extent. In view of this, I decided that it would perhaps be most appropriate to peg my inaugural lecture on an exposition of the discipline of Surveying.

In this lecture therefore, I hope to present to you the discipline of Surveying in its broad context, covering its scope and development over time and space. We shall not just look at the development of the discipline in a *linear*, historical context, but also in terms of *lateral* and *vertical* developments at given points in time. In the lecture we trace the development of the discipline from its foundations in antiquity to the modern era. We look at the status of the discipline presently, covering as well a review of its role in society today and then proceed to give an indication on the future directions the discipline is likely to take. Subsequently we contextualise the practice of geospatial technology to the Kenyan situation. To this extent then, I have chosen for the lecture, the title:

"From rope-stretchers to e-mapping: The story of the discipline of Surveying".

1.2 Structure of the Lecture

We start our story with the presentation in broad terms of what the discipline is about including its origins and scope (Chapter 2). From this we move on to a review of the geometric foundations of the discipline, covering as well the concepts of space, time and the universe (Chapter 3). Next we look at how the discipline has contributed to our understanding of the geo-graphic structure of the physical world around us (Chapter 4). We subsequently place the discipline in the context of the modern world and look at its practical role and function in society today (Chapter 5). We next review the directions the discipline is taking and try to extrapolate on where it is likely to be in the near future (Chapter 6). Eventually we come home to Kenya and take a look at the development of the discipline in Kenya and its practice in the country today (Chapter 7). We next tie this in with a look at the Surveying programme at the University of Nairobi (Chapter 8). The lecture is concluded with a recapitulation of the presentation (Chapter 9).

2

The Discipline of Surveying

2.1 Where in the World are We?

This lecture is taking place in the 8-4-4 multi-purpose lecture theatre, University of Nairobi, at 4 p.m. on 26th May 2006. This, all of us are agreed upon; for we are all here! However, in order that each one of us should have been able to get here for the lecture, we needed the information about the *place* and *time* of the lecture in its fullness. Consequently the place was specified to us as *the 8-4-4 multi-purpose lecture theatre at the University of Nairobi*, while the time was fixed as *4 p.m.* on *26th May 2006*.

Next, we had to physically get ourselves to this place, and for that we had to have *directions* on how to find the place of the lecture. But before we could even start we needed to know where we were. Then, beyond all this, we needed a *timing device* to help us establish when it was 4 p.m., being the time of the lecture. This looks all quite straightforward, and obvious to us. We know, and we expect, that for one to be at an event, the *place* and *time* of the event must be specified. We establish and find where we are or where we are going, by use of some unique system to enable us locate our position, both in terms of *space* and *time*. In fact, we have that the place that we specify is, itself, embedded in *space*, so that we still must speak of *space* and *time*.

In ordinary life, we are generally able to find a place by relating the location of that place to other features familiar to ourselves. For instance we might have been able to find this lecture theatre because we knew where the University of Nairobi was and then the exact location of the lecture theatre within the University of Nairobi. The University of Nairobi itself we might have been able to locate because we knew where it was within the city of Nairobi. We might extend this further to the location of the city of Nairobi within Earth itself. We note immediately a very interesting trend here; that we generally progress from the 'larger' place 'downwards' to the 'smaller' place within it. This of course places some hierarchy on the places we are dealing with, more in the pattern of an address.

In our daily life, we always want to know where we are at any one time. Being unable to establish where we are often makes us insecure and with the feeling of being lost. In fact we need to know where we are at any particular time in order that we can plan our next move, whether in geometric or social terms. It has of course been said that if we do not know where we are, we certainly cannot be able to find where we are going. Looked at carefully, one notices that, as human beings, we are always on the move; going somewhere at any one time. And over and above this we are always anxious to know where we are and the time at which we are there. This is the question: "*Where in the world are we?*" This is the fundamental question in the discipline of Surveying.

Intuitively, human beings, and indeed animals, have normally inferred where they were through mental analysis of their surroundings, largely based on past experiences as embedded in their memories. In this case we recognise our location through past experiences or instructions that might have been given to us by those with such past experiences. This approach is however far inadequate in terms of accuracy. Almost all of us here will recall at least one instance when we had to describe to some one else a particular location they were hoping to get to and just how inadequate we felt in giving the precise location of the place intended. Moreover the situation is further complicated by the fact that we often would like to know just "what lies beyond the mountain" without necessarily having to physically get there to establish this.

In order to be able to establish where we are, to establish the dimensions of the objects we work with, and to generally manage our environment, we must deal with the question of *geospatial location*. The point is: *Everything that happens, happens somewhere, at some particular time*. In this respect it might be significant to note that it has been estimated that about 80% of data used by Governments today has a spatial component. Whether one is dealing with the road infrastructure, population, information on taxation, housing, epidemiological distribution of disease, distribution of wildlife, the type and quality of flowers for export, or the distribution of bank customers, we quickly realise that *geo-spatial location* of the respective information is of utmost importance in order that the information may be of full use to us.

2.2 Surveying: Origins and Scope

The task of location finding is the principal objective of the discipline of Surveying. At the very basic level, the discipline of Surveying is concerned with *the geometric measurement of the Earth and its representation in graphical form*. To this extent, Surveying is usually understood to be about *land measurement and mapping*. Although the word 'Surveying' is today understood largely in the sense of

'measurement and mapping', it was not always so. The word 'surveyor' derives from the French word 'survoir', which means 'oversee'. The surveyor was then a person who oversaw an estate. He might have been involved in the geometric measurement of the estate, but such was not the understanding of his core function.

The first use of the word 'Surveying' in a technical sense was by an Englishman, *John Fitzherbert* in his book 'The Art of Husbandry' published in 1523. Fitzherbert defined a surveyor as "a person who took a view of the condition and situation of property, and overlooked its management". The idea of a surveyor here was that of a person who was primarily concerned with the overseeing of land in what we today know as land management and valuation. It is this broad view of the discipline that has been adopted by both the Royal Institution of Chartered Surveyors (RICS) of Great Britain and the International Federation of Surveyors (Fédération Internationale des Géomètres - FIG).

RICS has defined surveying as "the art of determining the value of all descriptions of landed, mineral, and house property, and of the various interests therein; the practice of managing and developing estates; the science of measuring and delineating the physical features of the Earth, and of measuring artificer's work". FIG on their part define the surveyor as "a professional person with the academic qualifications and technical expertise to practice the science of measurement; to assemble and assess land and geographic related information; to use that information for the purpose of planning and implementing structures thereon; and to instigate the advancement of such practices".

From these two definitions we notice that the RICS definition is relatively expansive and covers under the term 'surveying' the following: property valuation and management, property development and planning, building surveying and maintenance, minerals surveying and valuation, agricultural surveying and valuation, and land surveying and mapping. Land Surveying has generally been viewed in this sense only as a specialist discipline within the broad field of Surveying.

Land Surveying then is that aspect of Surveying that has traditionally been concerned with land measurement and mapping. Whereas the person who practices land surveying in England would be referred to as *land surveyor*, in other parts of Europe (e.g. France, Germany), because the discipline is viewed largely as being about the practical application of geometry in (land) measurement, such a person is normally simply referred to as *geometer* or *measurer*. The continental European concept of *practical geometry* lends itself to a much broader interpretation in terms of understanding what the discipline is really about since it does not restrict one to measurement of land.

In continental Europe, the scope of the discipline of Surveying as being largely concerned with the geometric measurement and graphical representation of the world was greatly influenced by the definition of geodesy by the German geodesist *Friedrich Robert Helmert* (1843–1917). In the German speaking world, Surveying of the 'geometrical measurement and mapping' type is known as *'Geodäsie'* (geodesy). Helmert defined *'Geodäsie'* as *'the science of measurement and mapping of the Earth's surface'*. He further considered *'Geodäsie'* to be divided into *'Erdmessung'* (global Earth measurement) and *'Ingenieurgeodäsie'* (land and engineering surveying or general surveying). As we shall see presently, in the English speaking world, although *Geodäsie* translates as *Geodesy*, the term *Geodesy* actually refers to *'Geodäsie'* as understood in the restricted sense of 'global Earth measurement' (i.e. *'Erdmessung'*).

The definition and scope of Surveying we adopt here is that of 'geometrical measurement and mapping'. In this context, Surveying, in the broader sense, has traditionally been considered to be comprised of three main areas, namely: *Geodesy* (global measurement), *Surveying* (land measurement), and *Cartography* (mapping). Onto these can today be added the technologies of *photogrammetry*, *remote sensing*, and *geospatial information systems*. We have in this structure that the sub-disciplines of Geodesy and (Land) Surveying are concerned with geometric Earth measurement while Cartography is about mapping. While (Land) Surveying might have been traditionally concerned with land measurement for both land management and engineering works, today the techniques of (Land) Surveying find application in precision industrial metrology as well.

At the very basic level, Surveying is concerned with the location of objects within geo-space. The principal means to define the location of an object within geo-space is the *coordinate*. It is through the use of coordinates that the precise position of any object within the physical world may be determined. Further, the representation of objects in a map itself is carried out only through the use coordinates. Working backwards from the map, we can also determine the position of an object in terms of coordinates using the coordinate system as provided on the map. The coordinate in fact is the thread that runs through all Surveying activities. Certainly the unique specialisation that the Surveyor possesses is *the ability to work with coordinates at the practical level.*

The geo-spatial location of an object would today be given to us through a *coordinate system*. Through such coordinate system, one is able to define the location of the particular object or event in an unambiguous manner. The coordinate systems used are themselves defined with respect to Earth, in the form of an *Earth-fixed coordinate system*. We therefore consider the locations of the objects to be given within the space of the Earth, or Earth-space. Consequently we speak of *geo-spatial coordinate systems* and the objects are said to be *geo-referenced*. The information that is geo-referenced in this way is further referred to as *geo-spatial information*.

Traditionally, geo-spatial information has been presented largely in the form of maps, plans, and charts, which themselves are the traditional outputs of the disciplines of *geodesy*, *surveying*, and *cartography*. Today, however, instead of the traditional maps, plans, and charts one speaks generally of *geo-spatial information*. The spectrum of geo-spatial information covers information about the *natural*, *built*, *industrial*, and *business environments*. This has meant that the traditional view of geo-referenced information, which was considered in the relatively narrow context of *surveying and mapping*, has had to be expanded into the broad field of *geo-spatial information science and technology*.

The basis of geo-spatial information technology is the traditional Surveying, which however came into existence due to the practical need to measure and to delineate land. The art of land measurement is one of the oldest professional activities in human history. Wherever people owned land, there developed a need to establish just how much land one owned. The boundary marker was protected by law and was treated with great respect. Already in the Old Testament (The Holy Bible, English Standard Version, 2001), we have in Deuteronomy and Proverbs thus:

> **Deuteronomy 19:14**: "You shall not move your neighbour's landmark, which the men of old have set, in the inheritance that you will hold in the land that that the LORD your God is giving you."
>
> **Deuteronomy 27:17**: "'Cursed be anyone who moves his neighbour's landmark.' And all the people shall say Amen."
>
> **Proverbs 22:28**: "Do not move the ancient landmark that your forefathers have set."

Around 10,000 BC various groups of people started to establish settlements that would eventually become city-states. The city-states flourished particularly in Mesopotamia, China, and parts of North Africa and Europe. Agricultural activity quickly developed and with this, land acquired special economic value. Parallel with all this it soon became evident that in order for the state to function, it needed money and to get this money it would have to levy taxes. An obvious area in which to levy taxes was land.

In order to tax land equitably it was necessary to establish just how much land one owned. This brought forth the art of *land measurement* and with this a profession of *land measurers*. The land measurers of this period were chiefly *geometers* (surveyors), *astronomers*, and *priests*, who used a combination of rudimentary geometry and astronomy in their measurements. Around 5,000 BC in Babylonian society, land ownership was already being recorded on clay tablets complete with the signature of the surveyor. The practice of the surveyor signing the record of his field measurements, computations, and the map is continued to today worldwide, except of course that the medium of record is today the paper rather than clay tablet.

The discipline of Surveying is however normally taken to have formally originated in Egypt around 3,000 BC. The Egyptian King (Pharaoh) is said to have divided the land into plots for the purposes of taxation. Every year the Nile would over-flood its banks and in the process sweep away the plot boundary markers. The boundaries would thus need to be re-established. Immediately there came into existence a cadre of land measures to carry out the task of re-establishing the plot boundaries. The land measurers were officially known as the *Royal Surveyors* or the *Scribes of the Fields* and used a special kind of rope, as their principal measuring tool. Consequently they became known as *rope-stretchers*, or in Greek, *harpedonaptai*. The rope-stretchers even had a professional society known as the *Royal Society of the Rope-Stretchers.*

The measuring rope used by the land measurers was divided into twelve equal parts. By using the rope to set out a triangle with sides 3-4-5 one obtained a right angle. One could also use it to set out an equilateral triangle with sides of 4 units, as well as a square with sides of 3 units. The right angle triangle was particularly important because it facilitated the setting out of right angles. The right angle was considered magical and the technique of establishing it was held in great secrecy by the rope stretchers. The rope itself was considered magical and sacred. Up to this day, many in the technical fields, such as masons and carpenters still employ the 3-4-5 triangle to set out right angles.

The Royal Surveyors were specially trained in mathematics and were among the best educated in their time. Besides land measurement, they also possessed skills in general calculation, agronomy and engineering. In engineering, they put to use their skills in measurement in the constructions of great engineering structures such as the pyramids. One of the finest examples of the measurement abilities of the rope-stretchers is the Great Pyramid (2,900 BC) at Giza. From their knowledge in agronomy, on the other hand, they were put in charge of the general management of the agricultural farms and the produce thereof. Two such surveyors were *Djeserkareseneb* and *Menna*, whose works are well represented by murals in their respective tombs at Thebes and Sheikh-Abd-el-Qurna in Egypt. Representations of these murals are given in Fig. 1a and Fig. 1b.

From the practical task of surveying, the Greeks developed *Geometry*. On to this, the Greeks were motivated by questions on how to describe space using geometry and the theory behind it. The prominent Greek philosopher *Heron of Alexandria* (10–75 AD) is reported to have written several treatises on surveying in which he explained various field surveying methods including plan drawing and surveying calculations. For several years, Heron's works were the standard in surveying

practice in Greece and Egypt. Many of these ideas formed the basis of the extensive application of Surveying in engineering constructions by the Romans. The Roman public works engineer *Sextus Julius Frontius* (10–104 AD) in an extensive treatise, recorded the surveying methods used by the Romans in this period. This work would remain the standard reference in surveying for many years.

Fig. 1a: The Egyptian rope stretchers – from the tomb of Djeserkareseneb (*www.osirisnet.net*)

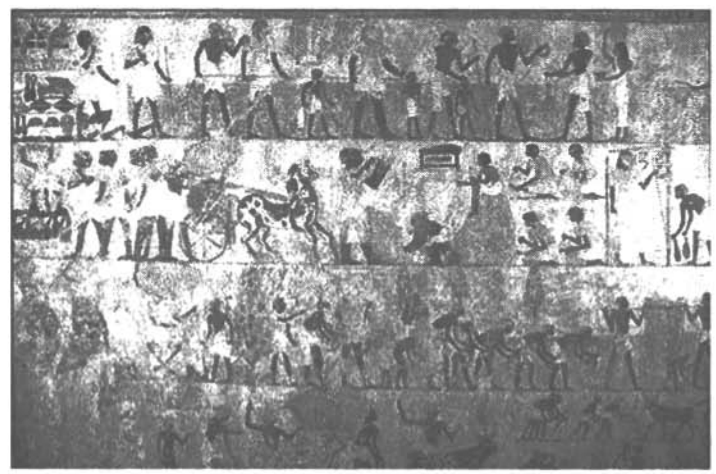


Fig. 1b: The Egyptian rope stretchers – from the tomb of Menna (*www.osirisnet.net*)

For a long time the techniques of land surveying were based solely on linear measurements with ropes, or equivalently, chains and tapes. This gave rise to the well-known technique of chain surveying. The first means of measuring angles for surveying and for navigation was through the use of the magnetic compass, which had been invented in China in the period 221-206 BC. It took however over some 1,050 years before the magnetic compass found application in the determination of direction in surveying and navigation. It is reported that the compass had become a common navigational device on ships in the period 850-1050 AD.

The technology of measuring angles however took a dramatic leap with the invention of the theodolite in the 16th century by an Englishman, *Leonard Digges* (1520-1559). The word 'theodelitus' was used for the first time in a book on surveying and cartography by Leonard Digges, which had been published posthumously by his astronomer son *Thomas Digges* (1546-1595) under the title *Pantometria*, in 1571. The full title of this work was actually "A *Geometricall Practise, named Pantometria, divided into Three Bookes, Longimetria, Planimetria, and Stereometria, containing Rules manifolde for Mensuration of all Lines, Superficies, and Solides*". Digges' theodelitus was basically a large protractor which facilitated the measurement and drawing out of horizontal angles.

The first documented theodolite which could read both horizontal and vertical angles was made by the Englishman *Humphrey Cole* (1530-1591) in 1574. Later on in the 18th century, a telescope was added on to facilitate better the setting out of the line of sight. The transit theodolite was introduced in England in 1840s. What however may be called the first modern theodolite was the Th1 which was developed by *Heinrich Wild* (1877-1951) in 1921 at the firm Carl Zeiss Jena of Germany. The Th1 had glass circles and was relatively compact in design; which design would define the general design of theodolites well into the 1980's. Subsequently, with two partners, Wild founded the firm Heinrich Wild in Heerbrugg, Switzerland. In 1923, the company brought into the market the Wild T2 theodolite. The Wild T2 theodolite would become a legend among surveying instruments.

The next major development in the discipline of Surveying was the introduction of *photogrammetry* in topographic mapping in the early part of the twentieth century. In photogrammetry one uses photographs to obtain reliable measurements about an object and is today the principal technology used in large-scale topographic mapping. The wide application of photogrammetry in topographic mapping really took off only after the invention of the aeroplane. The use of the aeroplane then facilitated the use of cameras in space to take photographs of topography in 'vertical photographic mode'. The term photogrammetry itself was first used by the Prussian architect *Albrecht Meydenbauer* in 1867.

The technology of measuring distances on the other hand made a huge leap with the development of the Geodimeter by the physicist-geodesist *Erik Bergstrand* (1904-1987) in Sweden in 1948. Bergstrand was in involved in experiments to determine the velocity of light. He quickly reckoned that with the velocity of light known, one could work backwards to determine the distance between two points if one could time how long it took the electromagnetic wave signal to travel through the distance. The Geodimeter used the light wave part of the electromagnetic wave spectrum and could measure distances of up to 30km with accuracies at the level of 1/1,000,000. This development had for the first time introduced the use of electromagnetic wave signals in Surveying. The measuring systems became known as electromagnetic (electronic) distance measurement (EDM).

Following onto the development of the Geodimeter, a South African telecommunications engineer *T. L. Wadley* developed, in 1954, another EDM instrument, the Tellurometer, which used radio waves to measure distances. The Tellurometer could measure distances of up to 100km and to an accuracy of 1/1,000,000. The Tellurometer went into commercial production in 1957. The instrument quickly became the principal equipment for the measurement of distances in the establishment of geodetic networks, which normally required the measurement of long distances.

In 1970, *K. D. Froome* and *R. H. Bradsell* of the National Physical Laboratory, Teddington, Britain, developed a new EDM instrument, the Mekometer. The Mekometer was a short distance instrument with a range limited to about 5km. Its strength was in its accuracy as it could measure distances with precisions at the level of 0.1mm (i.e. 1/100,000,000. The Mekometer remains the most accurate distance measuring instrument to today.

With the refinement in the accuracies obtainable in the measurement with conventional land surveying techniques, from 1970's, the techniques of Land Surveying began to find considerable application in areas non-traditional to land measurement and mapping. Such areas included analysis of deformation of civil engineering structures, industrial metrology involving precise measurements within the manufacturing environment, analysis of Earth deformation due to geodynamic and other phenomena, and in the monitoring of satellite orbits within the broad framework of space science and technology. All of this was considerably enhanced by the parallel advancement in computer technology that immensely facilitated the handling of extensive and complex computational problems.

In the last twenty years however, with the advancements in space, computer, information, and communication technologies, that have found extensive applications in Surveying lately, the discipline has acquired a much broader scope;

one that goes far beyond just land measurement and mapping. These developments started with *satellite positioning systems* in 1960's, followed by the introduction of *remote sensing* technology in 1970's and then the *geo-information (geo-spatial information) systems* (GIS) technology in 1980's. These new technologies have so dramatically changed the nature of the discipline in the last decade that referring to the discipline as Surveying, which is traditionally about land measurement and mapping, is no longer considered appropriate.

That which is geo-spatial in nature must however operate within space and over a duration given in the form of time. And here we today take it for granted that we live in a three-dimensional, infinite, space. First, this was never always so and secondly that space is only three-dimensional to some extent. The whole question of the three-dimensionality of space is made non-sense of by the fact that we also live within a time continuum. What then do we mean by space and time and how does all this tie up with the whole question of geo-spatial positioning, measurement, and modelling? In order to place things in perspective, we thus, right from the outset, take a brief look at the concepts of space and time, and indeed the universe, of which our earth is a part.

3

The Foundations:
Space and the Universe

3.1 Space and Time

The philosophical nature of space and time has intrigued mankind since the dawn of civilisation. Mankind has always been curious to establish where he was at a particular time, or even where a particular event occurred at a particular time. Indeed the question of the nature of space and time has consistently occupied some of the best philosophical minds since the beginning of mankind's existence on Earth. The origin of formal speculation on space and time can however be traced to the Bronze-Age cultures of the period 3800–1500 BC. In this early period, time, in an abstract sense was considered as some kind of god.

Some of the early ideas about space and time were propagated by Greek philosophers: *Zeno of Elea* (ca. 459–ca.435 BC), *Plato* (429–348 BC), and *Aristotle* (384–322 BC). Plato considered space to be homogeneous, immutable, spherical, infinite, everlasting, indestructible, and isotropic, as well as having no voids but possessing no qualities of its own. Aristotle, who in fact had been a student of Plato's, on his part taught that physical objects were made up of five fundamental elements, namely, earth, air, fire, water, and ether and that space was qualitatively heterogeneous, finite in extent, continuous, an-isotropic, object dependent, mind independent, immutable, and incorporeal. In addition Aristotle considered that space admitted of absolute positions, possessed causal activity of spaces, and was a plenum.

After Aristotle, questions about the philosophy and nature of space and time did not receive much attention until well into the seventeenth century. Then the discussion was taken up by the great English mathematician and physicist *Isaac Newton* (1642–1727). Newton argued that both space and time were *absolute*, in the sense that they existed irrespective of events within them. In this respect, Newton stated that "Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, ... Also, absolute space, in its own nature, without relation to anything external, remains always similar and immovable." The interpretation of this was that absolute time and space were in themselves not detectable but could be experienced through detectable phenomena that 'existed' and 'passed' through them.

Thus, according to Newton, even if there were no objects, space would still exist, and time would also exist even in the absence of any occurrences. According to this view, time existed even prior to the coming into being of the universe and that it would be possible for time to continue to exist even if the universe itself were to cease to exist. From the theological perspective this thus opened room for questions such as "where was God before the creation of the universe?"

Meanwhile Newton had sought to describe the motions of objects within the universe. This effort culminated in the establishment of the well known Newtonian laws of motion. Newton immediately adopted his newly established laws of motion and the universal law of gravitation to describe the motions of the planets around the sun. His calculations however failed to provide for a stable solar system due to certain inconsistencies that he was unable to account for. Newton proceeded to explain that, in view of the apparent instability of the solar system, God would need to intervene from time to time to straighten out the planets on their orbits.

Newton's position that space and time were absolute in nature, together with his mathematical explanation of the physical structure of the universe, were vehemently opposed by the German mathematician and philosopher *Gottfried Wilhelm Leibniz* (1646-1716). The argument between Leibniz and Newton on the nature of space and time generated a series of major correspondences between Leibniz and Newton (through Mr. Samuel Clarke, who was Newton's public relations agent) in the period 1715 to 1716. The correspondences were published in both England and Germany and became one of the most widely read philosophical books of the eighteenth century.

According to Leibniz space and time were nothing by themselves except that they acquired relative existences with respect to objects and events within them. Leibniz considered space to be merely an order of coexistences while time he viewed as an order of successions. To this extent he argued that space and time only made sense when viewed in relation to objects and phenomena within them. He held the view that space was infinite, continuous, and homogeneous; time on the other hand was infinite and continuous but inhomogeneous. He argued that time had to be inhomogeneous because, while in space no point had priority over another, in the case of time, those events that came earlier had priority over those that came later. He considered both space and time to have no vacua, hence that they were both continuous.

Leibniz found the consideration of Newton that God needed to intervene from time to time to stabilise the universe outrageous. He reasoned that this would mean that God was an imperfect God who could create a system that needed to be adjusted from time to time; this he found theologically unacceptable. In an exchange of correspondence with Newton, on this matter, Leibniz stated that "God's perfection requires that all his actions should be agreeable to his wisdom; and that it may not be said of him, that he has acted without reason." Leibniz could not see therefore how God could create an imperfect world. Moreover absolute space and time would admit of the position that there was existence before the creation of the universe, which according to Leibniz was not possible. He argued that space and time could only be perceived in a relative sense and could not be absolute as suggested by Newton.

The idea of absolute space and absolute time was also later on found untenable by other scholars. The French mathematician *Henri Poincaré* (1854-1912) supported the position of Leibniz and considered that there was neither absolute space nor absolute time. Space and time were thus considered to make sense only when considered in relative terms.

At the more practical levei, humankind was concerned about his geometric position within space. Thus alongside the philosophical speculations on the nature of space and time, there was the special interest about the physical structure of that space. The first formal speculation on this was by Plato, who taught that the universe was spherical with the Earth as its centre. This position was also echoed by Aristotle. *Claudius Ptolemy* (ca.100-ca.170 AD) extended this by considering that the planets revolved around the Earth in circular orbits but with the Earth placed eccentrically with respect to the centre of the orbit. Ptolemy's ideas about the universe were published in his book *Almagest*, which would remain the most authoritative publication on astronomy until well into the 16th century.

On the onset of the 16th century, the Polish astronomer *Nicolaus Copernicus* (1473-1543) was the first to delve once more into the question about space. He postulated that the sun was the centre of the universe and that the Earth, together with the other planets, revolved around the sun in circular orbits. The ideas of Copernicus about the universe were collected in his publication *De Revolutionibus*. The new model for the universe was however highly criticised by the Church. In the view of the Church, it undermined the spiritual significance of Earth, especially as presented in the Biblical story of creation. In 1600, an Italian scientist, *Giordano Bruno* (1548-1600) was in fact brought before the inquisition and burnt at the stakes for suggesting that the universe was infinite and that the Earth was only a planet in the system of the sun.

These ideas were followed up by the German astronomer *Johannes Kepler* (1571-1630), who subsequently extensively studied the geometry of the orbits of planets, and the nature of the motions of planets, around the sun. Between 1609 and 1619, Kepler published his, now well known, three laws of orbital motion. By this time the concept of the planets revolving around the sun was well established and Kepler's work only marked a refinement of the motions of the planets within this system. Kepler had been able to deduce his laws empirically on the basis of astronomic data observed by his late master *Tycho Brahe* (1546-1601).

Moving on from Kepler, the next most significant personality in the study of the universe was the Italian astronomer and physicist *Galileo Galilei* (1564-1642). Up to this time it was still believed by many, and especially the Church, that the earth was the centre of the universe. In 1635 Galileo published his work *Dialogue Concerning the Two Chief Worlds* in which he discussed the geocentric and heliocentric models of the universe. His objective here was to communicate the view that the universe was heliocentric. This however earned him a major controversy with the Church, which subsequently ordered him to appear before its court for heresy. He was sentenced to the equivalent of a house arrest for the rest of his life. Many will recall that Pope John Paul II finally on 31st October 1992 announced what amounted to an acquittal of Galileo on this matter.

In between, Galileo had become the first a person to construct a practical telescope for astronomic work. Through the use of his newly constructed telescope he discovered three of Jupiter's satellites, Io, Europa, and Callisto, and carried out more detailed observations of Venus and the Moon. He also predicted correctly the effect of gravity on falling bodies and thereby set the foundation for Newton's law of gravitation and Einstein's relativity theory.

Motivated by his newly established laws of motion, and especially the law of universal gravitation, Isaac Newton sought to describe the motions of the planets. He started off with a mathematical proof of Kepler's orbital motions of the planets. Subsequently he moved over to describe the perturbations of the moon and the planets. Newton published these ideas in his monumental work *Philosophiae Naturalis Principia Mathematica* (The Mathematical Principles of Natural Philosophy), commonly known simply as the *Principia*. Newton's law of universal gravitation unified so elegantly and beautifully the gravitational interaction between objects in space that the law remains the cornerstone of classical mechanics to today.

The task of describing the motions of celestial bodies beyond Newton was taken up by the French mathematician *Pierre-Simon Laplace* (1749-1827). Laplace devoted most of his active life as a mathematician to the problem of describing mathematically the motions of heavenly bodies. His work was firmly based on Newton's law of universal gravitation. When he was through, he presented this work in the masterpiece *Mécanique céleste* (Celestial Mechanics). In the *Mécanique céleste*, Laplace had collected all his work on astronomy in one comprehensive form. The *Mécanique céleste* provided the most comprehensive advancement on the theory of the motion of heavenly bodies in the space of 2000 years since the *Almagest*.

By the beginning of the twentieth century it was felt that the tools to describe the motions of objects in space had been conclusively provided for by Newton's laws of motion and universal gravitation and that all one needed was the *Principia*. Laplace on the other hand was considered to have described adequately the motions of heavenly bodies and all this was covered fully in the *Mécanique céleste*. However it was ever more being realised that Newtonian mechanics only held under certain conditions. Especially, Newtonian mechanics theoretically appeared to admit of motions that could move at rates even faster than the speed of light, a situation considered impossible.

From the apparent inadequacies of Newtonian mechanics, it was becoming evident that there was needed a more comprehensive theory to describe motions of objects in space and the structure of space itself. The more comprehensive approach was offered by the theory of relativity as proposed by *Albert Einstein* (1879-1955). In relativistic mechanics there was no such thing as absolute space or absolute time; events that appeared to occur simultaneously both in location and time when observed from one reference frame would appear to be at different locations and times when observed with respect to another reference frame. The theory of relativity was formulated in two parts; the special and the general relativities.

Einstein's special relativity theory was published in 1905. The special relativity theory was formulated to handle questions of motion within space and time in such a way that the speed of light remained constant and such that motions faster than the speed of light were not allowed. The theory of special relativity was based on two axioms: (i) it was impossible to determine whether one was in motion or at rest except if such is taken in relation to other bodies, and (ii) the speed of light was independent of the speed of its source and always remained constant for all observers. It is the special relativity theory that predicts the famous mass energy equation $E = mc^2$. In 1915 Einstein published the theory of general relativity. General relativity sought to offer a unifying theory of gravitation that would take into consideration the consequences of special relativity. In general relativity, gravitation was considered as a manifestation of curved space and time rather than as due to forces.

3.2 Measuring Space

Space and time or space-time however must essentially remain in the abstract until we can be able to measure and quantify them. From the beginning of his very existence, mankind sought to quantify space and thereby gain an idea of how large his world was and for how long the world had been in existence. What was the shape of the Earth, how large was it and how did it fit in with the rest of the universe? And what about time; when did it begin and how could we measure it and determine its length? Was it even indeed possible to put a measure on space and time? These questions occupied the minds of the best philosophers of the time.

However, when mankind began to get seriously involved with the measurement of space and time, this did not come from the philosophical perspective but from the need to deal with quite practical problems of state governance and agriculture. This was the desire by the state to raise money through taxation of land and hence the need to *measure land*, or surveying. And Surveying, as we have seen, is about the measurement, representation, and analysis of spatial relationships. In all this, a key parameter is the *coordinate*, which in fact is at the heart of the discipline of *Geometry*. It was only natural then that the need for land measurement would lead to the development of the discipline of Geometry. Subsequently, Geometry itself would form the foundation and core of the discipline of Surveying.

Webster's Dictionary defines *Geometry* as the branch of mathematics that deals with the measurement, properties and relationships of points and shapes, lines, angles, surfaces, and solids. One simple definition however is that *geometry is the study of size and shape* and still another one is that it is *the study of spatial relationships*. The concepts for the measurement of space and time are founded on the discipline of *Geometry*. In the four-dimensional space-time concept, the location of any point or event can be specified completely by four coordinates (x, y, z, t) in which the triplet (x, y, z) represents location in three-dimensional space while t represents the instant of the happening, i.e. time.

The idea to measure space started with mankind's desire to put measurement on his environment and the features around him. This, to the Egyptians and Babylonians was basically measuring the Earth (or the world). Consequently the Egyptians and Babylonians described the process as 'Earth measurement'. Much later on, the Greeks would introduce the term *geometry*, which was their translation of 'Earth measurement' into Greek. The term 'geometry' derives from the two words *geo* (= Earth) and *metria* (= measurement). The Greeks had realised that space could in fact be described in quantitative terms through mathematics, which at that time was basically geometry. The Greeks had held the view that geometry was the key to understanding the space of the world in quantitative terms.

Geometry is the oldest recorded mathematical science. The discipline is considered to have originated in the period around 3,000 BC with the practical task of *land measurement* in ancient Egypt as then practised by the *rope-stretchers*. As we have already seen, the Egyptian land measurers already knew how to use the 3-4-5 triangle to set out the right angle. The rope stretchers however had apparently not quite involved themselves with the theory of the 3-4-5 triangle but seem to have been contented just to apply the technique in practical measurement. Nevertheless, the discovery that the 3-4-5 triangle could be used to set out right angles is today ranked among the greatest in the history of mathematics and measurement technology.

The Greek philosopher *Pythagoras of Samos* (ca. 569 - ca. 475 BC) later on in the 6^{th} century BC sought to explain the theory behind the technique. Pythagoras had come across the rope-stretchers during his travels to Egypt and was most fascinated by their technique of setting out the right angle through the use of the 3-4-5 triangle. He then sought to establish the theory behind the triangle. Pythagoras' proof of the problem has come down to us as the *Pythagoras' Theorem*. The development of the theory behind the 3-4-5 triangle rule by Pythagoras is normally considered the origin of serious and formal geometrical thought.

Pythagoras theorem is generally considered as the root of all geometry and thus a major cornerstone of mathematics. And Pythagoras himself stands out as one of the lofty towers in the development of geometry and mathematics. After his journeys to Egypt and Babylon, Pythagoras returned to Greece where he founded a school at his hometown Samos. He subsequently moved to southern Italy where he founded and headed what was at the same time a school and a society for the study of philosophy and religion. Here he invented the term *mathematics* from the word *mathema*, which meant 'science'. The members of the society were known as the Pythagoreans and had their lives completely dedicated to mathematical and philosophical thought. Pythagoras in fact taught that, at its deepest level, *reality is mathematical in nature*.

From Pythagoras, the development of geometry passed on to the school around *Plato* (427-347 BC). After coming into contact with mathematics through the Pythagoreans, Plato founded the Academy in Athens in 387 BC. Plato's objective in establishing the Academy was to train young people to become future statesmen of good, solid, educational background. In mathematics he taught that: "*the reality which scientific thought is seeking must be expressible in mathematical terms, mathematics being the most precise and definite kind of thinking of which we are capable*". It is also said that he had inscribed at the entrance to the Academy that: "*Let no one ignorant of geometry enter here*". The Academy is of course normally considered as the beginning of the concept of the University.

The foundations of what we consider generally as conventional geometry were however laid by the Greek philosopher and mathematician *Euclid of Alexandria* (325-265 BC). Euclid studied all the geometry up to his time, provided interpretations for the various concepts, and presented all this in a monumental book of thirteen volumes, the *Elements*. In the *Elements*, Euclid treated of the foundations of geometry with such thoroughness and completeness, that the *Elements* would provide the reference point for the teaching of geometry well into the nineteenth century. It is great credit to Euclid's work that the *Elements* has in fact remained the most widely read non-religious book in the world. *Euclidean geometry* is of course the standard geometry we learn in school and often goes by the description *plane geometry*.

The geometry according to Euclid rests on five postulates, also commonly referred to as axioms. On these postulates, Euclid based all the proofs for the theorems in his book. The five postulates, re-stated are:

1. Any two points can be joined by a straight line
2. Any straight line segment can be extended indefinitely in a straight line
3. Given any straight-line segment, a circle can be drawn having the segment as radius and one endpoint as centre.
4. All right angles are congruent
5. If two lines are drawn which intersect a third in such a way that the sum of the inner angles on one side is less than two right angles, then the two lines inevitably must intersect each other on that side if extended far enough.

Geometry did not experience significant development for the next 1,800 years after Euclid. It is the French mathematician and philosopher *Rene Descartes* (1596–1650), who in the seventeenth century would provide the next serious direction in the development of geometry. Descartes realised that locations in space could be described in numerical terms provided one could define a reference system for this. He figured out that in the three-dimensional Euclidean space, the location of a point could be completely defined through numerical distances measured off three orthogonal reference lines. The numerical distances are commonly known as *coordinates* and would be represented in the form (x, y, z) for the three orthogonal lines x, y, and z. The geometry of Descartes is normally referred to as *Cartesian geometry*.

The use of coordinates in the location of points had in fact already been alluded to by *Ptolemy* in his work on map construction in 140 AD, which had grids more like our latitudes and longitudes of today. The fundamental contribution of Descartes was therefore not so much in the concept of coordinates as such, but that he brought forth the linkage between *algebra* and *geometry*, so that curves and surfaces in space could be described in algebraic terms using coordinates, which themselves were given in numerical terms. Cartesian geometry thus made it possible to describe space in numerical terms. Through this, Descartes had succeeded in quantifying space and thereby rendering it tangible.

For over 2,000 years, the geometry of Euclid was the geometry. It had been defined within the framework of our physical three-dimensional world and thus looked quite straightforward. In this Euclidean edifice however, the fifth, or parallel postulate, had stood out as a sore thumb as it had presented special problems. Mathematicians found the postulate too complicated to be accepted as an axiom necessitating no further proof. It was felt the fifth postulate needed further proof of its existence, or non-existence. It is stated that even Euclid himself was suspicious of the parallel postulate and in fact rarely used it. In the two millennia since Euclid, the quest for the proof of Euclid's fifth postulate would become the foremost challenge in geometry.

Ptolemy is reported to have been the first to attempt a proof of the postulate. Thereafter, for 2,000 years, generations of mathematicians would make their own attempts to prove the postulate, and fail. In the period 1813 to 1816, however, a new dimension was brought into geometry; geometry could be conceptualised of in spaces other the Euclidean. This new world was created in the first instance by the great German mathematician *Carl Friedrich Gauss* (1777–1855). Gauss was Professor of Mathematics and Astronomy at the University of Göttingen. In the history of mathematics he has been described as the "Prince of Mathematicians" and is regarded by many as the greatest mathematician of all time.

Gauss was able to establish, by 1824, that the fifth postulate could not in fact be proved within the framework of the space defined by Euclid. Instead, his attempts to prove the postulate led him to the discovery of a new type of geometry, other than Euclidean. In this new geometry, Euclid's parallel postulate did not hold. This was the geometry of *curved space* in contrast to the Euclidean geometry, which was of the *linear space*. With this, Gauss had discovered *non-Euclidean geometry* and with it, he had just introduced the next singular major revolution in geometrical thought since Euclid. Gauss had introduced into mathematics the general concept of non-Euclidean space. The specific Gaussian space within the general class of non-Euclidean spaces is the *hyperbolic space* with the corresponding geometry known as *hyperbolic geometry*.

In 1824, the young Hungarian mathematician *János Bolyai* (1802–1860) also demonstrated the existence of non-Euclidean geometry. On his discovery he had remarked to his father, *Farkas Wolfgang Bolyai* (1775–1856), another great mathematician in his own right, that "out of nothing I have created a strange new world". In 1829, the Russian mathematician *Nicolai Lobachevsky* (1792–1856) also published his own work on non-Euclidean geometry. The works of Gauss, Bolyai, and Lobachevsky on non-Euclidean geometry thus followed on to each other quite closely. It has been confirmed however that the three carried out their studies on the problem independent of each other and all the three have thus been accorded the priority of the discovery of non-Euclidean geometry in the hyperbolic space.

Consequently hyperbolic geometry is sometimes known as *Gauss-Bolyai-Lobachevsky geometry*.

Gauss then turned his interest to the geometry of mapping in which he next concerned himself with the mathematics of projecting an ellipsoidal surface onto that of a sphere or plane. With this, Gauss was thus also the first person to formulate the problem of *map projections* in sound mathematical terms. A most important offshoot of Gauss's work in geodesy and mapping was the development of *differential geometry*. Differential geometry was developed by Gauss out of the desire to analyse for distortions caused in maps as a result of projecting from one surface onto another surface.

The concept of non-Euclidean geometry was next pushed further by the German mathematician *Bernhard Riemann* (1826–1866). In 1854, Riemann gave a lecture at the University of Göttingen for consideration for the position of lecturer in mathematics under the title *Über die Hypothesen welche der Geometrie zu Grunde liegen (On the hypotheses upon which the foundations of geometry lie)*. Among his reviewers for this lecture was Gauss, who had in fact selected the topic out of the three originally proposed by Riemann. By this lecture, Riemann did take geometry to the next level; he had introduced the concept of *elliptic spaces* and *elliptic geometry*, within the broad class of *non-Euclidean geometry*. Elliptic geometry would eventually become known as *Riemannian geometry*.

For his new geometry, Riemann gave the corresponding interpretations for point, line, and plane. The plane in Riemannian geometry was taken as the surface of a sphere. For straight lines he took great circles, which effectively were *geodesics*; the geodesic being defined as the shortest distance between two points. The points on the other hand were taken as defined by two coordinates, being *latitude* and *longitude*. Thus the coordinate systems of latitudes and longitudes as we use them operate within the Riemannian elliptical geometry. A classical example of the application of elliptical geometry is in air navigation where the shortest line of flight is normally a geodesic (or great circle, if the Earth is considered to be spherical), which on the plane in fact appears as curved and not straight at all.

To demonstrate how the sphere functions as a plane and that the straight line on it is the great circle let us consider an object travelling on the sphere. If the object keeps the course of a great circle, it will see as if it is keeping on a straight course since its course would only be having a curvature in the direction perpendicular to the surface. On the curved spherical surface, the curvature perpendicular to the direction of motion is not felt by the object as curvature, instead the object will have the impression that it is on a plane surface and for all purposes, the object will see the surface as flat.

On the spherical surface we have that longitudes, which are great circles, must intersect each other at the poles; in fact any two great circles must intersect each other. Thus if on the spherical surface, we had two points at which we drew two straight lines (i.e. great circles) that were parallel to each other, the two lines would eventually meet. This is one of the demonstrations that the parallel postulate does not hold on curved surfaces. Moreover we notice that even the first postulate of Euclid is also violated since on the sphere, a great circle which is the straight line is only extendable to the extent that it completes the circle.

With the discovery of non-Euclidean curved space geometry, it was now time to go back to the beginning and to put the new geometry in an axiomatic setting. This task was accomplished by the German mathematician *David Hilbert* (1862–1943), who was Professor of Mathematics at the University of Göttingen. In 1899 Hilbert published his book *Grundlagen der Geometrie (Foundations of Geometry)* in which he proposed 21 axioms in the context of non-Euclidean geometry. Hilbert subsequently introduced the concept of the infinite-dimensional space, what is today known as *Hilbert space*.

Up to the end of the nineteenth century, the generally held view about the interaction between time and space was that physical space was three-dimensional and onto which time, which was one-dimensional, was superimposed. In other words, space and time were viewed and considered as independent entities. However, in a now famous lecture at Cologne, a Jewish-German physicist-mathematician, *Hermann Minkowski* (1864–1909), in 1908, introduced a completely new view on the interaction between space and time. He took the view that space and time constituted an integrated four-dimensional entity, the *space-time*. In Minkowski's space-time world, space and time were viewed, therefore, not as independent entities, but as one immutable four-dimensional entity. Minkowski considered that it was not possible to have either space or time without the other.

Space and time are continua, in the sense that, as far as is known, there are no gaps in space or in time, and that each of the entities can be infinitely divided into smaller and smaller units thereof. Minkowski therefore considered that space and time were coupled together in an immutable *four-dimensional space-time continuum*. In the four-dimensional space-time it is considered that the location of an event can be described completely through the coordinates (x, y, z, t) in which x, y, z would be the conventional three-dimensional coordinates while t would be the time coordinate.

Minkowski's work on space-time continuum had been motivated by the desire to describe the theory of special relativity in a mathematically more elegant manner. He felt that special relativity could be better explained mathematically through non-Euclidean geometry. At the Cologne lecture he stated his new concept of space-time continuum with the words:

> *"Die Anschauungen über Raum und Zeit, die ich Ihnen entwickeln möchte, sind auf experimentell-physikalischem Boden erwachsen. Darin liegt ihre Stärke. Ihre*

Tendenz ist eine Radikale. Von Stund an sollen Raum für sich und Zeit für sich völlig zu Schatten herabsinken, und nur noch eine Art Union der beiden soll Selbständigkeit bewahren"

("The views on space and time which I wish to lay before you have sprung from the soil of experimental physics, and therein lies their strength. They are radical. Henceforth, space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality".).

The new concept of space-time as derived within the framework of non-Euclidean, curved space, geometry set the stage for the fuller development of the *theory of relativity* by *Albert Einstein* (1879–1955). Relativity is today considered the greatest breakthrough in the understanding of the shape and structure of our universe and the space we live in. Over the years the validity of the theory of relativity has been tested and confirmed through a number of experiments. However one of the clearest applications of relativity in daily life has only recently been realised through satellite positioning systems. Observations obtained from GPS satellites must be corrected for relativistic effects on the satellite clock time.

3.3 Measuring Time

In order to make sense of time and to put it to practical use we must be in a position to quantify it. For this reason, quite early on, mankind found it necessary to establish means of determining time and putting a value on it. It obviously is difficult for us to visualise a life without time measurement; we need accurate time for many purposes. For ordinary information on what time it is, the accuracy of the ordinary clock or wrist-watch is good enough, however for scientific purposes and in certain aspects of business, we need much more precise timing. One of the areas requiring precise timing is in the *navigation of satellites* and the use of satellites in *positioning* and *navigation* as well as in *astronomic observations*. Even from this aspect alone, the technology of time measurement is of great importance to the subject of our discussion here.

The technologies of the measurement of the passage of time have generally been based on the repetitiveness of a given cyclic event. The instrument for the measurement of time is a clock and normally any phenomenon that has a relatively reliable form of repetitiveness can be used as a clock. The first of such clocks were natural events that were observed to repeat themselves. The most obvious of such events was the daily rising and setting of the sun which gave rise to the counting of *day*. Then there was the moon, which was observed to take exactly the same number of days to go through its phases in a repetitive manner which then resulted in the counting of the *month*. The third phenomenon was the

Earth's revolution around the sun, which was marked by the changes in the seasons and gave rise to the *year*.

Early humans reckoned the time of day in terms of early-morning, mid-morning, mid-day, late-afternoon, evening, and night. The day in most cases was considered to begin at sunrise and end at sunset, while night was treated by itself as a special case. In fact in many societies the day is still considered to begin at sunrise so that for instance, mid-day is considered the sixth hour in the day. Today of course we have that a full day is divided into 24 equal parts called hours with the day considered to begin and end at midnight. The twenty-four hour day was invented by the Chaldeans (Babylonians) of Mesopotamia in the period 1900–1650 BC.

Even though time is today not measured according to the motions of the Earth, the civil use of time is very much associated with the position of the sun with respect to the meridian of our standpoint. Meridians, which are also known as *longitudes*, are the imaginary lines that join the south and north poles and run on the surface of the Earth. The instant at which the sun is directly above our standpoint meridian is our *local noon*. From this it becomes immediately apparent that the time as reckoned must vary from meridian to meridian and therefore must essentially be local. Strictly therefore it makes sense only to talk of time at a particular longitude.

In order to deal with the problem of *local time* that had to be given with respect to longitude, several countries already in the nineteenth century specified principal meridians for civilian time use. So we had for instance the following prime meridians: Brazil - Rio de Janeiro, Denmark - Copenhagen, France - Paris, Germany - Potsdam, Italy - Rome, United Kingdom - Greenwich, Russia - Pulkovo, and USA - Washington. The use of multiple reference longitudes for the definition of time was particularly problematic for navigation at sea and there was thus a need to establish one common point of reference for the reckoning of time internationally.

In October 1884 an international conference was convened in Washington DC, USA, with the objective to establish one principal meridian to be used for the referencing of time internationally. The conference was attended by 41 delegates from 25 nations. By a vote of 22 for, one against, with two abstentions, the meridian at Greenwich, as was already in use by England, was adopted as the prime meridian for the world. Consequently Greenwich meridian was formally designated as the 0° longitude of the world. San Domingo (now Haiti) however had voted against while France and Brazil did not vote. France in fact did not adopt the Greenwich meridian until 1911

Corresponding to the 0 longitude on the other side of the world, at 180° longitude, there was established the *international dateline*, which was nominally twelve hours away from the Greenwich time. Anyone crossing the international dateline from the Asian to the American side repeats one day while one travelling from the American to the Asian side jumps one day. The great French science fiction writer *Jules Verne* (1828–1905) captured the effect of crossing the international dateline dramatically in his fictional story *Around the World in Eighty Days* (1872).

However, even with the international time system as based on Greenwich meridian, time as used on a daily basis was still largely local. In 1876, a Canadian survey engineer, *Sandford Fleming* (1827–1915), proposed the 24-hour clock format for the world and parallel with this a system of time zones for the entire world. The idea of the 24-hour clock was accepted in 1884 with Greenwich meridian as the line of reference. The idea of local time zones also caught up slowly but steadily and today there are some 39 time zones with each and every country of the world covered.

As reckoned with respect to the Greenwich meridian as reference, local time at a particular point is the time difference between that particular point and that at Greenwich meridian. This time difference is however simply equivalent to the difference in longitude between the two points in the sense that the Earth rotates through 360° in 24 hours, thus 1° of longitude is equivalent to 4 minutes of time and respectively 1" of longitude is equivalent to $\frac{1}{15}$ (or 0.067) seconds of time. This means, for instance, that two points on the equator separated by 30.922m (being 1" of longitude) would have a time difference of 0.067 seconds. Equivalently, for a separation of 111.319 km (being 1° of longitude) there would be a time difference of 4 minutes. The concept of time zones was introduced to facilitate the reckoning of time for civil use to circumvent the difficulty of having to deal with two points that were physically close to each other but which had to be assigned different times.

We have for the case of Kenya for instance, that the westernmost point at the westernmost end of Sumba Island in Lake Victoria is at longitude 33° 54'35" while the easternmost point at Maika Rie to the north-east of Mandera is at longitude 41° 54'44". This gives a longitude difference of 8° 00'09" which is equivalent to 0hr 32min 01sec, which then is the variation in local time across Kenya. This then means that when it is 12 noon local time at Maika Rie, it would only be 11hr 27min 59sec local time at Sumba Island. The local time kept over Kenya is in fact the East African Standard Time (EAST) which is reckoned with respect to longitude 45°. This means for instance that when it is 12 noon EAST the actual local mean times at Maika Rie and Sumba Island would be 11hr 47min 39sec and 11hr 15min 38sec respectively.

Greenwich Mean Time (GMT) was initially reckoned as 0 at midday. In 1925 however it was decided to change the reference point from midday to midnight. This 'new' time system was designated *Universal Time (UT)*. Because UT is based

on the Earth's rotation about its axis as well as its revolution around the sun, the errors that affect the Earth's motion in these two aspects are transferred to the derived UT. Consequently there are variants of UT depending on what correction one has applied to the 'raw' UT. When UT is corrected for the motion of the Earth's poles, the resultant is known as UT1. On correcting UT1 for the Earth's uneven motion around the sun, we obtain UT2. However even the UT2 is still not completely uniform.

Because of the non-uniformity of the motions of the Earth, it was felt that the motions of the Earth were not quite suitable as means of determining time. What was needed therefore was a time system that would be independent of the motions of the Earth. The natural solution was found in the characteristic frequencies at which specific atomic elements absorb or emit radiation. This brought into use what we today know as atomic time. The first atomic clock was built by the US National Institute for Science and Technology (NIST) in 1949.

Today we measure time in terms of year, month, day, hour, minute, and second with the definitive unit taken as the second. In 1967 the 13th General Conference of Weights and Measures defined the second as:

> *The duration of 9192631770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom*

Unknown to most of us who use time in the conventional manner, time measurement is today a most complex scientific activity. We possess watches and clocks which every now and then must be set to the 'correct' time. The question we often do not ask however is; what is this *correct* time and where does it come from? Assuming that the time comes from some master clock, the next question then is: where is this master clock and who keeps it?

The fact however is that there is no single master clock as such but instead, the international time standard is derived from a mean of time measurements taken from a number of clocks maintained by time laboratories distributed worldwide. Many of these laboratories keep time to accuracies better than one second in two million years. The standard atomic time is today provided through the *Temps Atomique International (TAI)* or the International Atomic Time. TAI is derived from a weighted mean of times kept by some 200 clocks in 50 countries worldwide. The realisation of the Universal Time (UT) through the atomic time system is known as *Coordinated Universal Time* (UTC).

In all this, the definition of the year as a measure of time is still of great importance. The time it takes the Sun to return to the same position on its path (the ecliptic) as viewed from the Earth is known as the *tropical year*. Usually the point of reference for the beginning and end of a tropical year is taken as the point of the *vernal equinox*, also known as the *First Point of Aries* (the vernal equinox usually occurs between 19 and 21 March). The point of the vernal equinox moves along the ecliptic due to precession. Due to the non-constant speed of the Earth around its orbit, the length of the tropical year is not constant but instead changes slowly, but regularly, with time.

The nominal year as we use it in daily life is still based on the Earth's revolution around the sun, which is measured in astronomic coordinates. The reference point for astronomic coordinates, including astronomic time, is an astronomic epoch. In 1984, the International Astronomical Union (IAU) adopted a new epoch J2000.0 with the reference point as *1st January 2000 at 12h TT* (where 'J' stands for 'Julian epoch' while 'TT' stands for 'Terrestrial Time'). This new epoch replaced the old one of B1950.0 (where 'B' stands for 'Besselian' after the German mathematician and astronomer *Friedrich Wilhelm Bessel* (1784–1846)). Terrestrial Time (TT) was adopted by IAU in 1991 as the astronomic time scale consistent with the theory of relativity. The epoch 1st January 2000 at 12h TT is equivalent to 1st January 2000, 11:59:27.816 TAI or 1st January 2000, 11:58:55.816 UTC.

As at this point of reference, the mean length of tropical year was 365.242189670 days (or 365 days 5hrs 48min 45.187secs). Since the change in the length of the tropical year is steady it can be expressed through a polynomial, which then makes it possible to calculate it at any one time. On the basis of this we have that some 2000 years ago, the tropical year was 10 seconds shorter than today. The actual time it takes the Earth to complete one orbit around the sun is one *sidereal year*. A sidereal year is the time it takes the Sun to occupy the same apparent position with respect to the stars. One sidereal year is 365.2564 mean solar days and is hence longer than the tropical year by 20 minutes and 24 seconds. Besides the tropical and sidereal years, there are several other types of years. These years are of different lengths and were generally defined for different purposes including scientific, religious, cultural, and even political.

In civil life we consider the year to be made up of $365\frac{1}{4}$ days, which is based on the number of nominal revolutions the Earth makes around the sun. Because taking $\frac{1}{4}$ of a day in the count of the year would throw our counting of the years completely out of tune with the length of day, we adopt the normal year as 365 days long. After four years however, the $\frac{1}{4}$ days would have accumulated to make one full day, and to compensate for the accumulation we set the fourth year one day longer, at 366 days. This longer year is usually the 'leap' year. The principal reason for the extra day on the leap year is to ensure then that the extra $\frac{1}{4}$ days do not accumulate out of hand as to disorient the counting of the years with respect to the revolution of the Earth round the sun.

The Christian calendar in use in most parts of the world today was initially defined by Julius Caesar and later on modified by Pope Gregory XIII. Julius Caesar, in 45 BC brought forth major reforms in the Roman calendar in order to

remove the many inconsistencies that were inherent in the calendar. The Roman year began at the vernal equinox and had twelve months: Martius, Aprilis, Maia, Junius, Quitilius, Sextilis, September, October, November, December, Januarius, and Februarius. The months of Martius, Maia, Quintilius, and October had 31 days, Aprilis, Junius, Sextilis, September, November, and December each had 29 days, and Februarius had 28 days. This gave a total of 355 days. In order to deal with the extra 10 days (respectively 11 days) an intercalary month of 23 days was inserted at the end of Februarius every two years.

Julius Caesar defined the year to be 365days 6hrs and introduced a leap year on every fourth year. The civil Julian year was taken to be 365 days long with the leap year being of 366 days. He retained the twelve month year but with the lengths of the months reorganised. One account is that Julius Caesar had odd months at 31 days long while the even months were 30 days long. The last month of the year, Februarius however took 29 days and 30 days only in leap years. Thus the lengths of the months were: Martius (31), Aprilis (30), Maia (31), Junius (30) Quintilius (31), Sextilis (30), September (31), October (30), November (31), December (30), Januarius (31), Februarius (30/29). Julius Caesar further decreed that the year begins with January and not at the vernal equinox in March.

At 365.25 days however, the Julian year was longer than the tropical year by 11min 14.813secs. In just 128 years this accumulates to a full day. By 15th century the discrepancy had accumulated well out of proportion, in particular it was noticed that the vernal equinox was no longer falling on 21st March but instead was moving backward in the calendar. To the Church this was unacceptable as the date on which to celebrate Easter was ever being pushed backwards from the original date agreed upon in 325 AD at the Council of Nicea. The Church needed then to do something about the calendar. *Pope Gregory XIII* (1502-1585) resolved to deal with the problem. The new Gregorian calendar was implemented in 1582 by having Thursday October 4th on the Julian calendar followed by Friday October 15th on the Gregorian calendar.

The reference point in the determination of the Gregorian calendar was the vernal equinox which was set to fall on 21st March as this was the position of the vernal equinox during the Council of Nicea. The new calendar retained the leap year concept but with a proviso. In order to ensure that the difference between the solar (Julian) year and the tropical year did not accumulate out of hand, century years would be leap years only if the century was divisible by 400. This would result in three leap years being missed out in every four centuries. The effect of this was that in 400 years there would have been a total of 146097 solar days against 146096.875868 tropical days (or 146096days 21hrs 01min 14.995secs). The discrepancy then comes to an average of 26.812 seconds per year, which was considered tolerable. We note that for this to accumulate to a day will require

3222.4 years. This means the next adjustment on the calendar shall be due in the year 4805 AD.

3.4 Measuring the Universe

We are only able however to conceptualise of space and time and even to put measures on them because there is a universe in which all this exists. We realise immediately therefore that in our dealing with space and time, the universe must in fact be the ultimate of such space and time. We must essentially involve ourselves with the general ideas about the universe and how we could also put measure on it. At any rate, the world in which we live is part of this vast universe and an understanding of its geometric structure is predicated on our understanding of the geometry of the universe itself.

Practically all of us have at one time or other looked up the sky and wondered just how large the universe must be. Early humans were confronted by this question just as we are today; just how vast is the universe and how would we measure its extent? We must essentially be confronted by this question from the point that the Earth on which we live is part of the universe. Moreover if we are to establish the extent of our Earth, we need to delve into its origins and to understand the forces that keep it in place and therefore shape its form. For all this however we must seek to understand, not only the structure, but also the extent and origin of the universe.

The story of the measurement of the universe begins with the first measurement of the size of the Earth in the period around 240 BC. Following on to this, the big question was about the geometric relationship between the Earth and the rest of the universe; was the Earth at the centre of the universe or not, and if not, what was then at the centre of the universe? When humans started to view the stars with some seriousness they could only do so with the naked eye, which obviously was a major handicap. The invention of the telescope in 1608 improved considerably the ability to observe stars and other heavenly bodies. Most importantly it became suddenly possible to view a lot more of the sky than had been possible previously.

In 1924, the American astronomer, *Edwin Hubble* (1889-1953), established that the universe was much larger than previously believed. Up to this time, astronomers had considered the Milky Way galaxy to constitute the full extent of the universe. In 1924, Hubble had established that the Milky Way was just one of the millions, probably billions, of similar galaxies dotting the universe. He further speculated that the universe itself also had to be billions of years old. In fact in 1929, Hubble and colleague *Milton Humason* (1891-1972), announced that they had established that, with the Earth taken as the point of reference, every galaxy

appeared to be receding away from Earth at speeds that were proportional to their distances away from the Earth, and further that every galaxy appeared to be receding from every other.

The expansion of the universe as observed by Hubble had confirmed the expanding universe model as developed earlier, in 1922, by the Russian mathematician *Alexander Friedmann* (1888-1925) as well as the independent development of the same by the Belgian astrophysicist and theologian, *Georges Lemaître* (1894-1966). Through this model, Lemaître was able to offer an effective explanation of Hubble's results. Being an ordained catholic priest, Lemaître had in particular been intrigued at the possibility of being able to explain the origin of the universe, and hence the whole question of creation of the universe. From the fact that the universe appeared to be expanding, Lemaître was convinced that the universe had originated from one source at one time, thus implying creation. Lemaître explained that the universe must had begun from a primeval atom which spontaneously disintegrated into smaller 'atomic stars'.

While many scientists were not convinced about Lemaître's explanation of the origin of the universe, most of them were however convinced about the expansion of the universe. The question now was how to determine the speed of this expansion and thereby put a measure on the size and age of the universe. In 1931 Hubble and Humason put the rate of the expansion of the universe at 558 kilometres per second per megaparsec (a megaparsec = ca. 3.26 million light years). This was interpreted to mean that two galaxies separated by a megaparsec would be moving away from each other at the speed of 558 km per second. This is equivalent to saying that, if two objects in space are separated by 10,000km they would be moving away from each other at the speed of 5.7 mm per year (1 light year = 9.461×10^{15} m). The rate of recession of galaxies is known as the *Hubble constant* (H_0).

Hubble's discovery that galaxies were speeding off away from each other at terrific speeds and the corollary to this that the universe must had originated from one point at the same time, revolutionised completely humankind's understanding of the nature of the universe. In the next two decades there ensued intensive discussions on whether indeed the universe was formed this way or through a 'steady state' process. The steady state theorists postulated that the universe was not formed through one single explosion but that it instead just evolved from a state of eternal existence.

The principal proponent of the steady state process was the English physicist *Sir Fred Hoyle* (1915-2001) who totally rejected the exploding universe theory. In 1949, Hoyle was asked by the British Broadcasting Corporation (BBC) to present a series of lectures on the nature of the universe. In the course of these lectures, in a cynical manner, he coined the term 'Big Bang' to describe the exploding universe theory. To his amazement, a terminology he had meant in derision at the 'exploding universe' theorists stuck. The fiercest opponent of the exploding universe theory thereby became responsible for the trademark by which the theory is known today; 'Big Bang'.

In the 1930s, the possibility to use radio waves in astronomy was realised and in subsequent years experiments to establish this method were vigorously pursued. In 1964, two Americans, *Arno Penzias* and *Robert Wilson* virtually stumbled on the evidence that Big Bang had indeed occurred. While testing a radio antenna, Penzias and Wilson, were confronted with a continuous background noise, which was later on interpreted as the remnants of the noise that accompanied the Big Bang process some 15 billion years ago. This, it was believed was the sound that two American scientists, *Ralph Alpher* and *Robert Herman* (1914–1997) had, in 1948, predicted would have to have been left over from the Big Bang. Previous to the Penzias-Wilson discovery, another scientist, *Karl Jansky* (1905–1950), had in 1933, discovered what he believed was cosmic radio waves. Penzias and Wilson were in 1978 awarded the Nobel Prize for physics for their discovery of cosmic microwave background radiation.

Today it is believed that the universe is made up of 100 billion galaxies each carrying some 100 billion stars all in a space of some 156 billion light years across and that all this came into existence some 15 billion years ago through the Big Bang process. However astronomers are still battling to determine each of these figures with higher precision. The determination of the size and age of the universe remains one of the most fundamental questions in science today. At the core of this investigation is the Hubble constant, which is the means to estimate the rate of expansion of the universe and subsequently its age on basis of the Big Bang theory. In the period from 1960's to 1990's, the Hubble constant was held to lie somewhere in the range 50 and 100 km. per sec per megaparsec. The latest value is around 70 km. per sec per mega parsec.

In this effort, the single most important project today is the Hubble Space Telescope (HST). The Hubble Space Telescope is a telescope in space, orbiting the Earth at a height of 600 km. It is the single most sophisticated astronomic instrument in space today and is virtually a full-fledged astronomic observatory. One of the principal objectives in the Hubble Space Telescope project is to determine more accurately the Hubble constant. Because of its location outside the atmosphere the telescope is able to observe much deeper into space than most terrestrial telescopes and to return extremely bright images not affected by atmospheric refraction.

4

Geo-Measurement and Geo-Graphics

4.1 The Figure of the Earth

We have seen that the most unambiguous way to locate an object within the geo-space is through the use of coordinates. The coordinates that we generally use for this location are usually defined with respect to the figure of the Earth. This then in the first instance calls for knowledge about the shape and size of the Earth, the location of its centre, rotation and general location in space, and the characteristics of its gravity field. Thus at the very practical level, in order to be able to establish the spatial relationships amongst objects and phenomena within the geo-space, we need to know the size and shape of the Earth. In the first instance we wish to know the exact location of an object or the phenomenon followed by its dimensions and then we want to describe it geometrically.

The big question is: How does Earth look like geometrically and how large is it? How do we determine its shape and size and what are the factors that influence this shape and size? The determination of the shape and size of the Earth is however a relatively complex process that has given rise a fully fledged scientific discipline; *Geodesy*. Geodesy is the study of the geometry and the gravity field of the Earth. The practical aspect of geodesy is concerned with the determination of the shape, size, and gravity field of the Earth as well as the precise location (in terms of coordinates) of points within the geo-space.

The shape and size that the Earth takes is determined by the Earth's position in space and the forces that act on it to keep it in its particular position within the universe. From elementary geography we learn that the Earth revolves around the sun once every year and rotates around its axis once everyday. We are also taught that the Earth's orbit around the sun is elliptical and generally obeys Keplerian laws (Kepler's laws) of orbital motion. From this we might have the impression that these motions of the Earth are neatly smooth and uniform. At the detail level, however, the motions of the Earth on its orbit and on its axis are not smooth at all but are instead quite complex. Particularly due to the non-uniform motion of the Earth, both on its axis and on its orbit, the study of the Earth's motion becomes of great interest in the study of the geometry, shape, and size of the Earth and indeed as well as of time and the Earth's gravity field.

The endpoints of the Earth's axis of rotation, we define as the poles of the Earth, i.e. North Pole and South Pole. The Earth's axis of rotation however does not assume the same position all the time, instead, the position of the axis executes a pattern in some regular motion. Correspondingly therefore the positions of the poles also execute a number of continuous motions. The motions of the Earth's axis of rotation are monitored by the International Earth Rotation and Reference Systems Service (IERS). The position of the instantaneous axis of rotation is correspondingly taken with respect to the position of a nominal axis of rotation as defined by the IERS for a particular epoch. The position of the nominal axis of rotation is then used to define the position of the geographic poles, which are then the conventional North and South poles.

Generally the actual Earth's axis of rotation executes a spiral type motion with respect to the conventional pole. The motion as translated at the poles is generally referred to as *polar motion*. This motion is known as the *Chandler Wobble*, as named after the American astronomer *Seth Carlo Chandler* (1846–1913) who discovered the motion in 1891. We present in Fig. 2, the path of the pole due to polar motion in the period 1994-1997 as given by IERS.

The conventional axis of rotation itself makes a rotation around an imaginary axis every 18.6 years. This motion is known as *nutation* and the axis of rotation is known as the *axis of nutation*. The displacement of the Earth's conventional axis of rotation from the nutation axis is in the region of 550m at its maximum. Further, we have that the axis of nutation describes a rough circle around another axis through the motion known as *precession*. One full cycle of precession takes roughly 25,800 years. Nutation is largely caused by the gravitational effect of the moon and was first noticed by the English astronomer *James Bradley* (1693–1762). Precession on the other hand is caused by the fact that the Earth is spheroidal in shape and further due to the combined gravitational effect of both the moon and the sun on the Earth.

The Earth's revolution around the sun, its own rotation about its axis, and the forces of other heavenly bodies on it are responsible for the geometry of its shape and size. Further, this shape and size is dynamic and varies continuously as determined at any particular time by the effect of the forces acting on the Earth. This strictly means that the shape and size that the Earth assumes at any particular

moment is only instantaneous. The principal objective of geodesy is to determine the shape and size of the Earth under the effect of these forces.

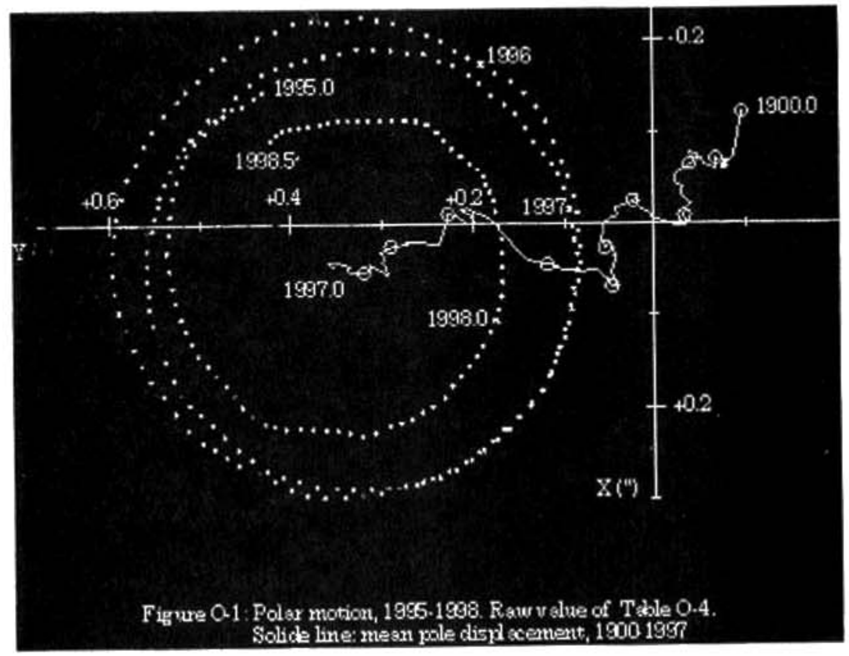


Fig. 2: The polar motion in the period 1994-97
(www.iers.org)

Right from the time humankind began existence on Earth, he was intrigued by the apparent vastness of Earth and about its possible shape and form. What exactly was the shape of the Earth and how large was it? And how could one determine its size and shape? Then for many years, the question of the shape and size of the Earth was only a matter of speculation and conjecture. Based simply on how far one could see and to what extent one could imagine, various people presented their postulations on what the shape of the Earth must be. The development of concepts concerning the shape of the Earth can be considered to have progressed in four stages: the *flat*, *spherical*, and *spheroidal* shapes, and then the *geoid*.

The very first thoughts about the shape of the Earth were that the Earth was flat and that it was possible to fall off its edges. *Thales of Miletus* (625–547 BC) later proposed that the Earth was a disc floating on an ocean. A further proposition shortly after this was by *Anaximander of Miletus* (611–547 BC) who even suggested that the Earth was a cylinder with the land on its curving surface. Today, many of us are taught that the Earth is a sphere. It was the philosopher and mathematician *Pythagoras* (569–475 BC) who was the first to propose that the Earth was spherical. Pythagoras argued that the Earth had to be spherical, because it was such an important object in the universe that it had to be of a perfect geometrical figure, and in Greek philosophy the sphere was considered the perfect geometrical figure.

The philosopher *Aristotle* (384–322 BC) added his weight to the spherical Earth concept and was in fact the first one to give philosophical reasons for this. Aristotle argued that the Earth had to be spherical in form because: (i) matter was generally drawn to the centre of the Earth by gravity, what then tended to compress the Earth into a sphere; (ii) as one moved northwards or southwards new star constellations appeared; this indicated that the Earth was curved in the north-south direction; and (iii) during the lunar eclipse the Earth's shadow on the moon was always round, and the only object whose shadow is always circular no matter the orientation is a sphere.

The very first measurement to determine the size of the Earth was carried out by *Eratosthenes of Cyrene* (276–194 BC). Eratosthenes was born in Cyrene in the present state of Libya in North Africa. While serving as the librarian at the then famous library at Alexandria in Egypt, in the period around 240 BC, Eratosthenes was intrigued at the prospect of determining the radius of the Earth. He had observed that on the summer solstice, which falls on June 22nd, at Syene (the present Aswan in Egypt), at midday, the sun cast its shadow right inside a narrow well. This meant then that the sun was exactly overhead at midday on the summer solstice at Syene.

Eratosthenes figured out that, if he could then determine the angle that the sun's rays made with a vertical stick at another place on the same meridian with Syene on the summer solstice at midday, then he could determine the angle subtended at the centre of the Earth by the arc between Syene and the second point. With the angle subtended by the arc at the centre of the Earth and the length of the arc, he could then determine the radius of the Earth. He chose as the second point a point at Alexandria. From this experiment, Eratosthenes obtained the radius of the Earth to be equivalent to 7,359 km. Compared against today's figure of 6,378 km. Eratosthenes' value was in error by just about 15%. A representation of Eratosthenes' experiment is given in Fig. 3. This experiment has normally been considered as marking the beginning of the discipline of geodesy, and for which Eratosthenes has been described as 'the father of geodesy'.

The radius of the Earth as measured by Eratosthenes would take almost two thousand years to be improved upon. In 1615 the Dutch geodesist-mathematician *Willebrord Snellius* (1580–1626) measured an arc approximately 127 km long using a triangulation chain and obtained the radius of the Earth as 6,150 km. This was in error by only 3.6% with respect to the current value for the equatorial radius at

6,378 km. Snellius reported on the triangulation method used by him in a famous work, *Eratosthenes Batavus*; this work has been considered as marking the beginning of modern geodesy. Subsequently in 1670, the French astronomer, *Jean Picard* (1620–1682) carried out the next measurement of the radius of the Earth. Picard obtained the radius of the Earth as 6,375 km, which was then in error with respect to today's equatorial radius by only 0.09%.

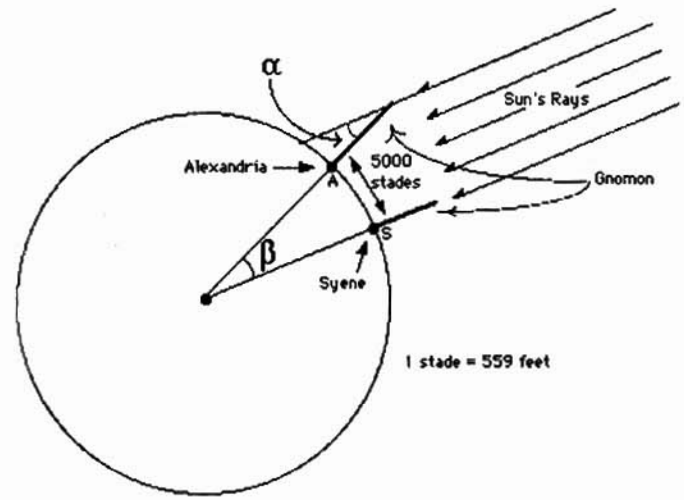


Fig 3: Eratosthenes's determination of the radius of the Earth (share2.esd105.wednet.edu/jmcald/Aristachus/Eratosthenes.html)

In 1672 a French astronomer *Jean Richer* (1630–1696) had observed that a pendulum clock that had been adjusted to keep correct time in Paris (at ca. latitude 49° N) when transported to a point near the Equator at Cayenne in French Guyana (at ca. latitude 5° N) lost time and required its pendulum to be shortened in order to keep correct time. The reason for this was that the pendulum was swinging much slower due to reduced acceleration due to gravity. The implication then was that the Earth's radius at the equator had to be larger than the radii towards the poles. The indication then from this was that the Earth was not spherical as such, but had its equatorial radius larger than its polar radius hence it had to have a bulge at the equator with a flattening at the poles.

Isaac Newton had already, on the basis of the theory of gravitation, postulated that the Earth had to be an *oblate spheroid* (i.e. bulging at the equator and flattened at the poles) due to the centrifugal force on the Earth as a result of its rotation on its axis. On the basis of the theory of gravitation, Newton had estimated that the flattening of the Earth (i.e. $f=(a-b)/a$ for $a=$ equatorial radius and $b=$ polar radius) was 1:230 while the Dutch physicist *Christiaan Huygens* (1629-1695) had obtained the value 1:578. A French astronomer, *Giovanni Cassini* (1625–1712) had however, through a triangulation measurement, obtained the surprising result that the Earth was a *prolate spheroid*, which is an ellipsoid that is elongated towards the poles. The two sharply contradicting views on the shape of the Earth generated a major scientific controversy.

To settle the Newton-Cassini controversy, the French Academy of Sciences sent out, in the period 1735–1743, two expeditionary teams of geodesists to carry out geometric measurements to determine the figure of the Earth. One group, comprising *Louis Godin* (1701–1760), *Pierre Bouguer* (1698–1758) and *Charles Marie de la Condamine* (1701–1774) was sent to measure a grade (i.e. length of degree along a meridian) near the equator, in Peru. The second group of *Pierre de Maupertius* (1698–1759), *Alexis Clairaut* (1713–1765) and *Anders Celsius* (1701–744) went to measure a grade at a point near the North Pole, in Lapland. The results of these measurements confirmed that the Earth was an oblate spheroid as had been postulated by Newton. From these experiments, an equatorial radius of 6,366.30 km with a flattening parameter of 1:310.3 had been obtained.

The principle of establishing whether the Earth was an oblate or prolate spheroid was based on the length of arc along a meridian subtending a degree of latitude at the 'centre' of the Earth. If the Earth were an oblate spheroid, then the length of arc subtending a degree of latitude would increase from the Equator towards the poles, and the reverse would be true for a prolate spheroid. The measurements by the French Academy of Sciences teams had yielded 111.49m for the Lapland measurement and 110.58m for the Peru measurement. Thus the Earth was confirmed to be an oblate spheroid.

Immediately after the measurements by the French Academy of Sciences teams, several other measurements aimed at establishing the actual radii of the Earth followed. We present, in Table 1, a listing of the results of the measurements in the period 1735 to 1835.

Of these arc measurements, the most extensive and dramatic was the one carried out over India by *Col. William Lambton* (1753-1823) and *Col. Sir George Everest* (1790–1866) in the period 1802 to 1866. The survey was known variously as the 'Great Trigonometrical Survey of India (GTS)' or the 'Great Indian Arc of the Meridian'. GTS extended from the southern tip of the Indian peninsula at Tinavalley to Banog at the foothills of the Himalayas. At its conclusion, this 2,400 km precise survey was the longest measurement of the Earth's surface to have ever been executed; had cost more lives than most contemporary wars; had involved mathematical equations more complex than any other project in the pre-computer age; and was described by the Royal Geographical Society of Britain as "the most significant contribution to the advancement of science in the 19th century".

Table 1: Geodetic arc measurements in the period 1735 - 1835

Year	Observers	Site	Latitude	Length of Arc - km
1735	Louis Godin Pierre Bouger Charles Marie de la Condamine	Peru	1° 31' 08" N	110.58
1738	Pierre de Maupertius Alexis Clairut Anders Celsius	Lapland		111.49
1740	Louis de Lacaille Cassini de Thury	Paris	46° 52' 02" N	111.21
1750	Abbe de Lacaille	Cape of Good Hope	33° 18' 30" S	110.87
1755	Ruggiero Guissepe Boscovich Giovanni Battista Beccaria	Rome	42° 59' 00" N	111.03
1790	J. B. J. Delambre Pierre Francois Mchain	France	44° 51' 02" N	111.11
1802	Roy Henry Kater	England	52° 35' 45" N	111.24
1808	William Lambton	India	12° 32' 21" N	110.64
1835	George Everest	India	16° 08' 22" N	110.66

From this survey, Everest established, in 1830, the parameters for the size and shape of the Earth as 6,377,276m for the equatorial radius and a flattening at the poles of 1:300.8, or equivalently a polar radius of 6,356,074.949m. This was in error by only 0.011% with respect to the current value of 6378km and was the most accurate determination of the shape and size of the Earth up to this time. Further, as a completely unexpected bonus, through the survey, it was established that the Himalayas were by far the highest mountain ranges in the world and most importantly, the discovery of the highest mountain peak in the world; Mt. Everest. Mt. Everest, which was named for Sir George Everest, had its height determined at 29,002ft (8,840m) as based on the computation by the Indian mathematician *Radhanath Sikdar* (1813 –1870).

The figure of 29,002ft (8,840m) would remain the official height of Mount Everest for the next one hundred years. In 1954, the height of the mountain was revised to 29,028ft (8,848m) based on the measurements and computation by the Survey of India under the direction of *B. L. Gulatee*. In 1999, an American team sponsored by the US National Geographic Society using the modern satellite positioning technology of GPS (Global Positioning System) obtained a height of 29,035ft (8850m). This is the current official height of the mountain. The

Nepalese Government on their part however refused to recognise this new figure on the grounds that "it had had conflicting reports from other scientists on the height of the mountain".

With Newton's postulation about the spheroidal shape of the Earth confirmed by the experiments by the French Academy of Sciences, the next major question about the figure of the Earth now focussed on the definition of what exactly constituted the figure of the Earth, since the spheroid was essentially only an approximation. *Carl Friedrich Gauss* proposed that the Earth comprised a basic mathematical form onto which the topography could only be considered to be superimposed. This basic mathematical form was considered by Gauss to generally coincide with the mean sea level and its hypothetical extension even into the solid land mass. Later on, Gauss's student, the mathematician *Johann Benedict Listing* (1808-1882) named this surface as the *geoid*.

The geoid is today taken to be the basic, scientific, form of the Earth, and is defined as the geopotential surface, which coincides with the mean ocean surface and continues into the solid landmass to create a continuous surface. In other words, it is that surface which is perpendicular to the gravity vector everywhere and coincides with the sea level over the open sea. From the figure of the geoid, we have that the basic form of the Earth looks like a potato. The general behaviour of the shape of the geoid is that it tends to be convex below mountains. This is because mountains, due to the concentration of landmass in them, tend to attract the gravity lines towards themselves.

For practical purposes, the geoid is used as the reference surface for the definition of the normal, ordinary, heights of topography, and to this extent it is taken as 'the mean sea level'. When one then speaks of height above sea level, one normally means the height as measured from the geoid directly below the point in question and as measured along the gravity vector (respectively gravity trajectory) to the geoid.

Because the geoid is an irregular, although smooth, figure, its determination must be carried out numerically by observing at discrete points and then plotting the surface using numerical interpolation techniques. How accurate a geoid one obtains depends therefore on the density and quality of observations and the sophistication of the interpolation techniques adopted. Consequently several versions of the geoid have been computed and are in use. One of the most accurate geoids available today has been computed by the Geo-Forschungs-Zentrum (GFZ) (Geo-Research Centre) Potsdam, Germany (Fig. 4).

The determination of the form of the geoid is normally carried out through a combination of gravity, astronomic, and geometric observations. Gravity values have to be observed at discrete points on the surface of the Earth and then using appropriate mathematical formulations the geoid or any other geopotential surface

(a geopotential surface is a surface which is perpendicular to the Earth's gravity vector at all points) may be generated. We have therefore that the study of the Earth's gravity field is absolutely essential for the understanding and determination of the shape of the Earth as defined by the geoid. The geoid however as represented at a particular moment is only a snap shot of the basic form of the Earth at a particular epoch. Because of the forces that act on Earth from other objects in space and those that are internal to itself, the shape and form of the Earth is constantly changing.

Fig.4: The geoid according to GFZ Potsdam (www.gfz-potsdam.de)

From the map of the world, we all have a pretty good idea of where a particular continent is with respect to the others. Further, from the map, the continents appear to occupy positions they have always occupied since the formation of Earth. Today however we know that the continents are not static but are in continuous motion. Thus the relative positions the continents occupy at this particular moment in time are only unique realisations for the moment. The process that keeps the continents in constant motion with respect to one another is known as *plate tectonics*.

According to the theory of plate tectonics, the Earth's crust is made up of seven large and another smaller nine blocks that 'float' on a less solid material. It is believed that some 250 million years ago, in the late Permian period, there was one super continent known as *Pangaea*. About 50 million years later, in the early Jurassic period, Pangaea began to break up, thus eventually leading to the current distribution of the continents and oceans. Today, plate tectonics is the overarching theory in the geological sciences and has been compared to relativity in physics, DNA in biological sciences, and the bonding theory in chemistry. The plate tectonic theory has been hailed as one of the most important scientific achievements of the twentieth century.

The fact however that the continents might had been once in different positions than today only began to be realised once accurate maps of the world began to appear on the scene. As the first accurate maps of the world began to be produced, cartographers became intrigued at the apparent near perfect geometrical fit between the eastern coast of the Americas and the western coast of Africa and Europe. The Dutch cartographer *Abraham Ortelius* (1527–1598) already in 1596 suggested that Americas were "torn away from Africa and Europe ... by earthquakes and floods" and further remarked that "The vestiges of the rupture reveal themselves when, if someone brings forward a map of the world and considers carefully the coasts of the three [continents]".

For the next three centuries, a number of scholars alluded to the idea of drifting continents, but there was no sustained discussion on the subject. The Scottish natural philosopher and theologian *Thomas Dick* (1774–1857) in 1838 wrote that it was "not altogether improbable that these continents were originally conjoined, and that at some former physical revolution or catastrophe, they may have been rent asunder by some tremendous power ...". The French naturalist *Antonio Snider-Pellegrini*, in 1858, after noticing the striking similarity between the fossil plants in coal beds from Europe and America, was persuaded to suggest that Europe and America were once joined together. In 1885, the Austrian geologist, *Edward Suess*, from the consideration of similarities in plant fossils from South America, India, Australia, Africa, and Antarctica suggested that these landmasses were once joined in one super-continent he named 'Gondwanaland". In 1910, two American geologists, *Frank B. Taylor* and *Howard Baker* had also speculated on the idea that the continents were once joined together.

On 6th January 1912, the German meteorologist *Alfred Wegener* (1880–1930) gave a lecture entitled "*Die Herausbildung der Grossformen der Erdrinde (Kontinente und Ozeane) auf geophysikalischer Grundlage*" *(The geophysical basis of the evolution of the large-scale features of the Earth's crust (continents and oceans))*, to the Geological Association in Frankfurt am Main. Four days later, on 10th January 1912, he gave another lecture to the Society for the Advancement of Natural Science in Marburg under the title "*Horizontalverschiebungen der Kontinente*" *(Horizontal displacements of the continents)*. These two papers marked the first systematic views on the idea of drifting continents.

Wegener's hypothesis subsequently became known as the theory of *continental drift*. He published the idea of continental drift in 1915 in his book *Die Entstehung der Kontinente und Ozeane (The Origin of Continents and Oceans)*, which today is a classic on the theory of continental drift. Wegener was persuaded about continental drift particularly from his studies of fossil flora and fauna but also initially from the relatively neat geometrical fit between the coastlines of Africa and Europe on one hand and the Americas on the other hand.

The idea of drifting continents however did not receive much support as critics felt that the evidence was not strong enough and further that Wegener had not quite explained the underlying forces that should have been responsible for the drift in the first place. In fact it is reported that the attacks on the idea of continental drift were so bitter that Wegener's career as a university lecturer got badly affected. In spite of his quite strong scholarly credentials, he could not secure a professorial position in his native Germany and had eventually to move over to the University of Graz in Austria, where in 1924 he was appointed to the Chair of Meteorology and Geophysics. Nevertheless, Wegener's ideas eventually started off a flurry of studies on the subject of continental drift by a number of scholars.

One of the very early proponents of the continental drift theory was *Alexander du Toit* (1878–1948), Professor of Geology at the University of the Witwatersrand in South Africa. Du Toit was convinced about the validity of the continental drift theory from the similarities between the fossil fauna and flora that he had himself observed between South Africa and South America in the period 1927–1937. In 1929 the celebrated British geologist *Arthur Holmes* (1890–1965) suggested that convection currents in the asthenosphere were responsible for driving the continents around.

In 1925 a German hydrographic survey team, using the relatively modern technology of sonar sounding was able to produce for the first time relatively reliable maps of the bottoms of part of the Atlantic Ocean. This mapping revealed the existence of a mountainous ridge, which ran along the length of the Atlantic up to near the Antarctica. Later on it was established that the ridge in fact extended as well to all the major oceans of the world. This ridge has generally been referred to as the *Great Global Rift*. *Harry Hammond Hess* (1906–1969), Professor of Geology at Princeton University, and *Robert Sinclair Dietz* (1914–1995), starting off from the idea of the Global Rift, subsequently, in early 1960's, suggested that "sea floor spreading" was responsible for continental drift.

Subsequent confirmation of plate tectonics was afforded by studies of palaeomagnetism of the ocean floor, and the occurrence of earthquakes and volcanoes. Studies of the sea floor with magnetometers revealed stripes of periodically reversed magnetism of the sea floor rocks, which indicated that rocks increased in age the further they were away from the centre of the mid-oceanic ridge. This confirmed further the idea of sea floor spreading. Further, analysis of the occurrence of earthquakes and volcanoes showed that these tended to occur at plate boundaries.

In 1965, *J. Tuzo Wilson* (1908-1993), Professor of Geophysics at University of Toronto, was the first to use the term 'plate' in reference to the broken pieces of the Earth's crust. Subsequently, in 1967, *Jason Morgan* at Princeton University proposed that the Earth's surface consisted of 12 rigid plates that moved relative to one another. In the same year, *Xavier le Pichon*, a seismologist at Lamont Laboratories, on the basis of seismic analysis, worked out the geometric relationships of the plates. Subsequently, working with all the available evidence at the time, *Robert Dietz* reconstructed the structure of the surface of the Earth backwards to 200 million years ago. By late 1960's the idea of plate tectonics had been quite extensively debated and tested and was considered ripe to be adopted as a theory. We show in Fig. 5 the plate tectonic boundaries and recent earthquake occurrences.

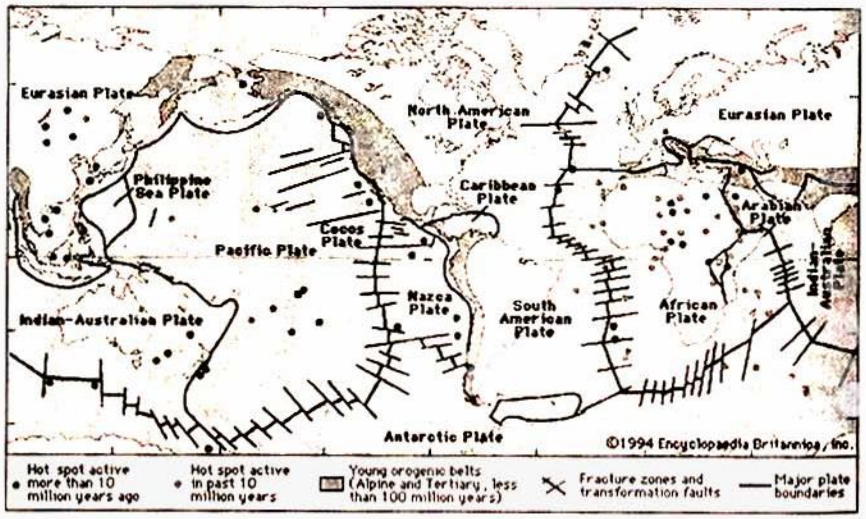


Fig. 5: Plate tectonic boundaries and recent earthquake occurrences (Encyclopaedia Britannica)

From the plate tectonics theory we have then that the Earth's crust is split into a number of plates that have been in constant motion from the entire period of Earth's existence. Today it is known that there are seven major tectonic plates, nine minor ones, and one sub-plate. The relative plate movements are currently in the range of 1cm to about 17cm per year. The fastest relative motion between two

neighbouring states is at the boundary between the Pacific and the Nazca plates, which are pulling away from each other at the rate of 17.2cm per year. Generally the Pacific plate is moving fastest, towards northwest, followed by the Australian which is moving northeast and the Nazca plate which is moving eastwards.

The plate tectonic theory revolutionised completely our understanding of solid Earth physics and geology. For the first time it was possible to explain with much more clarity the formation of mountain ranges and the nature and occurrence of earthquakes and volcanoes. It was, for instance observed that, earthquakes tended to occur much more frequently along the plate boundaries so that in fact a plot of earthquake occurrences almost virtually coincides with plate boundaries. Further, plate boundaries were generally marked by mountain ranges or deep valleys. One of the most prominent results of the plate tectonic motions was the Himalayas mountain range.

According to plate tectonic theory, about 250 million years ago in the late Permian period, what we today know as the Indian subcontinent was sandwiched between Africa, Antarctica, and Australia at a location near the current position of Antarctica. Some 50 million years later, in the early Jurassic period, India started to move northwards towards the Asian landmass. Moving at the relatively fast speed of 9cm per year, India finally collided with Asia some 40 million years ago, in the Eocene epoch of the Tertiary period. This collision between the Indian subcontinent and the Asian landmass was responsible for the formation of the Himalayas. India continues to push onto the Asian landmass and this is what is responsible for the apparent motion of the Himalayas in the northeast direction. We show in Figs. 6, 7, and 8, the changes on the Earth's landmass due to plate tectonics over a period of 500m years.

One of the unique plate tectonic features is the East African Rift Valley. The East African rift system is one of the only two divergent plate boundaries on the solid landmass; the other one is continuation of the mid-Atlantic ridge through Iceland. It is estimated that the East African Rift system was formed in the Miocene-Pliocene Epoch some 7 million to 2 million years ago. The East African rift valley is today estimated to be expanding at the rate of 2cm per year. At this rate, one hypothesis is that some 25 million years down the line, the Rift valley will have formed into an ocean with part of eastern Africa forming a new mini continent separate from the main landmass of Africa.

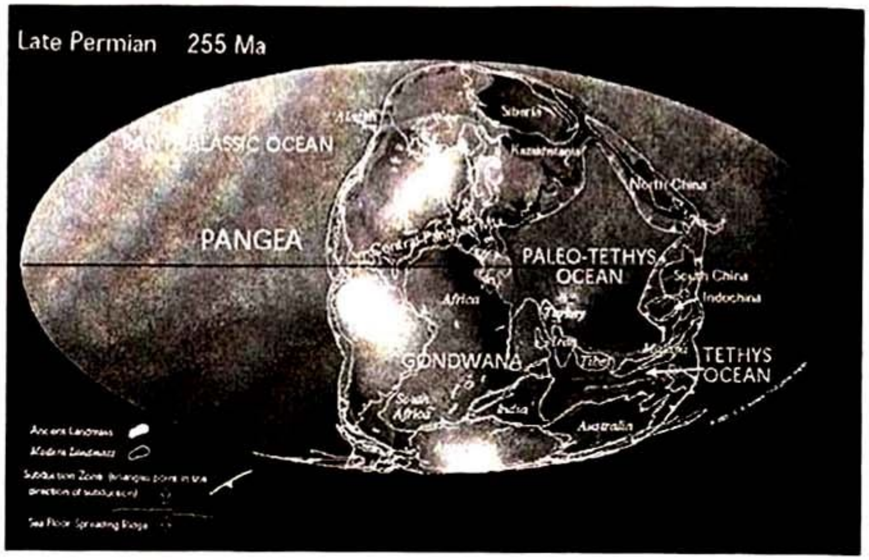


Fig. 6: The Earth in the Late Permian period 255 m years ago (Paleomap project (www.scotese.com))

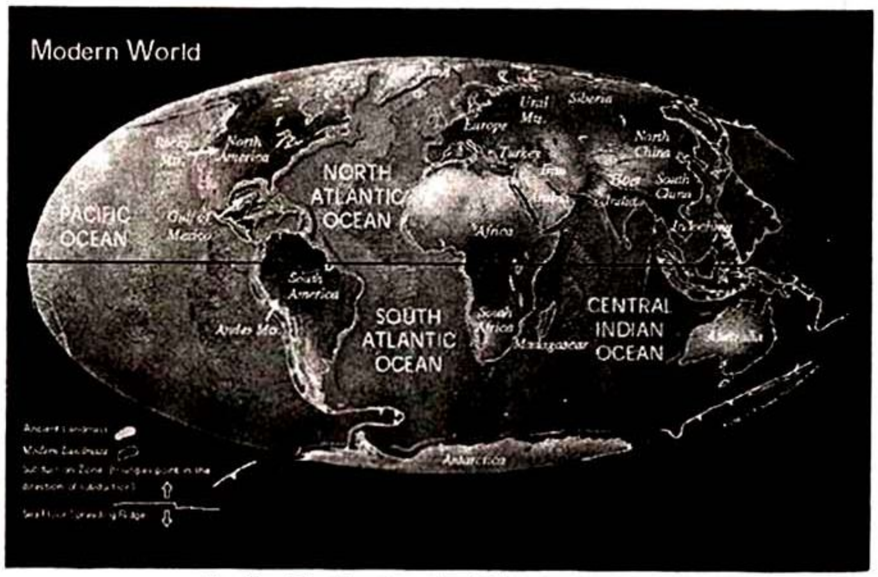


Fig. 7: The Earth today (Paleomap project (www.scotese.com))

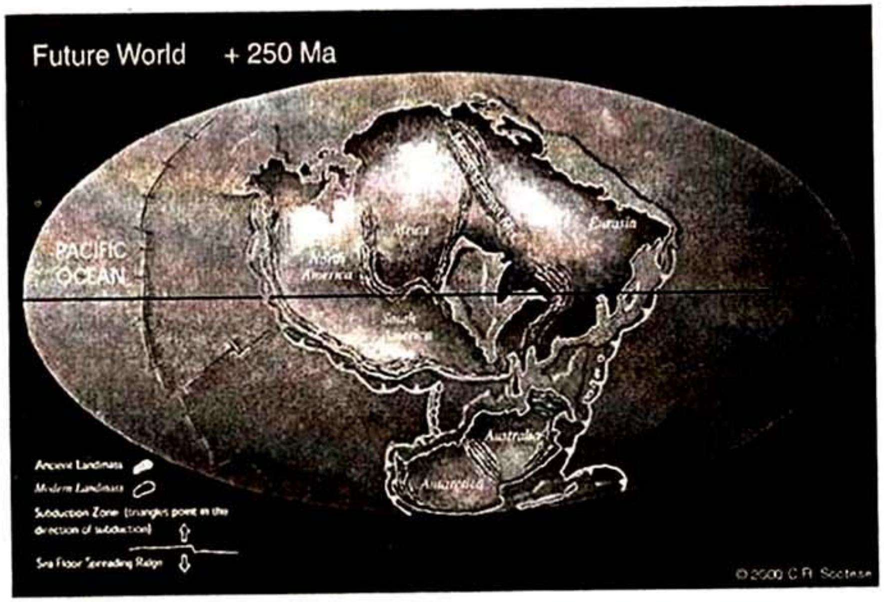


Fig. 8: The Earth 250m years into the future (Paleomap project (www.scotese.com))

The credibility of the theory of plate tectonics took quite a big jump since early 1980's due to the development of space and satellite positioning systems, which made it possible to measure and determine the positions of points on the surface of the Earth with relatively much higher accuracies. The principal techniques for the determination of relative motions of tectonic plates are today space technology based and comprise basically of Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and the Global Positioning System (GPS). Through the use of these positioning systems the inter-plate motions can today be determined with much more reliability and accuracy.

From the geodetic point of view we have that as the shape of the surface of the Earth changes so does the fundamental shape of the Earth as defined by the geoid also change. The geodesist is interested in capturing and recording these changes. Moreover, as already indicated above, some of the most reliable means of establishing plate tectonic movements are geodetic in the form of VLBI, SLR, and GPS. The plate tectonic theory together with other movements of the Earth such as polar motion and Earth rotation are today collected and studied under the discipline of *Geodynamics*. Until the development of plate tectonic theory, the shape of the Earth as determined from geodetic measurements was believed to be static and that it was only subject to gravitational effects and the Earth's motions in space.

Earlier determinations of the figure of the Earth as based on grade measurements resulted generally in ellipsoids which might have fitted relatively well onto the part of the world over which the grade measurements were taken without necessarily being a good fit for the rest of the world. Soon it was realised that best fitting ellipsoids could only be derived from data distributed globally as well as possible. The first such global ellipsoid was derived by the German geodesist *Friedrich Robert Helmert* (1841–1917) in 1906. This ellipsoid had the equatorial radius as $a = 6,378,200.0m$ with a flattening parameter $f = 1/298.3$. In 1909 the US geodesist *John Fillmore Hayford* (1868–1925) computed another global ellipsoid with the dimensions as $a = 6,378,388.0m$ and $f = 1/297.0$. The Hayford ellipsoid was subsequently adopted in 1924 by the International Union of Geodesy and Geophysics (IUGG) as the *International Ellipsoid.*

The determination of the best fitting Earth ellipsoid is today carried out in such a way that the ellipsoid should deviate as little as possible from the best available determination of the geoid at the time. Further, the ellipsoid is calculated on the basis of the best available geodetic data globally. The definition of the ellipsoid must essentially change therefore as more data becomes available with time. The International Association of Geodesy (IAG) coordinates the computation of the geoid and the international ellipsoid, and at its general assemblies every four years, publishes the parameters of the best fitting ellipsoid at the time. The most widely used reference ellipsoid today is the World Geodetic System 1984 (WGS-84). The WGS-84 ellipsoid is the one on which GPS coordinates are based. It has the dimensions $a = 6,378,137.0m$ and $f = 1/298.257223563$.

Geodesy as we can see is a relatively old science and indeed is generally considered the first genuine global science, for by its very nature it had to be global. The foundations for modern geodesy are generally considered to have been laid by the German geodesist *Friedrich Robert Helmert* (1843–1917). In his monumental work *Die mathematischen und physikalischen Theorien der höheren Geodäsie (The mathematical and physical theories of higher geodesy) (Vol 1 – 1880, Vol 2 – 1884)*, Helmert presented the theoretical foundations of geodesy in the most comprehensive manner. Helmert's ideas as presented in this book defined geodesy as a modern scientific discipline into the 20th century. His view of geodesy as being made up of mathematical and physical geodesy became the standard way of structuring the discipline well into the later parts of the 20th century.

Up to well into the middle of the twentieth century, geodesy was generally considered as comprising of geometrical (mathematical) and physical geodesy. It was only in the later part of the twentieth century when this view began to give way to the new concept of integrated geodesy. Today geodesy is considered to be concerned with the three main functions: (i) the modelling of the mathematical form of the Earth including the Earth's gravity field, (ii) the determination of the best fitting ellipsoid as the mapping surface for planimetry, and (iii) the precise

determination of positions on the surface of the Earth for geo-referencing on or near the surface of the Earth. All of this is today studied within the framework of a four-dimensional integrated geodesy combining the three-dimensional space with that of time.

4.2 Measuring the World

At the core to positioning of any object or event in space is our ability to assign unique numerical values to the position that denotes the particular location of the object or event. At the generic level, we have seen that the subject that deals with this problem is *Geometry*. A most important parameter in the study and practice of geometry is the *coordinate*. *Coordinates* are sets of numbers that may be used to define the location of an object or an event in space. Normally coordinates are taken with respect to some reference system and would, for instance, be given in the form (x_1, x_2, x_3), where x_1, x_2, and x_3 are the coordinates defining the location of the point in question within a three-dimensional space.

In geometry, one works with spaces extending from zero to infinity. The ordinary, real, world that we are used to however is three-dimensional, and if we include as well the time element, then we may also view it as four-dimensional. In the Cartesian geometry, we are able to describe, in a numerical, analytical, sense, the location of any point in terms of coordinates of the type x, y, z as indicated in the diagram of Fig. 9. In the two-dimensional space, the Cartesian coordinate system may be represented by the set (x, y). Correspondingly, in the four-dimensional space, in which we consider time (t) as the fourth dimension, we speak of an *event*, which we must now represent according to the coordinate set (x, y, z, t).

There are of course available several coordinate systems, of which the Cartesian system is however only the most commonly used. Depending on the task at hand, a particular coordinate system may be more suitable than the other. The radial coordinate system represented through the triplet (r, α, β), as in Fig. 9, would normally be adopted to represent a situation in which a radial distance (r), a horizontal angle (α), and a vertical angle (β), between two points have been measured. On the global scale, the position of a point is often defined through latitude (φ), longitude (λ), and height (h) in the form (φ, λ, h). The (φ, λ, h) coordinate system was developed chiefly by sailors, who needed a grid-like coordinate system for determination of position on the surface of the Earth.

In order to determine the coordinates of a new point, one requires in the first instance coordinates of points to be used as reference (i.e. some kind of starting point). The coordinates of the new point are then determined through computation with observed parameters such as distances, horizontal angles, angles of elevation, height differences, gravity differences, and coordinates of points derived through either astronomic determinations or satellite positioning. The computations, which can be carried out in one, two, three, or even four dimensional spaces, are based on three elemental principles of geometrical construction: *polar*, *intersection*, and *resection*.

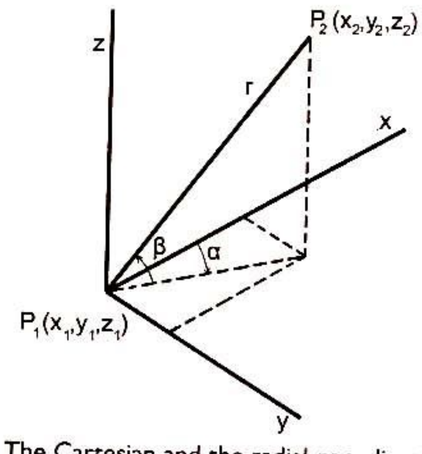


Fig. 9: The Cartesian and the radial coordinate system

In the *polar coordination* we determine the position of a new point P_2 from a known point P_1 through the use of an angle and distance. In *intersection*, the position of the new point is determined from other points of known positions through the use of either angles or distances. Normally if we are working in the two-dimensional space then we shall require at least two measurements from two known points. In *resection*, angles are measured from the unknown point to known points. Multiple points can now be coordinated on the basis of each of these elemental principles. From repetitive polar coordination we have a *traverse*; from repeated intersection or resection with angles we obtain a *triangulation*, while with repeated *intersection* (resection) with distances we have a *trilateration*. We show a representation of these in Figs. 10.

Virtually all the techniques for the determination of coordinates of points and events in space are based on simple rules of this type. The sophistication in the methodology is only brought about by the complexity of the task at hand including as well the accuracies desired. The determination of desired parameters in Surveying begins by field data collection in which observations (measurements) of various field parameters are carried out. The observations are then mathematically processed to yield the results for the parameters that are being determined.

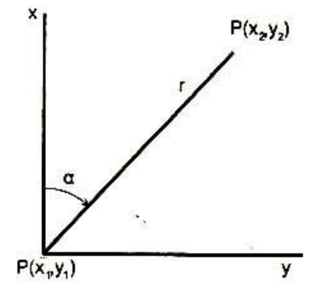


Fig. 10a Polar coordination of a point

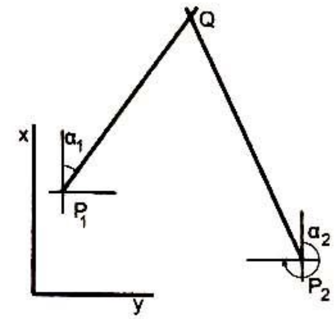


Fig. 10b: Intersection of a point by angles

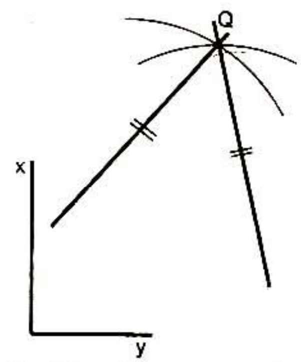


Fig. 10c: Intersection of a point

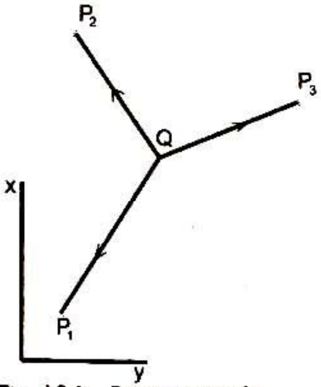


Fig. 10d: Resection of a point by distances

In as much as the coordinate is at the core of surveying and mapping operations, coordinate systems are in the large defined 'artificially', mathematically, only. Because of the largely artificial nature in defining coordinate systems, coordinates of any point are not absolutely unique but depend only on the manner in which the particular reference coordinate system has been defined and the particular reference frame determined. In surveying and mapping, coordinate systems are defined in terms of 'geodetic datums'. A geodetic datum is a coordinate reference system whose definition has been agreed upon.

Various regions of the Earth have in the past adopted geodetic datums unique to themselves, so that a given point within Earth-space would have different coordinates depending on the geodetic datum adopted. Such regional datums were considered 'local' in the sense that they were meant to be only useful in a particular region of the Earth. There are today also 'global' geodetic datums, which are meant for use on a world-wide scale. As has been indicated, one such global reference system is the world Geodetic system 1984 (WGS-84) upon which the Global Positioning System (GPS) coordinates are based.

In surveying, every observation (measurement) is assumed to be contaminated with observational, random, errors. In the processing of observational surveying data therefore, one of the most important factors to be considered is the analysis of errors inherent in the observations and their effect on the resultant determined parameters. Because one must essentially deal with large sets of data to be processed, error analysis and numerical data computing constitutes a principal area of study in the discipline of Surveying. The area concerned with the study of errors and general numerical data processing has generally been referred to as *adjustment theory and computations*.

Today the basic mathematical tool in the analysis of surveying data is the *method of least squares*. The method of least squares is a statistical tool that allows for the analysis of observational data in such a way that the results derived from such data deviate as little as possible from the observational set due to random observational errors. The method of least squares was developed by Gauss and also independently by the French mathematician *Adrien-Marie Legendre* (1752-1833). Gauss is particularly credited with the rigorous presentation of the method of least squares on the basis of the *normal distribution* of probability theory. The normal distribution theory itself was first published in an article by the French mathematician *Abraham de Moivre* (1667-1754) in 1733.

In the period 1818–1847 Gauss engaged himself in the geodetic survey of the state of Hannover. In this exercise he took personal charge of the measurements and computations. In the course of this work he invented a survey instrument the helioptre, which enables the sighting of long distance targets for angle measurement with a theodolite, through the use of reflected sun's rays. An important mathematical by-product of this survey was however that, in order to balance out the random errors in his measurements, Gauss applied the method of least squares and parallel with this also presented an analytical formula for the normal distribution. To this extent the normal distribution has become known as the Gaussian distribution. Subsequently in the further analysis of data with least squares, the geodesist Friedrich Robert Helmert in 1875 introduced the *Chi-square distribution*, which is well known in statistics.

4.3 The World in Geo-Graphics

A map is a graphical representation of any phenomenon that has a spatial attribute. Such phenomena could be the physical topography of the Earth, rainfall variation, the distribution of population, the network of roads, the location of buildings, or the distribution of disease. Maps seek to represent the real world graphically in as accurate a manner as possible through the use of generally agreed symbolisms and conventions. In general, a map depicts the real world in symbolic but generally accurate form at a scale smaller than the real world itself. Virtually anything that can be thought of in terms of spatial location can be mapped. Hence the dictum: "Anything that can be spatially conceived of can be mapped".

The study of maps and the art, science and technology of map-making is known as *cartography*. The cartographer's principal objective is to represent graphically the value of an occurrence as to indicate its spatial relationship with respect to other factors depicted on the map. Usually the information to be depicted will have been collected from the field by some kind of surveyor, whether topographer, demographer, meteorologist, or epidemiologist. The overarching requirement in the information that the cartographer works with, however, is that such information must have a geo-spatial location so that it can be appropriately placed on the map.

Cartography developed out of the need to record in graphical form the general lie of one's environment, both physical and built. The early 'maps' were nothing more than sketches and diagrams which had no scale relating them to the real world that they sought to represent. The actual origins of cartography are however not quite known. Nevertheless a town plan of the town of *Catal Hyuk* in Anatolia, Turkey, is believed to be the oldest extant map, having been dated at 6,200 BC (Fig. 11). The oldest extant map of the world on the other hand is that of a Babylonian clay tablet dated at ca. 600 BC (Fig. 12).

From Babylon, the quest to construct the map of the world moved over to Greece. The first Greek believed to have produced a map of the world was Anaximander of Miletus. The world then was considered to comprise the three old continents of Europe, Africa (Libya), and Asia. A rendering of Anaximander's map shows the three continents as separated by the Mediterranean Sea, the Nile, and River Phagio (Fig.13). The structure of the map of the world as set by Anaximander dominated the approach adopted for subsequent constructions of the map of the world by the Greek for the next four centuries without much serious modifications.

The first serious expansion of the view of the world was in 194 BC through a new map of the world constructed by Eratosthenes of Cyrene (Fig. 14). Eratosthenes' map showed the world as extending as far as India and the eastern reaches of what today is eastern Russia. It further showed a relatively reliable representation of the Nile up to the present Khartoum and postulated upon the sources of the Nile in the Ethiopian and east African highlands. In this map, Eratosthenes introduced for the first time some sort of grid to facilitate the location of features on the map.

This obviously was the precursor of what we today know as *latitudes* and *longitudes* on virtually all our maps.

Fig. 11: The Catal Hyük map ca. 6200 BC (www.henry-davis.com)

No personality however influenced the art of map construction in antiquity as *Claudius Ptolemy* (ca. 100–170 AD). In his very monumental work under the title *Geographia*, in 140 AD, Ptolemy presents relatively comprehensive maps of what was considered the known world then. Ptolemy's maps presented considerable advancement on previous maps and would remain the point of reference in mapping for the next fourteen centuries. Ptolemy's map of the world is presented in Fig. 15.

The principal reasons for the stagnation in map-making for the next fourteen centuries was largely due to the spread of the Roman Empire on one hand and that of Christianity on the other hand. The Romans appear not to have placed much interest in the construction of world maps. It is thought that it was the mathematical nature of map construction, which prevented the generally non-mathematical Romans from involving themselves intensively in the subject. However, the Romans produced quite some good quality engineering plans based on data gathered through land surveying measurements.

As Christianity spread through Europe, increasingly the learned became largely Churchmen who however taught that the truth about the form of the world lay in the Bible and all else was considered anti-Church and the work of pagans. Thus any serious scientific enquiry that could have lead to the advancement of map-making and an understanding of the geometrical form of the world was considered heretical and mere pagan foolishness. In fact, in spite of the fact that the world had been held to be spherical since the time of Aristotle, the church still held the view that the world was flat and rectangular and that the sun revolved around it causing day and night. The Bible was often quoted extensively to support these views.

Fig. 12: The Babylonian map – on clay tablet - ca. 600 BC (www.henry-davis.com)

Anaximader's Map of the World

Fig. 13: A rendering of Anaximander's map of the world (www.mlahanas.de/Greeks/PtolemyMap.htm)

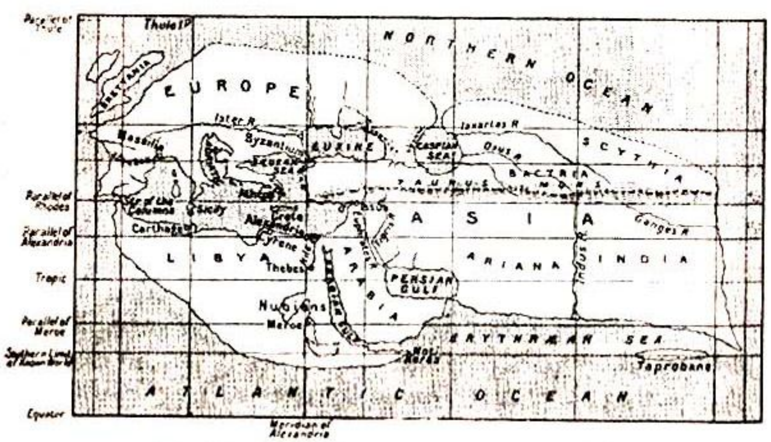


Fig. 14: Eratosthenes's map of the world (www-gap.dcs.st-and.ac.uk)

Fig. 15: Ptolemy's map of the world (150 AD - reproduced 1482 AD) (www-gap.dcs.st-and.ac.uk)

After fourteen centuries of relatively little activity in cartography, the 15th century saw tremendous renewed interest in the production of maps. This was in particular propelled the intensive exploratory activity from Europe in this period. This is the era that saw the famous exploratory journeys of *Bartholomew Dias* (1450–1500), *Vasco da Gama* (1469–1524), *Christopher Columbus* (1451–1506), *Amerigo Vespucci* (1454–1512), and *Ferdinand Magellan* (1480–1521). These explorations on one hand motivated considerably the need for accurate maps and on the other hand brought in new information that fed into the construction of even more accurate maps.

Based on the 'discoveries' of the new lands, cartographers immediately went to work to produce maps of these new lands as based on the information gathered from the explorers. Most of this information however had been based only on sketches and qualitative descriptions and hence the resultant maps were not always very accurate. Whatever the case however, these maps marked major advancement on the maps of the world up to then.

One of the greatest cartographers of this era was the German *Martin Waldseemuller* (1470–1518). Based on the collected information from Columbus and Vespucci, Waldseemüller produced in 1507 what was the first map to include the newly discovered continent to the west of Europe (Fig. 16). This new continent he named America on his maps after Amerigo Vespucci, who was the first European to sight the continent. Waldseemüller is quoted to have named the new continent with these words: "*Since another fourth part [of the world] has been discovered by Americus Vesputius, inasmuch as both Europe and Asia received their names from women, I see no reason why anyone should justly object to calling this part Amerige, i.e., the land of Amerigo, or America, after Americus the discoverer, a man of natural wisdom.*"

Fig. 16: Martin Waldseemüller's World map of 1507 (www.henry-davis.com/MAPS/Ren/Ren1/310.html)

The greatest personality in cartography in the 16th century was however *Gerardus Mercator* (1512-1594. Mercator was born Gerhard Krämer to German parents in the small town of Rupelmonde in Flanders (now Belgium). He subsequently changed his name to the Latin version Gerardus Mercator. He studied humanities, philosophy, mathematics and geography at the University of Louvain. Mercator was a keen traveller with an acute awareness of geography. He was particularly fascinated by the application of mathematics in map-making, and in 1537 produced as his first map, the map of Palestine, which was largely based on the Bible descriptions of the region. In 1552 he moved to Duisburg in Germany during which period he embarked on a major project to produce a new map of Europe. The map was completed in October 1554 and was a most accurate piece of work. This work immediately established Mercator as the foremost cartographer in Europe at the time.

In 1569 Mercator produced a greatly improved version of the world map on a new projection (Fig. 17). The projection was particularly aimed to be suited for use by sailors and navigators. Normally sailors and navigators needed to take the shortest distance to their destination while keeping a particular course. This new projection would enable sailors to keep a straight-line course on the map, which on the ground would translate as the shortest distance to their destination. Such a line is known as a *rhumbline* or a *loxodrone*. The projection is generally known as the Mercator projection. The Mercator projection is today used widely in the design of maps, both large and atlas scale maps. For his design of the Mercator projection, Mercator is considered one of the greatest cartographer's of all time.

A most remarkable point about Mercator's projection is that it was invented well ahead of its mathematics. The mathematics for the projection is based on differential geometry and requires the use of calculus and logarithms. The concept of logarithms was not invented until 45 years later, in 1614, by *John Napier* (1550-1617); calculus was invented by Isaac Newton and Gottfried Wilhelm Leibniz, more than a century after Mercators's map, and differential geometry was developed more than two centuries later by Carl Friedrich Gauss. In fact it is Gauss, who, in 1828, on the basis of his differential geometry, subsequently developed fully the mathematics of conformal mapping, of which the Mercator projection is a part.

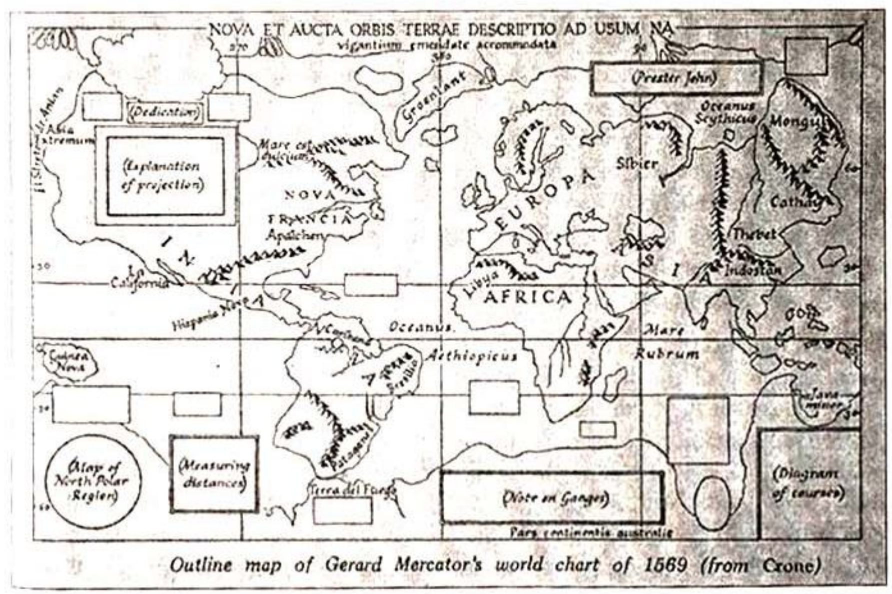


Fig. 17: Mercator's map of the world (an interpretation of) (www-henry-davis.com/MAPS/Ren/Ren1/406C.htm)

In 1570, a year after Mercator produced his map, a friend of his, Abraham Ortelius, published, in Antwerp, a collection of 70 maps in what is generally considered the first modern atlas. Mercator however was the first to adopt the word 'Atlas' to describe a collection of maps and it is said that he is the one who encouraged his friend Ortelius to produce the atlas. Mercator is reported then to have adopted the word 'atlas' with the words: *"...to honour the Titan, Atlas, King of Mauritannia, a learned philosopher, mathematician, and astronomer".*

By this time the existence of Australia to European mapmakers was still quite hazy. The Greeks had all along speculated that there had to exist a large continent in the southern part of the world in order that there might be a symmetrical balance between the northern and southern continents of the world. Many maps in the fifteenth century had consistently indicated the existence of the southern continent under the title *Terra australis nondam cognita* (the southern land not yet known) or simply *Terra australis incognita* (the unknown southern land).

With the Americas already recorded on the map, the next major challenge was that of establishing the existence or otherwise of the fabled *Terra Australis*. The Englishman *Captain James Cook* (1728-1779) led three major expeditions into the Pacific in the period 1768 to 1780 to look for *Terra Australis* as well as the Northwest Passage which was believed to exist between Eurasia and North America. During these expeditions, Captain Cook reached New Zealand and Australia. He surveyed and mapped the entire coastline of New Zealand as well as the north-eastern coastline of Australia.

With most of the world thus explored and represented in map form, further progress in cartography was now aimed at covering the whole world with maps based on accurate and reliable survey measurements. Until the early part of the 20th century, collection of survey and mapping data was exclusively by ground methods. These methods were relatively slow and tedious. In the first half of the twentieth century however photogrammetry, which facilitated surveying from aerial photographs, became relatively well established and made it possible to survey large tracts of land rapidly.

Towards the end of the 19th century it was already felt that there was a need for a consistent map of the world. A German Geographer *Albrecht Penck* (1858-1945) thus proposed at the Fifth International Geographical Congress in Berne, in 1891, that there be established a coordinated effort to map the world at some set specific standards. He proposed then the creation of the *International Map of the World* by which the world would be covered by some 2,500 maps at the scale of 1:1,000,000. At a subsequent international conference in 1913 the idea was adopted and the project started upon. The International Map of the World project subsequently became known as *The Millionth Map*.

The Millionth Map project did not however progress as originally expected. The two world wars slowed down the pace considerably in the first half of the twentieth century. In 1953, the project was taken over by the United Nations. However this did not improve much the progress on the project. By 1980's only about 40% of the maps had been produced and still less than half of these were actually up to the standards originally set.

Today practically every part of the solid landmass of the world has been mapped in some way or other; what may be at stake is only the quality of such mapping. The main scales at which most mapping agencies carry out base mapping are 1:50,000 and 1:100,000. The United Nations Secretariat has normally kept track of the general status of mapping in the world and as of 1990, they reported that 33.5% of the world had been covered at the scale of 1:25,000, 65.6% at 1:50,000, 55.7% at 1:100,000, and 95.1% at 1:200,000. A more detailed presentation of this is provided in Table 1.

Table 1: Status of world mapping (1990) (Konecny, 2002)

Region	Scale Range			
	1:25,000	1:50,000	1:100,000	1:200,000
Africa	2.9%	41.4%	21.7%	89.1%
Asia	15.2%	84.0%	56.4%	100%
Australia and Oceania	18.3%	24.3%	54.4%	100%
Europe	86.9%	96.2%	87.5%	90.9%
Former USSR	100%	100%	100%	100%
North America	54.1%	77.7%	37.3%	99.2%
South America	7.0%	33.0%	57.9%	84.4%
World	33.5%	65.6%	55.7%	95.1%

A major challenge in the design of maps is that of establishing a suitable projection for the map. The idea of a map projection is to facilitate the representation of the curved surface of the Earth on a flat medium such as a piece of paper. A map has three principal parameters that normally would be paid attention to in its representation, these are: direction, distance, and area. Unfortunately there is no map projection that mathematically would maintain all these attributes simultaneously. Hence any given projection would aim at maintaining one of these characteristics only while sacrificing the others.

Since no particular map projection could accommodate the three principal parameters of a map simultaneously, several map projections have been devised over time in order to accommodate specific aspects of maps according to their intended uses. There are, today, several map projections, but they can normally be classified into three main categories: conformal, equidistant, and equal area. Conformal projections maintain shape around a point; equidistant projections maintain distances from the centre of the projection, while equal area projections represent areas correctly.

Fig. 18: The world map on Mercator's projection (http://en.wikipedia.org)

Due to the fact that it distorts areas considerably away from the equator, the Mercator projection has often been criticised as being too Euro-centric to the extent that it depicts Europe as much larger than it actually is. The exaggerated size of Europe on the Mercator projection was seen as being favoured by colonial

Europe, which then might have wished to convey the impression that Europe was relatively large and was therefore justified in keeping colonies abroad. Because of this, the use of Mercator projection for the production of world maps has in the last few decades been severely criticised. However even as this may be so, it would be remembered that Mercator never devised the projection for general use as such but for use in navigation by sailors.

As an alternative to Mercator's map as the standard wall map in schools, a German historian and journalist, *Arno Peters* (1916–2002), in 1974 presented a map of the world on a 'new' projection that preserved areas. The purpose of Peter's map however was to present political units in equal area as to facilitate reliable comparisons of sizes of continents and countries. Although this objective was eloquently achieved, the resultant map was considerably distorted in scale and direction and many thought it was positively 'ugly'. This in itself generated considerable controversy that has made Peters map still a most controversial map today. The Peters projection was however not entirely original as a similar projection had been devised already in 1855 by the Scotsman *James Gall* (1808-1895); for this reason the projection is often referred to as Gall-Peters projection.

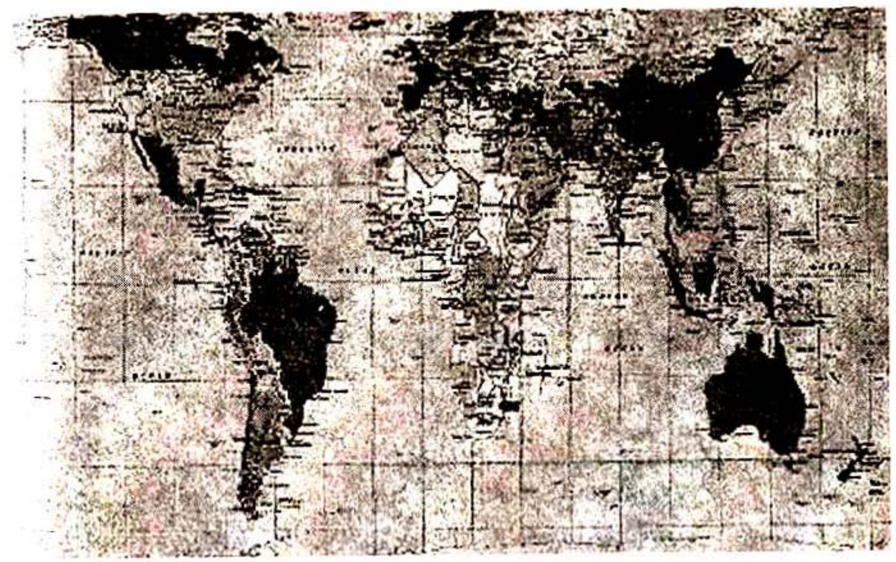


Fig. 19: Peters map of the world (http://www.petersmap.com)

Recently, in 2002, a British cartographer, Mick Dyer, has devised an equal-area projection, which is similar to the Gall-Peters projection but with less distortions and hence considered more appealing to the eye. An American company ODT Inc was interested in an equal area map like the Gall-Peters projection but one which had less distortion. Mick Dyer produced the projection through a modification of the Behrmann cylindrical projection, which had been devised by the German cartographer *Walter Emmerich Behrmann* (1882-1955) in 1910. The projection is known as the *Hobo-Dyer projection*. The name of the projection derives from the names *Howard Bronstein*, the president of ODT, *Bob Abramms* the founder of ODT, and the cartographer *Dyer*.

5

Applications: Geospatial Science in Practice

5.1 Geospatial Positioning and Geo-referencing

One of the principal objectives of geodesy is to determine precise positions within the geo-space. Such positions can be on, below, or above the surface of the Earth. The determination of positions below the surface of the Earth generally arises in the case of mining activities and in tunnelling engineering. The determination of positions above the surface of the Earth on the other hand largely involves the determination of positions of artificial satellites in space. Basically most of the positioning involves locating the positions of objects on the surface of the Earth. This of course should be expected from the fact that it is on the surface of the Earth where most of human activity takes place.

In measurement, we are usually only able to determine the measured value of a given parameter with respect to some reference value. This is valid whether we are measuring distance, mass, or time, which are the basic quantities in physics. In geospatial positioning, the location of an object or phenomena is defined through the use of coordinates. Such coordinates must themselves be defined through some other reference. The coordinates used in geospatial positioning are normally taken with respect to earth and are thus referred to as earth-centred.

What may be considered the basic coordinate system in geodesy is the geo-centric Cartesian coordinate system. This is a coordinate system defined by three straight lines which all pass through the earth's centre of mass and are perpendicular to one another. The earth's axis of rotation is taken as the principal axis (x). The second axis (y) is that straight line contained in the plane of the meridian of Greenwich and lies on the equatorial plane of the earth. The third axis (z) is set out such that the triplet forms a right handed system. With this coordinate system the position of any point in space can then be defined with respect to the mass centre of the earth in terms of coordinates (x, y, z).

However one of the coordinate systems that would be most familiar to us is that of latitudes, longitudes, and height. In order to establish this type of coordinate system one needs a reference surface. Usually the reference surface would be that surface which best approximates the general shape of the earth. We have already seen that, depending on the level of accuracy we are adopting for our purposes, the earth can be considered as a sphere, an ellipsoid, or a geoid. In formal geospatial positioning however, the ellipsoidal or geoidal surfaces are usually adopted depending on whether we wish to work with mathematical or physical coordinates.

Whether the surface of reference adopted is the ellipsoid or geoid, the principal parameter in the definition of coordinates is the line perpendicular to the surface. In the case of the geoid, the perpendicular to the surface is the direction of force of gravity while for the ellipsoid this is simply referred to as the normal. For both systems, the latitude is the acute angle that the perpendicular to the surface at the particular point makes with the equatorial plane; the longitude is the angle between the plane of meridian through Greenwich and that of the meridian through the point of interest; and the height is the perpendicular distance from the surface to the point. The ellipsoidal coordinates are mathematical while the coordinates taken with respect to the geoid are physical.

From the fact that reference ellipsoids are normally derived mathematically and are thus artificial in nature. A reference ellipsoid is defined on the basis of its two principal radii of curvature; the equatorial and the polar radii. Once the reference ellipsoid has been thus defined geometrically, it must be located with respect to the geocentric Cartesian coordinates (x, y, z). This process constitutes principally in defining the location of the origin of the reference ellipsoid as well as the orientations of its three axes x, y, z. The location of the ellipsoid and the orientation of the ellipsoidal axes will normally be carried out in such a way that the general deviation between the ellipsoid and the geoid over the area of interest is kept to the minimum.

When the ellipsoid has been defined and placed within earth-space in this way, the resultant system is referred to as a geodetic datum, which can now be used as reference for subsequent location of points within geo-space. Because of the artificial nature of the ellipsoidal geodetic datum, there can be any number of such geodetic datums. A geodetic datum can be defined for any given area of earth's surface with the consequence that there are today several geodetic datums in use worldwide, ranging from those covering single countries to the entire globe. The coordinates for a given point as defined by any two datums are essentially

different. Thus the ellipsoidal latitude, longitude, or height of a given point is not in itself unique but entirely depends on the adopted datum of reference.

The physical coordinates that are taken with respect to the geoid are the astronomic latitude, astronomic longitude, and height measured from the mean sea level. These coordinates, because they are taken with respect to the physical, gravity field, are unique. Whereas the ellipsoidal latitude and longitude can be predicted mathematically, the latitudes and longitudes as taken with respect to the geoid can only be determined through point to point observations of these parameters or their elements thereof. We normally have that latitudes and longitudes plot on maps as smooth curves that curve in the same direction. Physical latitudes and longitudes however curve in unpredictable patterns, since they are determined according to the, physical, gravity field.

Because of the unpredictable nature of the physical coordinates, such coordinates are never used for determining coordinates in maps, instead ellipsoidal coordinates are used. The fact that ellipsoidal coordinates are not unique means therefore that the coordinates we have on maps are also not unique, although in general they differ from the unique, physical coordinates only slightly. This means therefore, for instance, that the line of the equator that is shown on the topographic maps, is not unique but depends only on the way the coordinate system used has been defined. If therefore, we were to determine the unique equator we would have to determine such through the determination of astronomic observations. Such equator however when plotted on a map would not appear as the straight line we are used to but as an unpredictable curved line which can only be plotted through joining up single individual points determined to be of latitude 0°.

We have seen that in the simplest form, the world in which we live is geometrically of the three-dimensional Euclidean space plus the element of time, which then makes it four-dimensional. When the three-dimensional form is integrated with time, then we have the four dimensional space-time. In the determination of position therefore, at the most basic level, one would be expected to present position in a four-dimensional format. Until very recently, geodesists and surveyors were concerned only with the representation of position within the three-dimensional Euclidean space; time on the other hand was treated completely separately. The three-dimensional representation itself was treated in the form of a two-dimensional space representing 'planimetry' with a one-dimensional space for height.

Traditionally, geodesists and surveyors established the 'planimetric' position on the surface of the Earth through the measurement of chains of interconnected triangles in what was known as a triangulation. The concept was based on the simple exploitation of the geometry of the triangle through intersection as has already been indicated. By repeating the process of triangulation with successive triangles, a chain of triangulation may be built up. With the invention of electromagnetic (electronic) distance measuring (EDM) equipment, it became possible to measure distances more easily and hence the measurement of distances could be incorporated into the determination of position within the triangulation network system. Moreover it also became possible to work with polygons in the form of traverses as means to determine position. The final situation for a triangulation may look as in Fig. 20.

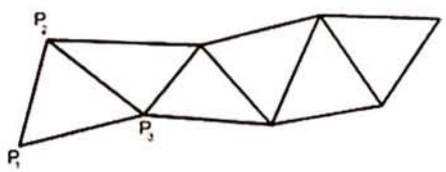


Fig. 20: Triangulation

The height on the other hand has traditionally been determined through levelling in which an instrument that defines a horizontal line of sight is used to determine the height difference between two points. The conventional modern levels use a spirit level of the type of the carpenter's level to determine the horizontal line, which in essence is simply a line perpendicular to the direction of the gravity vector at the standpoint of the instrument. The principle of determining height of a point is that if the height difference between the two points is known and the height of one of the points is also known then the height of the second point can be determined. Usually the initial point of reference in the determination of heights of points is taken as the mean sea level, which then is taken as height zero. Thus one speaks of 'height above mean sea level'.

The determination of position in the form of two-dimensional planimetry with the one-dimensional height as quasi-separate entities, which were then simply mixed to create the three-dimensional view, was the traditional approach to positioning in geodesy and surveying well into the 1970's. The approach though was considered to be not so rigorous mathematically as it created an artificial separation between planimetry and height on one hand and between physical and geometric parameters on the other hand. Within this context geodesy was viewed in terms of two distinct concepts of geometric and physical geodesies.

The desire to compute position within the three-dimensional Euclidean space was however already recognised in 1878 by the German geodesist and mathematician *Ernst Heinrich Bruns* (1848–1919) who also proposed the mathematical formulation of how to go about this problem. After some further mathematical formulations in the late 1940's to mid 1980's, the concept of computing location in the three-dimensional Euclidean space in a manner that integrated both

physical and geometric parameters within one computational model only got established in geodetic positioning in the 1990's.

The principal means to determine geodetic position today however is through the use of artificial satellites. The satellite positioning systems determine the coordinates of an unknown point through the use of distances measured between the point and the satellites. The coordination is then performed on the basis of intersection of distances. We have that the locus of a point at the end of a distance from a fixed point is a sphere. Within the three-dimensional space the point of intersection of three such spheres is the point of interest. The distance between the satellite and the unknown point is measured through the timing of how long it takes the signal to travel from the satellite to the point and then with the known velocity of light the distance can be derived.

Positioning with satellites requires that the position of the satellite is known. This is achieved through continuous monitoring of the position of the satellite. From such monitoring, the position of the satellite for the next 24 hours can be predicted and information of its predicted position input into its system. When a signal is received from the satellite at a particular time then the satellite shall communicate its position to the receiver as based on the information of its position as it has it at the time. In reality we have that there is usually some discrepancy between the actual position of the satellite and its apparent position as communicated to the user. This discrepancy eventually finds its way in the determination of the position of the user and is a major source of error in positioning with satellite systems.

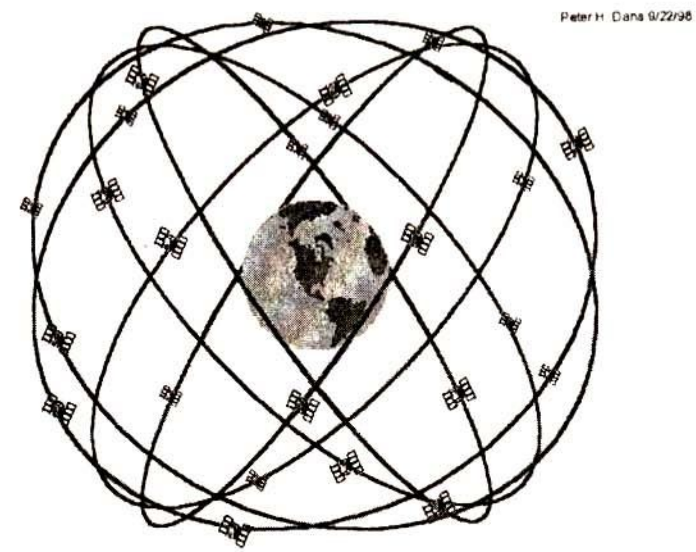
In the positioning with satellites, the receiver needs to tap onto signals from at least four satellites for a determination of position. This is because at any one unknown point there are four unknown parameters needed to be determined, namely, the coordinates x, y, z and a time correction δt. Mathematically each of the distances from a satellite results in an equation and from the four equations the four unknown parameters may be determined. The results obtained from such single positioning are generally sufficient for most civilian uses. In geodesy and mapping, however, higher accuracies at the sub-centimetre levels and less are demanded. Geodetic use of satellite positioning systems therefore normally involves observation to several satellites with several receivers. The processing of the observations for geodetic positioning normally involves the use of relatively sophisticated computational mathematical models.

The satellite positioning systems in principle determine the position of points in three-dimensional coordinates with one of the variants of such coordinate systems being that of latitude, longitude, and height. Such latitude, longitude, and height coordinates are based on the reference ellipsoid, which as has been indicated, is an artificial reference surface. The coordinates of points as derived on the basis of the reference ellipsoid are artificial in the sense that they are not related to the gravity field. It is desirable however that the coordinates of points should have physical significance, such that for instance when one point is said to be higher than the other then we expect for instance that water would flow from the higher to the lower point. In the case of coordinates derived from satellite positioning systems, the mere fact that one point is shown as higher than the other does not necessarily imply that water would flow in the direction from the higher to the lower point.

In order that coordinates derived from satellite positioning should be linked to the physical, gravity, field, such satellite derived coordinates must be corrected for the effect of the gravity field. The most rigorous way to do this is to integrate terrestrial and satellite observations in the computation of the geodetic coordinates of points. The need to correct satellite derived coordinates for the effect of the gravity field is particularly of critical importance in aircraft navigation. Many aircraft today are fitted with satellite positioning devices for navigation, which indicate then the position of the aircraft in terms of both latitude and longitude on one hand and height on the other hand. Because the satellite derived height is basically artificial and thus not an indication of the actual height above sea level as such, it is quite possible that an aircraft would under-estimate the height of a mountain with possible tragic consequences.

Currently there are in operation two satellite positioning systems with one other system planned for. The American Global Positioning System (GPS) and the Russian GLONASS have virtually matured while the European GALILEO system is just being worked on. GPS was the first of these to be established and has generally served as the standard in satellite positioning systems technology. GPS is made up of 24 satellites orbiting the Earth at the height of 20,200 km in orbits inclined to the equatorial plane at 55^0 to the east. It takes each satellite 11hours 58mins 00secs to orbit the Earth once. The satellites are arranged in six orbits with four satellites per orbit. At any one time only 21 satellites are operational with three others as spares. The satellites are monitored from five centres on the surface of the Earth with one of the centres also operating as a control centre. We show in Fig. 21 a representation of the GPS satellite constellation.

The American Government established GPS as a military tool and to this extent the system is controlled by the USA military. The system was originally designed to give positional accuracies of 400m. This level of accuracy was considered sufficient for the monitoring of a military ship, which was a principal objective in the design of the system. Initial tests with the system however returned quite surprisingly high accuracies, in the range of 15-40m. In order to deny the advantage of such high accuracies to potential enemies, the US Government deliberately had the accuracy of the GPS system degraded to the level of 100-150m for ordinary users through what was known as 'Selective Availability' (SA). Only the US military and other selected users would then be allowed to access the high accuracy level free of SA.



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Fig. 21: The GPS satellite constellation (www.colorado.edu)

The ideas to develop a satellite system for positioning and navigation were motivated by the launch of the first artificial satellite, Sputnik, by the Soviet Union in 1957. By 1960 the United States of America had started seriously on the development of an all weather satellite positioning and navigational system. The first such complete system was the Navy Navigation Satellite System (NNSS) also known as the TRANSIT, which was developed by the American Navy.

The TRANSIT system consisted of six satellites orbiting the Earth at an average height of 1,075 km. The system became operational from early 1960's but became available for civilian use in 1967. It was originally developed for use in the navigation of the American Polaris missile submarines. The TRANSIT system used the concept of the Doppler shift (named after the Austrian mathematician and physicist *Christian Andreas Doppler* (1803-1853) who discovered the effect) to measure ranges (distances) and was thus popularly known as the *Doppler satellite positioning system*. The TRANSIT system was formally retired in 1996.

The relatively good success with the TRANSIT system motivated the American Government to work towards a more versatile satellite positioning system. The new system would be known as Navigation System with Timing and Ranging

(NAVSTAR) Global Positioning System (GPS). The GPS project attained Initial Operational Capability (IOC) in July 1993 when 24 satellites were fully operational for the first time. The Full Operational Capability (FOC) was however declared only a year later in July 1994. On 2nd May 2000 SA was turned off by the US Government and since then civilian users of GPS have enjoyed the use of the system with accuracies generally at the level of 15m.

The Russian GLONASS (Global'naya Navigationnaya Sputnikovaya Sistema (Global Navigation Satellite System)) basically functions on the same principles as the GPS. The system comprises 24 satellites in three orbits at a height of 19,100 km. The satellite orbits are inclined at angle of 64.8° with the equatorial plane to the east. One orbit period is 11hrs 15 min. The system was launched in 1982 and was declared operational by the President of the Russian Federation in September 1993. Plans towards the establishment of a satellite navigation system were initiated by the Soviet Union in late 1960's. The principal objective was to set up a system that could be used in the precision guidance of ballistic missiles. Like the American GPS therefore, GLONASS was conceptualised as a military system.

Earth orbiting satellites keep in position principally due to the Earth's gravitational pull on the satellite and the satellite's momentum generated by the satellite's velocity. The velocity of the satellite is a function of the gravitational force due to Earth, and since this force is not uniform all along the satellite's orbit, the velocity of the satellite is also not uniform but varies slightly due to the variations in the underlying gravity field. Because of the variability of the underlying gravity field and hence the velocity of the satellite, the orbit of the satellite normally does not keep strictly to the theoretically expected orbit as specified by Keplerian laws. The errors on the satellite orbit get translated into errors in the determined position and are thus largely responsible for the errors in position with satellites.

The use of GPS (and GLONASS) to obtain geodetic level results is an amazing effort in the application of mathematics and field observation design to convert what was effectively a low accuracy technology into a most accurate measuring tool. The biggest source of error in GPS is in the modelling of the satellite orbit and consequently the determination of the actual position of the satellite at the time of observation. To offset the bulk of this error, in geodetic GPS work, what is determined is the vector between two receivers at which observations to the same satellites had been carried out at the same time. This way the resultant vector is largely free of the satellite orbital errors, which generally would have cancelled themselves out at the two observing stations. In this, the distances between the two satellite receivers would normally be maintained at less than 120km.

The principal use of geodetic positioning is in geo-referencing, which is concerned with locating a point in terms of coordinates within geo-space. Traditionally geodesists and surveyors established coordinates of points on the surface of the Earth through the process of triangulation. In a given region, coordinates would in the first instance be determined to the utmost of accuracies at fundamental points. Such fundamental points then provided the principal geo-reference framework for the region. At this level, the fundamental points would normally be at distances of the order of 40 to 100 km. The fundamental points were then used as reference for the establishment of other points at the lower level. The process of breaking down the reference framework was continued until reference points were brought to the level of 5 to 10 km apart. The entire network then constituted the geo-reference framework for the area of interest. The points constituting the framework have generally been known to many of us as trigonometric points.

Generally trigonometric points were set up on high ground, particularly on top of hills. The reason for this was that, with terrestrial observation methods, it was essential that the two points between which an angle or a distance was being observed be inter-visible. Today, GPS is a principal tool in the observation of geo-reference frameworks. The use of GPS in the establishment of geo-reference frameworks removed completely the need for points connected by observations to be inter-visible. Instead, in GPS observations, what is needed is a clear line of sight between the satellite and the receiver. The use of GPS thus has removed the need for setting up geo-reference points on high ground. While the traditional geodetic reference point was made up of a concrete pillar, the modern geodetic reference point is an active GPS station, which connects with a user's receiver to produce highly accurate coordinates of positions for the user.

With a geo-reference framework thus established, the determination of the location of any other point may now be determined by linking such unknown point with observations to points of the geo-reference framework whose positions are known. Using geometric relationships, the coordinates of the unknown point may then be determined from those of already known coordinates. In mapping, this process has to be repeated for each and every point whose location is to be determined. The map is in fact eventually determined by joining such discretely determined points through smooth curves and surfaces. The term 'geo-reference' is today however used mostly in connection with geospatial information systems (GIS) and remote sensing work. GIS is map-based, but a map is not a map until positions on it have been related to the physical, ground, positions through geo-referencing.

Because of the problems with working with local reference datums, geodesists have over the years proposed reference datums for international use. On such datums the coordinates are held consistent throughout the entire globe as based on one reference system. The best known international reference datum today is the World Geodetic System 1984 (WGS-84), which is the basis for GPS coordinates. The WGS-84 reference ellipsoid is defined as of equatorial radius

$a = 6,378,137m$, the polar flattening $f = 1/298.257223563$ (and equivalently, polar radius $b = 6356752.314m$). This has been determined on the basis of observations carried out globally and processed in such a way that the deviations between the resultant ellipsoidal coordinates deviate as little as possible from the physical coordinates taken with respect to the geoid.

The definition of international coordinate systems is today the responsibility of the International Earth Rotation and Reference Systems Service (IERS). (Until 2nd April 2002, this organisation was simply known as The International Earth Rotation Service (IERS), when it changed to its present name however it retained its original acronym 'IERS'). IERS has been assigned this responsibility because the establishment of earth-centred coordinate systems is strongly dependent on the behaviour of the rotation of the earth. IERS is responsible for the determination and maintenance of global reference coordinate frames and global time.

A realisation of the global coordinate reference frame is the International Terrestrial Reference Frame (ITRF). ITRF was established in 1987 jointly by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG) with the objective to define and maintain a terrestrial reference system and a celestial reference system. ITRF currently provides the best coordinate reference framework for global use. In principle ITRF is defined on the basis of WGS-84, but is realised through a much more elaborate observational dataset and processing system. ITRF is realised through many more observations distributed on a much wider scale globally and the observations processed to accommodate such factors as plate tectonics, polar motion, and tidal effects. For this reason ITRF coordinates are much more accurate than those of the conventional WGS-84. Because of the dynamic nature of ITRF coordinates, a new ITRF is defined virtually every year.

5.2 Geospatial Measurement and Metrology

The first calling of the surveyor has always been to carry out field measurements and to produce maps from such measurements. The maps may usually be of any type provided the feature or phenomenon being represented on the map has geospatial location as to be able to facilitate geo-graphic representation in map form. All the maps produced from survey data may be classified into two types: *topographic* and *thematic*. Topographic maps are maps that usually represent the natural and artificial features of an area. In short a topographic map is a general map of the area in question and is usually considered a base map of the area.

Thematic maps are those that deal with a particular theme; the themes represented may be physical, man-made, or a phenomenon. For instance, such maps may show population distribution, incidence of disease, the level of

pollution, or the distribution of rainfall. Usually one requires a base map on to which one would superimpose the thematic information. The data collection for thematic mapping would normally be carried out by an expert in the particular area, sometimes in conjunction with a surveyor to assist in the geospatial location of the particular phenomenon being mapped.

One of the traditional areas of thematic mapping is *cadastral mapping*, which is concerned with the measurement and mapping of plot boundaries. The process of field measurement for cadastral mapping is known as *cadastral surveying*. This is one aspect of surveying with which most of us will have interacted most directly. The technical aspect of cadastral surveying usually involves the establishing of boundary marks for the plot in question. The placement of such boundary marks would normally be based on mathematical procedures that would allow for the replacement of the markers in case of loss in the future. The boundary in such case is in fact defined mathematically so that the marker is only the visible outward sign of the boundary which can always be replaced at any time according to the original mathematical calculations and records.

Cadastral surveys are legal in nature since they are used in the determination of registration of land ownership. Because of the legal nature of surveys for land boundaries, the surveyors who carry out this type of work must normally be licensed by a Government statutory body. In Kenya, for instance, only licensed private surveyors or Government surveyors may carry out legal surveys. The licensing is done by the Land Surveyors Board, whose chairman is the Director of Surveys, who is the Government chief land surveyor. The rules governing the execution of legal surveys are quite stringent and surveys of this type may strictly only be carried out by those expressly authorised by the Government to do so.

Another traditional area of application of Surveying is in *construction engineering*. Surveying measurements are usually required in the design and construction of civil engineering works such as roads, railways, bridges, buildings, water systems, dams, tunnels, airports, and harbours. Usually surveying data was needed in the form of maps in the design of the structure. Once the design of the structure was complete, the design would need to be set out on the ground. This setting out stage also depended on survey measurements in order to ensure that the structure was put in place exactly in accordance with the design.

Today a lot of design for civil engineering structures is accomplished through the use of digital maps in softcopy form. In such softcopy form, the map can be manipulated to facilitate an analysis of the object in simulated situations. Through such simulations, one is then able to adjust the design as may be appropriate to fulfil certain conditions as may be learnt through the simulations. In the actual implementation of the project one normally aims to transfer the designed structure into reality in such a way that the realisation of the project fits in with the theoretical design as best possible. Such is accomplished only through survey measurements by which one ensures that the designed measurements are transferred from design into reality in the most faithful manner possible.

Usually once the structure has been implemented, measurements would be carried out to produce a model of the reality which would then be compared with the original design to establish the level of fitness with the original theoretical design. With this completed however, the structure obviously moves over to the usage stage. This stage is normally accompanied with wear and tear, which may be caused by the mere usage of the structure or by natural causes such as weather and climatic factors. Such wear and tear would to a great extent be manifested in the form of geometric deformations of the structure. Such geometric deformation would need to be monitored, in order that the structure may not pose a danger to users and the society in general. The geometric monitoring of the structures would is carried out through survey measurements and the subsequent analysis of such data.

The engineering application of surveying technology however today goes far beyond the traditional area of civil engineering. The technologies of measurement originally designed for use in land measurement have in the recent past found application in areas such as precision metrology in the manufacturing environment and biomedical applications. This brought forth a sub-discipline within the broad field of surveying known as *industrial surveying*. In industrial surveying, one is concerned with the application of surveying measurement techniques in the industrial manufacturing environment and in other areas of precision engineering. Today, surveying measuring techniques are applied in the manufacture of virtually any piece of object that requires to be produced with precision; from small nuts to automobiles, aircraft, and ships.

Within the manufacturing environment, dimensional measurements are basically carried out as part of the quality control task. When a piece of equipment has been designed, the next step is usually to produce a prototype of the piece. To ensure that the prototype, as produced, is a true representation of the design, the prototype must be precisely measured and the measurements used for the comparison with the design. The methods used involve typically dimensional measurements of the type linear, angular, and height. These are measurements that can be carried out using typical surveying equipment such as precision electromagnetic distance measuring (EDM) equipment, precision theodolites, precision levelling instruments, and terrestrial laser scanners.

5.3 Navigation and Way Finding

One of the traditional areas for the application of positioning and maps is navigation. Navigation is the art of finding one's way from one point to another, safely and efficiently. Without much active realization, we are always navigating. Whether we are walking on foot, or driving, or using any other means of transport, we are always trying to get to wherever we wish to get to safely and efficiently. In most cases before we set off, we want to establish how to get there by specifying the route to take, even if only in rough terms. This is something that mankind has been involved in from time immemorial, simply because mankind has had to move about his environment.

As used in the technical sense, navigation originally referred to the direction of sailing craft, such as ship. Consequently the term 'navigation' derives from the Latin words *navis* (which means 'ship') and *agere* (meaning 'to move' or 'to direct'). Navigation thus literally means 'to move or direct a ship'. No wonder therefore that when we think about 'navigators' we often tend to associate this with only those who navigated across the high seas - we would be relatively familiar with the name *Henry the Navigator* (1394-1460) in connection with the development of navigation. Today of course navigation is understood in the more general sense of simply finding one's way, whether on land, sea, or space.

In order to find one's way, we require to have the means to enable us establish in the first instance where we are, whether we are on track or not, and most importantly, whether we have arrived or not. This brings us back to coordinates. Today, it is through coordinates that we best establish where we are at any one time. Whereas in the case of geo-spatial positioning, we considered coordinates of a particular stationary point, in the case of navigation, we require the coordinates of a craft or a person whose location is changing continuously.

From time immemorial, people have devised means to show them the way from their homes and back. They were keen to ensure that they made their travels by taking the most efficient routes possible and generally returned without getting lost. To this extent they noted significant features on their way and often placed markers on the ground, as well as sketches on clay tablets, to help them determine the way back.

It is difficult to establish exactly the origins of formal navigation. From the Egyptian hieroglyphics it is however indicated that the Egyptians were already involved in extensive sea voyages by 3,200 BC. These are considered to be the oldest recordings of what may be described as navigation. Already from antiquity, people had learnt that one could use the heavenly bodies as reference points to enable one find one's way. The Greeks used particularly the North Star, Polaris, to estimate direction in the night, while during the day they used the sun. The distances, on the other hand, they estimated by the duration it took them to cover the specific distance. Generally because the navigational tools were rudimentary with extremely poor maps, sailors were constrained to keep to the coastline so that they could use land objects to provide reference.

The art of navigation was however greatly revolutionised in the 13th century when the magnetic compass became available to mariners for direction finding. The magnetic compass was first used in China in the 4th century BC, however at this stage the compass was largely being used by magicians as a tool for magic. The instrument did not in fact get into the hands of seafarers until the 13th century when it became established as a major tool for navigation. The fact that sailors could now determine directions facilitated considerably their ability to navigate with a bit more accuracy. In the same period, mariners also used the *astrolabe* as a navigational tool. The astrolabe was used particularly to show the pattern of the heavenly bodies at a given time and also simply to show the time of day.

The next major instrument in the development of navigation was the *sextant* which had been invented in 1731 independently by *John Hadley* (1682–1744) in England and *Thomas Godfrey* (1704–1749) in Philadelphia, USA. The sextant is an instrument for determining the altitude (vertical angle) of a heavenly body. From knowledge of a vertical angle of the sun or star as it crosses a meridian, one is able to determine one's latitude. The sextant thus was principally used to determine latitude. With the determination of latitude only, however, sailors were still not able to determine their positions fully as longitude could still not be determined reliably. This constrained sailors to generally travel in courses that kept the same latitude as far as possible or along coastlines. The navigation process was thus still extremely slow and tedious, and in fact many sailors got lost at sea due to inability to determine their positions accurately.

By the beginning of the 17th century, one of the biggest challenges in maritime navigation and mapping was how to determine longitude. The inability to determine longitude was considerably frustrating navigation as well as the production of accurate maps. The determination of longitude was thus declared a major scientific priority. The problem of navigation and accurate production of maps was considered so important that relating objectives were in fact set out in the founding documents of the Royal Society (of Britain) in 1662 and the French Royal Academy of Sciences in 1666. In the original charter of the Royal Society, one of the stated aims was "Finding the longitude". The stated broad objective of the French Royal Academy of Sciences was "to study a broad range of scientific activities" while one of the specific objectives was "to improve maps and sailing charts and advance the science of navigation".

The problem of the determination of the longitude was considered so fundamental, that a number of countries placed out quite attractive prizes for the solution of the problem. On their part the British, through a parliamentary resolution, on 16th June 1714, passed the Longitude Act, with the objective to promote research on the determination of the longitude. A prize of £20,000 (estimated to be equivalent to twelve million US dollars in today's terms) was offered to the person who would present a viable solution to the problem. A Commission known as the Board of Longitude was formed to judge the proposals and to routinely advise the Government on the project. On the Board were some of the greatest scientific minds in Britain at the time including Isaac Newton and *Edmund Halley* (1656-1742), the Astronomer Royal.

It had long been known by navigators that the longitude of any point could be determined by comparing one's time at the standpoint with that at some other point of reference. What was needed then was a timing device that could keep time sufficiently accurately as to be able to facilitate a comparison of time between the two points. The reliable means to measure time up to this period was the pendulum clock, which had been invented by the Dutch scientist Christiaan Huygens in 1656. The problem with the pendulum clock was that it could not be portable on board a sailing ship.

In 1759, an English clock mechanic, *John Harrison* (1693–1776), produced a robust portable clock that fulfilled all the conditions set by the Board of Longitude. The clock had been tested on a return journey to Jamaica and was found to have lost only five seconds on arrival in Jamaica, after 81 days at sea. In a second trial run of the clock to Barbados and back, the clock lost just 15 seconds in five months. An interesting twist to this story however is that, in spite of the fact that Harrison's clock had in fact out-performed the Board's set specifications, the Board refused to award the prize to Harrison on the grounds that the results were too good to be true. The prize was finally awarded to Harrison however only after the intervention of King George III and the Parliament in 1773. Harrison had thus invented what we today know as the *chronometer*.

The combined use of the sextant and chronometer meant that both latitude and longitude could now be determined accurately whether on land or at sea. With this, navigation as a science suddenly made a huge leap of progress. For almost two hundred and fifty years, the sextant and the chronometer remained the most important pieces of equipment for navigation at sea. These techniques were supplemented only much later through the use of electronic navigation systems based on land-based electromagnetic wave transmission systems. A serious rival to sextant and the chronometer however only came in with the onset of satellite positioning technology (i.e. GPS and GLONASS). However, celestial navigation is today still carried out virtually exclusively through the use of sextant and chronometer.

The principal tool for navigation today however is still the map. Nevertheless many of us will be aware of the fact that not everyone who moves about normally carries with themselves a map and yet they still find their way around without much undue hindrance. Unbeknown to many of us, we in fact still use a map; a mental map stored in our brain according to the description of the way as was given to us or as may be based on our previous experiences. If we have been following a particular route for some time we are bound to have a mental record of the details of the route so that every time we are using the route we need not ask for ways around or carry a map with us.

In order to find our way around even on a route that is familiar to us, we need points of reference. These usually are features that are familiar to us, which then assist us to establish our location and then orientations so that we may be assured that we are still on course. We are quite aware of the fact that if the features along a road that we have traditionally used for establishing our location and orientation should change abruptly from our perspective, then we have always had difficulties finding our 'bearings' even on a route that ordinarily should be familiar to us.

At the more professional level where navigation must be precise, the mere use of the map becomes relatively inadequate. In this case one's location must now be given in terms of coordinates, which however might be converted into an analogue position as represented on a map. Today, it is therefore through coordinates that we best establish where we are at any one time. This calls for the use of instruments and methodologies that find location and give position in terms of coordinates. The principles used in locating position in navigation are basically the same as those used in conventional surveying as already indicated above.

Using positions whose locations are known as reference points, one determines one's current location through distances or angles observed between one's position and the known points of reference. In *celestial navigation* the points of reference are usually the stars or the sun to which appropriate angles would be observed to facilitate the determination of the unknown location. The most widespread techniques for navigation however use terrestrial points of reference. *Terrestrial navigation* techniques in particular allow for the use of both distances and angles. Usually the distances would be measured through the use of electromagnetic wave signals. At the third level there is the use of satellite techniques for location finding.

The introduction of satellite technology in navigation has completely revolutionised the way people viewed navigation. For its entire history, navigation was a highly specialised craft that could be practised only by experts. In its early stages of development as a navigation tool, GPS was applied mainly in the traditional areas of navigation at sea and in the air. However, today, GPS is increasingly being used in the navigation of motor vehicles and pleasure boats. Moreover, in the very recent past there has been rapid progress towards

incorporating GPS technology in such consumer electronics as mobile telephones so that even individuals can be able to locate their positions anywhere anytime.

The introduction of GPS (and its variant technologies) is slowly making vehicle tracking a conventional affair in asset management and in finding our directions and locations generally. With GPS it is today possible to find the location of a vehicle instantly with the accuracy of less than 10 metres. The vehicle is fitted with a GPS receiver, which is used to determine the location of the vehicle from GPS satellite signals. The position of the vehicle can then be displayed as coordinates or as position on a digital map as displayed on a screen on the vehicle. If it is desired to establish the location of a field vehicle from a central control centre, then the position of the vehicle would be transmitted to, and displayed at the centre.

GPS as a tool is being used extensively in the monitoring of movements of fleet. An organisation is then in the position to establish the location of its fleet at any one time and give appropriate instructions in the field. GPS has become particularly useful in the management of railway traffic, as one is able to 'see' where a particular train is at a particular time through the positions of the trains as projected on a digital map. Moreover, GPS is slowly also becoming the major tool for the tracking of stolen vehicles. Using the same principles for fleet monitoring a vehicle fitted with GPS can be tracked from a control centre to its exact location in terms of coordinates.

Today many automobile manufacturers are installing GPS technology for vehicle monitoring as standard equipment. Besides the basic technology of location determination, most of these equipment have further capabilities, which include: the ability of the user to navigate their way through environments they have not been before by use of a digital map on board the vehicle. There are also available systems with route planning software that enable the user to optimise their route and to avoid traffic jams; the ability to interrogate the vehicle in order to establish its position at any time; and ability of the driver to communicate their positions to the control centre at any one time.

At the very basic level is usually the navigation of self as a pedestrian. Beyond finding our location purely on the basis of experience, we often make use of the map, which many of us are familiar with from elementary map reading. With GPS however, as pedestrians, we are today able to locate our position to accuracies down to 3m through the use of a mobile telephone integrated with a GPS receiver. In situations where GPS may be used, we can in fact determine our position in four-dimensional space to accuracies of 1 cm in x, y, z coordinates and to 1 second in time. Moreover it is already possible to make appointments in terms of coordinates x, y, z, t as provided fully by GPS equipment of the type of a wrist watch.

5.4 Geoinformatics and Geoinformation Systems

One of the most powerful applications of the concept of location in our times is the ability to represent virtually any type of spatial data in a geo-referenced graphic form and to manipulate such data for the analysis of spatial relationships. The principal tool in this is the map. Until well into the 1990's, the map was viewed largely as a navigational tool and was thus mainly being used by those who needed to find their directions and by engineers in construction and planning projects. In the last decade, the map has become a most powerful tool for the modelling and analysis of interrelationships between spatial objects and phenomena. This has been made possible largely due to the recent advances in computer and space technology.

The specific modern technologies that have driven this advancement are *geospatial information systems (GIS), remote sensing, global positioning systems (GPS), digital mapping*, and *digital image processing*. We have already looked at GPS in a previous chapter, so here we shall focus more on geoinformatics and geoinformation systems, which are normally understood to comprise digital mapping, GIS, remote sensing, and digital image processing. Usually we use the term 'Geoinformatics' to refer to the integration of GIS, remote sensing, and digital mapping. 'Geoinformation Systems' is a contraction of Geospatial Information Systems, which refer to systems about the geo-space that are generated through the technologies of geoinformatics.

Remote sensing may be defined as the study of the characteristics of an object or phenomenon from a distance. The standard known product of remote sensing is imagery, which could be of the environment or of any other phenomenon. The imagery can be acquired either through terrestrial or satellite platforms. The greatest power of satellite remote sensing as a tool for analysis of the environment is its ability to produce images of large expanses of Earth in digital form. The fact that the images are in digital form facilitates the further manipulation of the images to give emphases to aspects of the object of study that needed to be given particular prominence. A particular characteristic of remote sensing imageries is the false colour rendering of such imageries in order to emphasise particular aspects of the object of study.

Remote sensing technology grew out of the traditional *aerial photography*, which had been used for many years especially in the mapping of the environment within the framework of the technology of *photogrammetry*. Whereas photogrammetry had used basically aerial platforms to acquire images, remote sensing technology extended this into space, with cameras mounted on satellite platforms. Moreover, while photogrammetry chiefly provided the images on the standard photographic film, remote sensing on the other hand provided the images in the form of electromagnetic wave signals, which could be further processed to produce the final image in either hard or soft form.

In late 1960's, NASA started on the Earth Resources Technology Satellite (ERTS) remote sensing satellite programme and in July 1972 ERTS-A was launched as the first satellite on this programme. This marked the beginning of satellite remote sensing technology. The ERTS-A satellite was placed in a north-south orbit at a nominal altitude of 900 kilometres. ERTS-A was designed to collect natural resource data over the entire surface of the Earth with imageries at the resolution of 80m. The ERTS programme was later renamed the Landsat programme and ERTS-A satellite renamed Landsat-1. As of 1999 a total of seven Landsat satellites had been launched into orbit. The latest of these is Landsat-7, which was launched on 15th April 1999 and returns images with resolution in the range of 15-25m.

The French were the next to join the remote sensing satellite league with their SPOT (Satellite Pour l'Observation de la Terre) commercial Earth observation satellites. The first of these was the SPOT-1 satellite launched in 1985. SPOT-1 produced imageries with a resolution of 10-20m. By 2002 the SPOT programme had launched a total of five remote sensing satellites. The latest of the SPOT satellites is SPOT-5 which returns images with a resolution of 2.5-5m. A number of satellites with relatively high resolutions have been launched lately, most of them with resolutions in the range of 1-4m. As of 2003, however, some more than thirty remote sensing satellites had been launched with spatial resolutions ranging from 500m to 1m. Nations and organisations with remote sensing satellites so far include USA, France, European Space Agency, Japan, India, China and Brazil.

Some of the standard applications of satellite remote sensing technology include: general monitoring of the environment, including environmental degradation (depletion of forest cover and environmental pollution); climate and weather monitoring and analysis (weather prediction, environmental hazards such as floods and hurricanes, monitoring of temperature and humidity, and early warning systems for drought); agriculture (crop inventory and yield prediction, crop damage through weather or disease); geological mapping and prediction of geological hazards such as volcanic eruptions; general topographic mapping; and urban mapping and settlement monitoring.

A most revolutionary development in the way we view and use maps however has been due to our ability to produce *maps in digital or electronic form*. This has promptly brought forth what has been referred to as *digital or electronic (e-) mapping*. The technology of digital mapping has only matured in the last decade. The development of the technology was greatly facilitated by the widespread use of the personal computer in the last twenty years, but more generally by the technological advancements in the broad area of information and communication technology

(ICT). Because of this, the term *electronic-mapping* (e-mapping) is sometimes used in place of digital mapping.

Electronic or digital maps are maps held in electronic or digital form. Such maps can then usually be displayed as may be appropriate. Compared to the traditional paper maps, digital maps offer considerable flexibility in use. One can, for instance, choose the features one wishes to highlight, say, roads, buildings, topography, rivers, lakes, or vegetation. Further, one is able to decide on the scale one wishes to use; in short, the maps facilitate for zooming in and out as one may desire.

Through electronic or digital mapping, the use of the map has been brought down to the ordinary level as never envisaged only a few years ago. Whereas in the past, the production of a map, even a simple one, required intensive involvement of a surveyor and cartographer, today it is possible to produce maps of quite reasonable quality simply through the use of GPS equipment and some database information with appropriate software on a desktop computer. Many maps are now being produced on customised specifications and quite efficiently too. Examples here are the journalistic maps familiar to us from the TV and newspapers. The use of the electronic map has thus completely revolutionised the way maps have always been viewed and used. Today, through the electronic map, the map has for the first time genuinely become an ordinary consumer item.

The production of digital maps allow such maps to be further processed and manipulated to facilitate a clearer understanding of spatial relationships. This has been responsible for the development of the technology of *geospatial information systems (GIS)*. There are many formal definitions for GIS, most of which derive from the fact that a GIS is based on database management and the use of the computer. A simple definition of a GIS is *a combination of layers of several thematic digital maps with a common geo-reference system and each of which can be analysed either independent of, or in combination with the others* or simply *a spatial database*. In a mere two decades, GIS has grown into a multi billion dollar industry touching onto virtually every undertaking that has a spatial dimension.

A most powerful feature of a GIS is its ability to work interactively with digital maps, which can then be queried and manipulated to provide the necessary information from the database. The heart of a GIS is thus a database of spatial information and their respective attributes. Basically a GIS represents, for a particular area, various themes, each of them in a digital map of its own (Fig. 22). The various themes can then be analysed with respect to each other within an interactive environment. For example, we could have themes for topography, the incidence of malaria, and temperature distribution. We might then wish to investigate for any correlation between topography, malaria, and temperature. Through the manipulation of the respective digital maps representing the various themes, one is able to analyse for the interrelationships amongst the factors being considered.

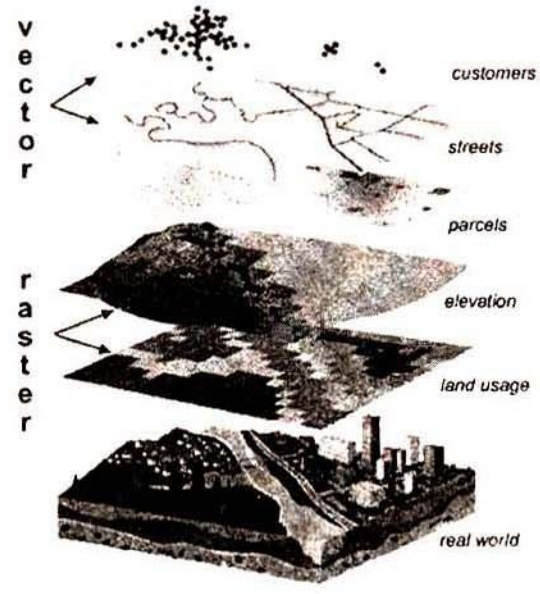


Fig. 22: GIS layers (ESRI)

The development of geospatial information systems was influenced by the need to be able to process large spatial datasets using the computer. There were earlier efforts towards this in the 1950's, in the era of the earlier computers then. However what may be considered the first real GIS was the Canadian Geographic Information System (CGIS) project, which was initiated in 1964. The objective of this project was to create a computerised inventory of Canadian rural lands. In modern terminology, this was in fact a Land Information System (LIS). The project was completed in 1971 and is still operational. This pioneer project in GIS was directed by *Roger Tomlinson* who also in the course of the project introduced the term 'geographic information system (GIS)'.

From the University side, a scientist at Harvard University, *Howard T. Fisher*, in 1964, established the *Harvard Laboratory for Computer Graphics and Spatial Analysis*. Fisher's objective had been to develop a general purpose mapping software. The Harvard Laboratory grew to be a major leader in the development of GIS and into the 1980's produced some of the major GIS software, most of which were designed for operation on the mainframe. Some of the earlier leaders in GIS were people who grew up at the Laboratory; among them was *Jack Dangermond*. In 1969, Dangermond, with his wife, Laura, co-founded *Environmental Systems and Research Institute (ESRI)*. ESRI has become by far the leader and trendsetter in GIS technology worldwide.

Today GIS finds application in virtually any enterprise requiring the analysis of spatial relationships, whether in the physical, built, industrial, or business environments. The areas of applications of GIS are today so vast that the limit can only be determined by our own imaginations. Any attempt therefore to list the areas of application immediately gets rendered hopelessly inadequate. Nevertheless if only to demonstrate the vast scope of GIS, some of the areas in which GIS is applied today include: agriculture, environmental pollution monitoring, transportation planning and analysis, urban design and management, marketing research and strategy, public health and epidemiological research, demographics and population analysis, climate and weather analysis, environmental impact assessment, natural hazard management, geological analysis, agricultural and natural resource management, archaeological studies, and land and property management.

In all this, the traditional way to present a map has been that of projecting the mapped features in the two-dimensional space as to be able to be presented on a flat surface. In a few cases three-dimensional representations have of course been made but these were generally very special cases involving considerable effort. With the ability to work with digital maps however, a new way to represent spatial features has come into the scene. This is *cartographic visualisation* or *geospatial visualisation*. We consider the term geospatial visualisation to be the broader of the two and in order to be a little more comprehensive we shall adopt it for our purposes here.

Geospatial visualisation is concerned with the three-dimensional representation of the environment and the ability to manipulate the so obtained model in order that the desired characteristics of the reality may be appropriately highlighted. In an environmental impact assessment for instance, it would be possible, within the framework of geospatial visualisation, to simulate various scenarios of the environment and to study the possible impact in each case. The power of geospatial visualisation lies particularly in the ability to create virtual real world situations and to be able to work with such models to study situations in simulated form. Working with studies in simulated form means that for any given problem at hand, any number of scenarios can be analysed in virtual reality situations at minimal cost.

Any situation for which a cartographic representation would be possible can be rendered in three-dimensional form within the framework of geospatial visualisation. Examples of areas of application are: route design, urban planning and design, environmental impact assessment for large scale civil engineering

constructions, planning for emergency evacuation services, business location and market research, documentation of cultural and architectural heritage, and in general environmental management.

5.5 Location Based Computing and Services

A most revolutionary application of geospatial technologies today however is in *Location Based Services* (LBS). This is the location of a service in terms of its geospatial location and to provide services with information about such geospatial locations. The key factor in LBS is the ability to determine the position of the service to a level of accuracy sufficient for the particular service. While in precise positioning, expected accuracies will be at the sub-centimetre level, for most LBS, accuracies at the level of 100m will normally be sufficient. The main strength of LBS is that one is able to establish the location of an event or a service. LBS therefore makes it possible for us to personalise a service with respect to its location, which means then that we can offer the service, or respond to the emergency, with much more efficiency and effectiveness.

In Nairobi today one of our most serious concerns is security. How many of us have had to report an incident to the Police and our first immediate frustration is that we cannot guide the Police to get to the site because the descriptions of the location of the incident cannot be adequately communicated to the Police? This is because we often find ourselves describing location in terms of 'tall trees', 'black gates', 'a blue kiosk', or some other feature that happens to be nearby. Through LBS it is now possible to give the precise location of any event in terms of coordinates such as latitude, longitude, altitude, and time. At the core of LBS technology is the ability to determine location with relative ease. This has been made possible particularly through the use of GPS technology.

In the mobile environment, GPS is used particularly as an embedded technology in the mobile telephone. A mobile telephone with GPS capability will normally be able to determine its location through the use of GPS satellites. In situations where the GPS satellites may not be accessible, particularly due to physical obstruction, such as in buildings, the mobile telephone could be located through specially designed terrestrial systems. Usually once the location has been established in terms of coordinates, the coordinates are superimposed onto a geo-referenced map to provide the location of the event in terms of recognisable physical features as depicted by the map. The maps are provided in digital form and can be downloaded in the mobile telephone from the Internet or through special services provided by an LBS provider.

In a bold move towards institutionalising LBS, in 2001, the United States Federal Communications Commission (FCC) launched its new Enhanced 911 (E-911) services, which was to be integrated with LBS technology. With E-911, providers of emergency wireless services were expected to upgrade their emergency telephone services to include the location of the emergency caller. Basically the system used a radiolocation technology, whether terrestrial or GPS, to locate the position of the caller using the technique of triangulation. The programme provided that by 31st December 2005, emergency service providers were expected to have been able to establish the location of their callers to within 150m on the average.

LBS can be provided for any service whose position can be defined in terms of geospatial location. This means in fact any service, for there is no service that does not take place at a geospatial location. Examples of areas of application include emergency response and evacuation, vehicle monitoring and tracking, traffic and fleet management, self and vehicle navigation, business market analysis, crime analysis and control, and wildlife monitoring. Strictly however, LBS find application in virtually any area where an event on the surface of the Earth may be located according to geospatial coordinates.

Clearly one of the areas in which LBS is slated to find most exciting application is in mobile communication. In this case the position of a mobile telephone user's position is determined from signals received from at least three mobile base stations. From the signals, distances from the mobile user to the base stations can be determined. The determination of position is based on the principle of triangulation as used, for instance in satellite positioning. It is necessary that the coordinates of the base stations are known since the mobile position is to be determined with reference to the positions of the base stations. A slightly less precise way to locate the mobile user is through the identity of the cell position. This however does not give the exact location of the user but rather the cell within which the user is.

The concept of LBS has had the clearest effect of bringing down positional technology from a specialist task to that of a consumer product that is available to the ordinary person. Today more and more mobile telephones are being installed with LBS capability and correspondingly most new mobile telephony infrastructure is being constructed to facilitate LBS technology. It is estimated that by 2006, some 44% of mobile telephones in Western Europe shall be having some form of LBS capability with the LBS market being responsible for some $6.6b.

At the core of LBS is the need for a system that processes information in a location sensitive environment. Such systems process the information about the service by taking into consideration the specific location of the system and the locations of other systems within the vicinity that are relevant to the particular service. These systems are generally referred to as location based computing or location aware computing. Essentially these systems have to be mobile and

consequently they are also known as mobile computing systems. For the sake of consistency, we shall here adopt the term location based computing (LBC).

We have today that most of the devices we use in our daily routine are affected by location, even though we may not always be conscious of it. In recent times, perhaps no technology has given mankind so much freedom and personalised interaction with others as the mobile telephony. We are already so hooked on to this personalised communication behaviour that we can not imagine how things would be without it. The next realm of freedom is going to be in the ability to locate our positions and the positions of the devices and equipment we use in our daily routine. Equipment and devices such as the car we are travelling in, the watch we wear, the personal mobile or desk telephone, and laptop we are using are all going to be able to determine routinely their locations.

It is already being predicted that location based computing will mature into a system where most of the devices and equipment we use shall be computer controlled and location determination shall be a central factor in all this. In this context a new concept known as *ubiquitous computing* is already being seen as forming the computing environment of the future. In ubiquitous computing a person shall have access to several computers at the same time that would control a number of his or her activities. Most importantly however most of these activities shall be location based and shall require location computing capabilities.

6

New Directions and Trends

6.1 New Identities

Some of the most dramatic changes in the discipline of Surveying have taken place only in the last fifteen years. Remote sensing had been with us since 1970's but really got established as a serious tool for environmental analysis only in the 1980's. Satellite positioning systems on the other hand matured in early 1990's with the American *Global Positioning System (GPS)* leading the way and closely trailed by the Russian *Global Satellite Navigation System (GLONASS)*. And then recently, the European Space Agency have started on efforts to establish an independent, civilian, satellite positioning system, *GALILEO*. With the satellite positioning systems, it was now possible to obtain the position of any point on, or near, the surface of the Earth at any time, through artificial satellite measurements. Parallel with the development in space positioning technology, *GIS* technology was also rapidly developing.

These developments have greatly been facilitated by the corresponding development in computing capability, particularly through the development of relatively powerful desktop computers. With the availability of all this technology it suddenly became possible to collect large sets of geo-spatial data and to analyse and interpret geo-spatial phenomena through multidimensional computerised graphic presentations. Together with advanced techniques in imagery and imaging systems such as applied in remote sensing and in engineering generally, digital photogrammetry, as well as virtual reality modelling, these technological developments have dramatically changed for ever, the face of the discipline that has traditionally been known as Surveying.

We have already seen that today the discipline of Surveying is involved with measurement science covering from precise industrial metrology to large-scale measurements into space and geometric positioning, on one hand, and the analysis, presentation and interpretation of geo-spatial data on the other hand. In between, the discipline continues to be fully involved in the traditional collection of geo-referenced data and in the setting up and use of geo-spatial databases. Consequently, the scope of involvement of the modern discipline of Surveying is today so diverse as to cover practically any application requiring the knowledge of *dimension*, *shape*, and *place*.

The core knowledge of the discipline has thus today dramatically shifted from the application of geometry in the measurement and graphic representation of land to the application of geometry in a much wider sense in order to answer the broader question dealing with dimension, shape, and place within geo-space. It is this current orientation of the discipline that is defining its future directions.

Because the discipline has today acquired such a much wider scope, the description of the discipline under the term 'Surveying' has been found extremely limiting, inadequate, and to some extent altogether misleading. The term 'Surveying' continues to be understood to cover only the traditional area of land measurement and mapping. From the areas of application indicated above, one has that the area covered under 'Surveying' is now only part of a discipline with much broader scope. The graduate in the modernised discipline of Surveying today finds employment in any area of business dealing with geometric measurement, determination of location, and spatial analysis.

Whereas, therefore, classical surveying operated mainly within the physical and built environments, we have that the modern discipline of Surveying today embraces as well the industrial and business environments. Thus the term 'Surveying' in its traditional sense clearly no longer effectively describes the discipline. Due to the fact that 'Surveying' no longer fully captured the scope of the current discipline, academics and professionals in the broad field of Surveying, have tried to respond to this by describing the discipline in terminologies considered more inclusive.

In early 1990's a wave started off in Canada that introduced the terminology. *Geomatics* as a suitable description for the discipline. 'Geomatics' was a neologism, coined from the combination ***Geo***+infor***mat***ion+automa***tics***. The term 'Geomatics' was meant in particular to convey the application of modern computerised information technology in the presentation and analysis of geo-spatial data as based on some *geo-reference system*. Universities and professional bodies in Canada quickly adopted the term 'Geomatics'. Soon other universities in North America, Australia, and Europe followed suit and had their programmes described as 'Geomatics', 'Geomatics Engineering', or 'Geomatic Engineering'.

Being new terminologies, there was need for some proper definitions. For instance, York University (Canada) defined Geomatics and Geomatics Engineering as follows:

> ***Geomatics*** is the combination of several disciplines dealing with geospatial information (i.e. information tied to geographic or other spatial coordinates). It includes geodesy and geodetic positioning, global positioning systems (GPS, GLONASS, other), satellite imaging and photogrammetry, remote sensing, computer vision and image processing, geographic information systems (GIS), surveying engineering, land management, computer mapping, digital terrain modelling, and the wireless and web-based dissemination of geospatial data.
>
> ***Geomatics Engineering*** is concerned with the development of new technologies for the acquisition, analysis, storage and transmission of geospatial data and with the creation and implementation of new decision making tools and applications based on the geospatial information. It involves designing, testing and mounting small portable sensors and transmitters on satellites, aircraft, land-based vehicles and water-based vehicles. It also involves the design of new software tools to analyse, interpret and graphically represent the acquired data in formats useful to the end-users.

Lately however it is increasingly being felt within the broad profession of Surveying that the term Geomatics may after all not be the most apt description of the discipline. It is considered that the discipline under consideration is principally about *geometric* description and analysis of, and within, the *geo-space*. The key word that keeps on featuring in the definitions of the discipline is 'geospatial'. Consequently terminologies such as 'Geospatial Information Systems', 'Geospatial Information Technology', 'Spatial Information Systems', 'Spatial Information Engineering', and 'Spatial Science' have lately been adopted for certain academic programmes.

In their response to the changing scope of the discipline of Surveying, the British *Institution of Civil Engineers (ICE)* together with its counterpart the *Institution of Civil Engineering Surveyors (ICES)*, after extensive consultations, in 1998, adopted the term *Geospatial Engineering* as a description for the expanded version of what was previously known as *Engineering Surveying*. The Institution then remarked as follows: "The technical advances in the surveying and mapping sciences meant that civil engineering surveying (CES) no longer adequately defined those working in the profession. Geospatial Engineering is the new term for CES". ICES proceeded to define Geospatial Engineering as follows:

> *"The professional discipline of those people, working within the built and natural environments, involved in the construction of, maintenance of and output from the Geospatial database. It encompasses the specialisms of engineering surveying, land/hydrographic survey, photo-*

grammetry and remote sensing, geographic information systems and cartography/visualisation."

The direction the discipline is going to take in the foreseeable future shall be defined by 'geospatial technology', and shall be much more encompassing and broader in scope than the traditional discipline of (land) surveying. The consequence of this is that, the description of the discipline as 'surveying' has virtually been lost for good. The practitioner of the discipline is likely to be referred to as *geospatial technologist/engineer*. However in the actual practice of the discipline one can expect to have three broad types of professional: *the geodetic scientist, the geo-spatial engineer*, and *the geo-information technologist*.

The geodetic scientist will continue to concern himself/herself with the scientific study of the geometry of the Earth including that of planets as well as being the specialist in positioning and navigation at the global level. The engineer on the other hand shall take over the current responsibilities of the (land) surveyor but shall extend these to applications in precision metrology and industrial operations in general. The geo-information technologist shall be an information technologist specialising in the application of information technology in the broad area of geospatial technology.

Consequent to this, one can envisage professional and technologist programmes at the University and polytechnics, respectively, responding to these new areas of practice. Programmes aiming to produce a geo-spatial engineer shall be styled geospatial or geomatic (or geomatics) engineering. On the other hand, to prepare for careers in geo-information technology there shall be programmes such as geo-information technology, geo-informatics, or geo-information science. The programmes aiming to produce the geo-spatial engineer and the geo-information technologist can be expected to be at the undergraduate level in the first instance. However the geodetic scientist shall continue to be trained largely at the postgraduate level, chiefly with backgrounds in geospatial engineering, mathematics, and physics.

6.2 General Trends

The last decade has seen some of the most dramatic developments in the discipline of Surveying. These developments have largely been occasioned by technological developments. Of particular significance have been the developments in computer technology, GIS, GPS, and communication technology. In computer technology, the personal computer became the main tool for most data processing, where previously one would have had to work with the mainframe computer, which in most cases was not quite flexible to work with. GIS

began to mature in the mid 1990's especially with the ability to produce digital maps on desktop systems. The most dramatic development was however brought about by satellite positioning systems which matured in the second half of the 1990's. From the communication technology side the most dramatic development has been that of the mobile telephone system.

One of the frustrating points in the use of GPS is that the height as obtained from the system is not quite the physical height taken with respect to the mean sea level, but is instead one based on a mathematical surface; the reference ellipsoid. The determination of GPS height with respect to sea level requires that the geoid as the representation of the sea level be known accurately. One of the challenges that geodesy is going to continue to grapple with is the production of a geoid accurate to the centimetre level across the entire surface of the Earth. This will facilitate the determination of the height above sea level with GPS to the centimetre level.

A traditional function of geodesy is to establish geo-reference frameworks comprised of precisely coordinated points. While traditionally such geo-reference frameworks were established as passive concrete pillars on high, well visible, ground, geo-reference frameworks of the future shall be made up of active reference points. Terrestrial reference points in this system shall comprise active stations of known positions which shall be transmitting signals to other users to enable the determination of coordinates of the known points much in the pattern of GPS positioning. The coordinates shall be communicated to users in the four dimensions of space-time, i.e. in space (x, y, z) and time (t). Positioning within this framework, as is presently, shall continue to involve an integration of terrestrial observations with those from satellite systems

Such reference systems shall be available to both the professional and consumer users of position. The professional users such as geodesists, surveyors, navigators, engineers shall be able to determine their positions with reference to the active geodetic points, much more efficiently. Depending on the level of accuracy desired, the information as received by the user from the reference points may need further processing. For the ordinary user however, since the expected accuracies will be within the 100m level, the positions as obtained directly from the geo-reference system should suffice without need for further processing. It will suffice then for the ordinary user to have appropriate piece of equipment for this.

An important role of the future geo-reference framework is going to be in geodynamic monitoring. The geo-reference points shall have their coordinates determined on a continuous basis through satellite positioning systems. Thus it will be possible to give the coordinates of the points in four dimensions, i.e. including the time element. Already the coordinates on the international geodetic reference framework, the International Terrestrial Reference Frame (ITRF), are given in terms of epochs from the recognition that such coordinates are not fixed with respect to time.

A major area of application of the geo-reference framework will be in *location based services* and *mobile computing*. Using the active geo-reference stations, it will be possible for one to determine one's location with a mobile system, such as the mobile telephone, from any point where one could receive signals from at least three such active stations. One envisages that conventional mobile telephone transmitting stations could be built into the geo-reference framework as part of it. Such mobile stations would then be used to position mobile users through the mobile telephones and other suitable devices.

Another major area of application of geospatial technologies will be in *Intelligent Transport Systems* (ITS). Intelligent Transport Systems are concerned with the management of traffic using modern location based technologies. The core technology in ITS is the use of satellite positioning systems which makes it possible to locate the position of a vehicle appropriately fitted with the technology. The core of ITS is the ability to combine knowledge about the position of the vehicle or craft with a service connected to such vehicle or craft. For instance a vehicle would be fitted with a digital map of the information about the highway together with a GPS device that would enable the vehicle to relate its position to any relevant information on the highway. Intelligent Transport Systems are being applied in land, water, and air transport.

A further area of application of the knowledge about location into the future is *precision agriculture*. Precision agriculture is a system of tools designed to optimise agricultural productivity through the application of the technology of location and the analysis of the spatial distribution of the characteristics of a farm. The core technologies in this are satellite positioning (GPS etc), remote sensing, GIS, and information technology (IT). Through the use of satellite positioning technology a farmer is now in the position to locate precisely, to a few centimetres, a point of interest within the farm which can then be connected to certain characteristics in the farm and analysed through a GIS map. For instance, it is now possible to apply fertiliser on a farm as based on soil characteristics from point to point.

The ability to work with digital maps and to be generally able to hold large sets of geo-spatial data in digital form has generated special interest in the creation of *geospatial data infrastructures* (GDIs). GDIs (also known as *spatial data infrastructures* (SDIs)) are huge datasets of geospatial data held at various locations that are interconnected under some agreed standards protocols such that they can be accessed and used by various groups at different locations. In the last two decades, when it became possible to produce, and work with, digital maps, it became apparent to many users of geospatial data that the huge amount of geospatial data that was being generated could be held in datasets and be made available to users.

This would forestall the need for every user to always generate new data at great expense. In order that the data may be transferable between users it was essential that such data must be held in databases at the agreed specifications.

Strictly, GDI is not an entirely new phenomenon. In cadastral surveys for land title, surveyors have always had to deposit their data and plans for such surveys with the Government Survey Department so that such data may be available to other surveyors who may need them. Such data were held in files at Government Survey offices and formed a database of survey data albeit a manual one. In the modern GDI the data is held in electronic form and such data cover a wide range of geospatial information. In the modern GDI format, such information would be available to users online, whether through Internet or through any other appropriate communication system.

It is envisaged that GDIs shall be established basically at the national level in what are generally referred to as National Geospatial Data Infrastructures (NGDIs). Efforts to establish NGDIs have so far been initiated in Western Europe, South-East Asia, Australia and New Zealand, North America, and some countries of South America. A number of countries also plan to come together to establish regional GDIs. It is envisaged that the regional GDIs could eventually be brought together in a Global Geospatial Data Infrastructure (GGDI). The GGDI shall be a most ambitious project aimed at making available geospatial data to users on a worldwide scale.

6.3 The Digital Earth Concept

There can be no question about the fact that in the entire human history, humankind has never been able to access so much information as is available to us today through the Internet. Whatever it is that we would like to get more information about; the Internet seems to have it, in text. Can we now imagine a situation where instead of just getting the Internet information in text form, we are also able to link that information to a geographical location? That for instance, when we look for University of Nairobi in the Internet, we shall not just be getting text information about the University, but that we would be in a position to explore as well the entire University, and in detail, in a geographical sense, and in fact also extended in historical time perspective. This introduces us to a new concept to be known as *Digital Earth*.

The term 'Digital Earth' was coined by NASA and popularised by former Vice-President of USA., Al Gore. On 31st January 1998, Al Gore, in a lecture entitled "The Digital Earth: Understanding our planet in the 21st century", at the California Science Centre, Los Angeles, outlined the concept of 'Digital Earth'. In the lecture, Mr. Gore stated as follows:

"A new wave of technological innovation is allowing us to capture, store, process and display an unprecedented amount of information about our planet and a wide variety of environmental and cultural phenomena...Much of this information will be "geo-referenced" - that is, it will refer to some specific place on the Earth's surface...The hard part of taking advantage of this flood of geospatial information will be making sense of it - turning raw data into understandable information. ... The tools we have most commonly used to interact with data ... are not really suited for this challenge ... I believe we need a "Digital Earth" ... A multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data."

Digital Earth shall be a digital representation of information about our Earth in a geo-referenced format and one that shall allow people to explore the world in a three-dimensional virtual reality environment from a view of the entire Earth to the smallest details possible. Geospatial information and data shall be held on networked computers in an elaborate geospatial information system. This information shall then be made available to users worldwide through the Wide World Web. A fundamental difference between Digital Earth and the Internet shall be that, while in the Internet we search for information using a text address, in Digital Earth the address shall basically be based on geospatial (geographical) coordinates.

In technical terms, Digital Earth shall involve the handling of huge volumes of data in real time and interactively. Moreover, Digital Earth shall ordinarily be expected not only to handle the Earth as in the three-dimensional space, i.e. incorporating height, but in fact also with the time dimension built in, thus actually operating in four-dimensional space. In this respect, it shall be noted that the Internet as current, being operational largely in text mode, operates thus with just one-dimensional data.

Digital Earth will function in hierarchical levels of detail. A user wishing to visit any part of the Earth would start at the gross level and then progressively zoom in onto the lowest detail desired. Thus for instance, a person looking for the Great Court at the University of Nairobi might start with Kenya, then move down to Nairobi, then to the University of Nairobi, and finally to Great Court. Normally each level of detail would be marked by a refinement of the coordinates that are required to zoom in onto the particular feature. A further point in all this is that the information would also have a time perspective built into it so that one could go backwards in time to obtain historical information and events about the particular feature.

A major challenge in the Digital Earth initiative will obviously be how to handle the huge volume of data. The amount of computer capability required to realise the Digital Earth concept is certainly enormous. Further there is the challenge to

generate high-resolution data and to have this available to users in near real time. Generation of high-resolution data through satellite observation has itself been a major challenge since the inception of remote sensing technology. In this case however the situation would be further complicated by the requirement that the data be available to the user in near real time. Moreover this information would be coming in from multiple sources in various forms of format and sophistication, which must then be processed and put in a form that can be used in a seamless manner. Clearly all this will call for highly sophisticated computing capability.

In all this, Digital Earth concept shall play a defining role to the discipline in the introduction of a completely new concept of what a map is and its use as a modern information technology tool. It is difficult however to visualise just now the full breadth of what the applications of Digital Earth technology would look like. One may want to compare this with the way the applications of GIS have developed into areas which only a few years ago were completely unimagined.

7

Geospatial Technology in Kenya: Development and Practice

7.1 Historical Background

Just like in old Egypt, the development of surveying and mapping in Kenya was chiefly motivated by the need to carry out surveys in order to determine the extent of land that was owned by an individual. This was important for the purpose of orderly management of land as well as to enable the Government to levy taxes on land appropriately. Further, in order to be able to govern the country efficiently, it was imperative that the land be mapped and reliable administrative maps be made available. These two factors have driven the surveying and mapping effort in this country for the last one hundred years.

On 4th December 1823, a British naval vessel, the HMS *Baracoutta* put to anchor in Mombasa initially to replenish its stores. The *Baracoutta* was one of two survey vessels sent out by the British Admiralty to carry out hydrographic mapping (charting) of the East African coast, under the command of one Captain *William Fitzwilliam Wentworth Owen*. After picking up stores, Owen and the *Baracoutta* departed from Mombasa. Owen however had noted the potential of negotiating a deal for the control of Mombasa from the Mazrui. On 7th February 1824, Owen returned to Mombasa on his other ship, HMS *Leven*. He struck out a deal with the Mazrui through which he acquired Mombasa and some two hundred miles of coastline. This would mark the beginning of British colonisation in Kenya.

Owen became then the first British Colonial Head of Mombasa and de facto the first Governor of what eventually would be known as British East Africa or Kenya. Owen's Governorship lasted exactly four days, from 9th February to 13th February 1824. On 13th February Captain Owen left Mombasa to continue with his original task of hydrographic surveying. The new British possession along the east African coast was then left in the hands of one of Owen's officers, *John James Reitz*, from South Africa, as Governor. Reitz ruled Mombasa and its environs as a British possession from 13th February 1824 to 29th May 1824, when he died of malaria. Many of us will be familiar with Port Reitz in Mombasa, which in fact was named after John James Reitz.

The first survey of what today is known as Kenya came with the building of the Kenya-Uganda railway from Mombasa to Kisumu. Before the railway could be built there was a need for a survey to establish a proposed alignment for the line. This task fell to *Captain J. R. L. Macdonald* of the Royal Engineers. In November 1891 a survey party of some 389 men, under the leadership of Capt Macdonald set for the interior from Mombasa to establish the route that the railway line would take. By the time the survey ended some nine months later, Macdonald's party had covered a total distance of some 4,280 miles (or 6,888 km.).

Capt Macdonald's team had estimated that the railway line would cost some £3,685,400, which however proved to have been too optimistic, as the railway line eventually cost some £5,000,000. From the survey, a 657-mile railway line was proposed. This alignment in fact proposed that the railway line should hit the shores of Lake Victoria at Berkeley Bay, where River Nzoia enters Lake Victoria. The eventual alignment that would have the railway line terminate at Kisumu was arrived upon only subsequently.

On 1st July 1895, the British Government assumed responsibility for the territory known as the East African Protectorate that had hitherto been under the administration of the Imperial British East Africa Company (IBEAC). The new Government immediately started on the process of establishing a survey and mapping service in the territory. With the completion of the construction of the railway line and the large influx of settlers into the colony, the need for a survey office had became even more urgent.

In April 1903, the Government appointed the first Chief Surveyor for the colony. The Chief Surveyor also functioned as the Engineer-in-Charge at the Public Works Department, Inspector of the Railways, and Land Officer. For a while therefore surveying and mapping was part of the Public Works Department. On 1st April 1906 however, an independent Survey Department was established. By 1949, the Survey Department had grown into a large Government surveying and mapping service with branches dealing with cadastral surveys, topographic mapping, and trigonometric surveys. On 1st January 1949 the Department was designated with the well-known trade mark 'Survey of Kenya'.

As has been indicated elsewhere here, the basis for any surveying and mapping is a geometrical (trigonometrical) framework onto which all other measurements are tied. The need for such a framework in the surveying and mapping of the territory was recognised right from the outset. A Trigonometrical Section was thus

established in the Survey Department already in 1906. From 1907 up to the beginning of First World War in 1914, trigonometric surveys of some 1,300 km of triangulation had been established over the territory.

There was no further triangulation work carried out until after the Second World War, when the Survey Department felt once more sufficiently able to carry out such extensive a task as the establishment of a triangulation network. The proposal was for a comprehensive re-triangulation of the country as it was considered that the earlier triangulation was no longer accurate enough for the survey requirements almost half a century later. The work towards the re-triangulation began in 1950. By the time of the exercise stopped in early 1960's about 40% of the country had been covered by relatively accurate trigonometric network system. This network still constitutes the primary framework for geo-referencing in this country today.

The triangulation provided the coordinates of a point in the two-dimensional space as projected onto the ellipsoid, chiefly in the form of latitudes and longitudes. However for a complete survey there is still the need to determine the height of a point, usually above sea level. To establish the heights of points over the country, it was necessary to establish a network of points of known heights within the country, through levelling. During the construction of the railway line however, levelling had been carried out along the entire line. The heights along the railway line were taken with reference to a point whose height was defined with respect to sea level at Mombasa. The railway levelling remained the only major levelling in the country until 1948.

In 1948, the Government embarked on a major levelling exercise meant to cover as much of the extent of the country as possible. The reference benchmark was a 1931 tide gauge established at Kilindini, Mombasa, by the Railways and Harbours administration, which then provided the reference height above mean sea level (MSL). The levelling exercise proceeded vigorously in the period 1948-1953 before being suspended due to the Emergency. Subsequent to this levelling survey, some further levelling was carried out in the later years. As of today, the whole country has however yet to be covered by adequate points of known heights, in fact less than one-third of the extent of the country is covered by levelling of any geodetic quality.

The topographic survey section had been established in the Department in 1907. With the establishment of this section, work towards the mapping of the country had started immediately. The progress of the topographic mapping was however relatively slow, so that at the start of First World War, only about 100 square miles had been mapped. From 1914 no further topographic mapping of significance was carried out until 1932 when some small mapping project was carried our around Kakamega for the purposes of the gold mining prospects there.

Serious mapping of this country however was started only in 1947 with the introduction of aerial survey techniques into the country. By the end of 1951 some 145 maps at the scale of 1:50,000 had been completed. Subsequently, the first complete and comprehensive map of Kenya at the scale of 1:1,000,000 was produced in 1951. This map was both a physical and political map of the country and was entitled 'Political and General' map of Kenya. Thus in 1951 Kenya was able to produce its first map along the lines of the International Map of the Word programme mentioned earlier. Today the official complete map of Kenya is still on the scale of 1:1,000,000 and comes in two sheets.

7.2 Land Surveying and Mapping

Today 60% of Kenya has been covered by the 1:50,000 or the 1:100,000 map series while the whole country has been covered by the 1:250,000 map series. The standard base mapping scale is actually 1:50,000 but in certain parts of the country, with relatively sparse human activity, such as in the north-eastern part, the base mapping has been at 1:100,000. The base maps are normally the most accurate maps a country has and are derived from original field surveying and mapping or through updating of already existing maps. From the base maps all the other maps at lower scales would normally be derived through compilation. This for instance is the manner in which the 1:1,000,000 map of Kenya or the maps found in atlases are produced.

Right from the outset however a major reason for establishing a surveying and mapping service in this country was to survey land, especially that which was under the control of the European settlers. In the early years before proper survey reference systems could be established through triangulation, cadastral (land) surveys were carried out on isolated reference systems and were therefore not based on any unique system of geometric identification. In 1919 the Government introduced the Registration of Titles Ordinance (RTO), which guaranteed title to a piece of land. This brought in an urgent demand for precise cadastral surveys on a uniform reference system. The RTO is still in force today as the Registration of Titles Act (RTA).

Land surveys under the RTO were relatively expensive and slow as they were generally too precise. It was obviously not practical to expect that the whole country could eventually be covered by this kind of survey within any reasonable space of time. Meanwhile the Government was getting ever more convinced about a system of secure tenure for African land in the 'Native Reserves'. The accomplishment of this task would require some kind of survey, which however could not be carried out through the use of precise survey methods. The best

approach would have to be one based on mass production techniques and which would be cheap.

In order then to provide secure land tenure to Africans, in 1959, the Government passed the Land Consolidation Act. This Act provided for the consolidation of pieces of land owned by an individual into one piece which would then be placed under one title. This process was started in parts of the current Kisumu and Siaya Districts and Central Province. The land consolidation project however did not progress quite well, as many people were unwilling to exchange their pieces of land for others as was demanded by the consolidation exercise. The process was thus discontinued and in its place a new process of land adjudication was introduced.

The Government started on the process of adjudication in 1962. The respective law governing the adjudication process was however passed only in 1968 as the Land Adjudication Act. To take care of the registration of land aspects within the land adjudication process, the Registered Land Act (RLA) was passed in 1963. This is the Act that regulates the registration of rural land in Kenya presently. Under RLA the process to provide tenure for African lands in large scale was initiated for the first time.

The registration of rural lands in Kenya in accordance with RLA was conceptualised as a large scale project to have lands under African ownership in rural Kenya registered. As has been indicated, precise survey methods could not be employed in this exercise as such would be too expensive and not cost effective. The survey techniques were simple and required the use of the simplest pieces of equipment, with the principal piece of equipment being the surveyor's chain. Once the boundaries were established, the parcel owners were asked to mark the boundaries with hedges. In order to produce the maps of the parcel boundaries, air photography of the entire adjudication area was carried out. This would show the parcel boundaries as marked by hedges and through direct tracings of such boundaries from the photographs the respective plot boundaries could be shown in map form.

In the strictest sense of the word, the maps of parcel boundaries under RLA are actually not maps. The original intention in the production of these 'maps' was that the photographs would be corrected for errors of distortion on them before they could be traced to produce the 'maps'. However in order to save on time and expense, the photographs were simply used without any corrections for errors being applied on them. The resultant intermediate maps were simply considered as preliminary diagrams and were consequently referred to as *Preliminary Index Diagrams* (PID). The photographs have however never been corrected for errors, and the PID has in fact stuck as the official 'map' for land registered under RLA.

The accuracy in acreage of land registered under RLA is guaranteed only to within an error of 20%. That is to say, a parcel whose area is shown as 10 acres would have its area considered acceptable provided it was between 8 and 12 acres. Further, the boundaries are not guaranteed as correct, instead even what is shown on the map is considered only as a rough indicator of the extent of the parcel. Usually the boundary is as marked by the agreed boundary marker between the two neighbours. The Chief Land Registrar is the authority on land boundaries under RLA and in case of boundary dispute it is the Chief Land Registrar who shall be called upon to show where the boundary is. The Chief Land Registrar may call on the surveyor for assistance in the determination of the boundary, but this is not an absolute requirement.

Under the Registration of Titles Act (RTA), the land boundary surveys are carried out on the basis of precise survey techniques. Such surveys are generally restricted to urban areas where the value of land is relatively high. Usually the boundary beacons would be placed to an accuracy of about 3cm. All the field survey and computational data as well as the ensuing map of all approved title surveys under this Act are the property of the Government and must be lodged with the Director of Surveys for safekeeping. In order to control the quality of survey work under RTA, only Government surveyors under the general direction of the Director of Surveys and private surveyors licensed by the Land Surveyors Board are allowed to carry our title surveys. The Director of Surveys is the authority on boundaries for surveys carried out under RTA and shall be the one to be called upon for expert opinion on disputes regarding such boundaries.

The Land Surveyors Board is a statutory body under the Survey Act (Cap 299) Laws of Kenya, which is the Act that regulates the operations of land surveyors for title surveys in Kenya. The Survey Act defines land surveying as that aspect of surveying concerned strictly only with title surveys. Consequently the Act is also only concerned with the control of title surveys to the exclusion of other types of surveys. The consequence of this is that anybody in Kenya can today get away with describing himself as surveyor provided they do not engage themselves in title surveys. This has been responsible for the poor regulation of the profession in this country with the attendant consequences that high standards of practice can not always be guaranteed. However the Institution of Surveyors of Kenya (ISK), in an effort to bring in some control in this area, has recently set out guidelines for the practice of non-title surveys

Through the land registration system under RLA, Kenya in fact has one of the best land registration systems in the developing world. The system is relatively cheap but effective. However the process of registration has moved on quite slowly to the extent that although it has been in operation for close to fifty years, hardly 30% of the country has been covered. There is currently an effort to introduce the computerised land information system (LIS) in the registration of land titles by Survey of Kenya. It is expected that the introduction of LIS shall result in efficient land management in Kenya.

While there has been considerable progress in the area of cadastral surveying, the task of national mapping has lagged considerably behind in the last forty years. Immediately after independence, in 1963, there was an accelerated need to settle a large number of indigenous Kenyans and to generally provide title to Africans who owned land in rural Kenya. The Government consequently focussed most of its effort in land adjudication and provision of title deeds. The consequence of this was that other aspects of surveying activity such as geodetic surveying, hydrographic surveying, and general mapping were given little priority. Thus although the entire country has been covered by topographic mapping at the 1:50,000 and 1:100,000 scales, the contents of most of these maps are quite old as they have not been revised as often as they ought to be.

The official map of Nairobi as published jointly by Survey of Kenya, for instance, has information dated at 1970's. Although the map has over the years been reprinted, this has only normally been based on the original data that is now more than thirty years old. However through the assistance of the Japanese Government, Survey of Kenya, jointly with the Japan International Cooperation Agency (JICA), has in March 2005 produced a set of most up to date, detailed and high quality maps for the city of Nairobi. In this mapping project, Nairobi has been covered by a total of 119 maps of which 60 cover the central part of the city at the scale of 1:2,500 while the rest of the city is covered by 59 maps at the scale of 1:5,000. The maps are also available in digital form, which means they can be manipulated for further analysis.

7.3 Modern Geospatial Technologies

As has been indicated, collectively, modern geospatial technologies are understood to comprise satellite positioning systems, geoinformation systems, and remote sensing. All these technologies today find quite significant application in Kenya. Many surveyors and engineers currently use satellite positioning systems, chiefly of the GPS type, for surveying and mapping purposes. On the other hand, the application of GIS, particularly in environmental analysis, is spreading out quite fast within the professional community in the country. The application of remote sensing technology in Kenya has been much more entrenched in the areas of environmental analysis and general map production. Kenya in fact has historical associations with these technologies that go to their very earlier practical tests.

Kenya has been involved with space technology for roughly forty years now. In 1964, the San Marco space research programme of Italy already set up, at Malindi, along the Kenyan coast, a platform for launching satellites into space. The first satellite was launched from this platform in April 1967. Three years later in 1970 a second satellite, Explorer 42, was launched. Explorer 42 became also known as

Uhuru satellite and was in fact the first American satellite to be launched by a foreign team. Subsequently eight other satellites were launched from the San Marco station in the period 1967 to 1988. The San Marco station is still operational and is today part of an important international network of stations used for the monitoring of satellite orbits and satellite status in general.

Satellite positioning technology on the other hand only came to Kenya for the first time in 1972-73. In this period a team from the United States Defense Mapping Agency and the Royal Engineers of the UK, carried out a test survey of the then newly introduced Doppler satellite positioning system. During this survey, fifteen points were occupied for observation at which Doppler satellite positioning coordinates were obtained. These also were the first points on the African continent,. and among the first anywhere in the world, at which coordinates had been derived through satellite positioning technology. Subsequently these points were incorporated into a major Africa-wide Doppler satellite positioning project (Africa Doppler Survey - ADOS) carried out in the 1980's under the direction of the Regional Centre for Surveying and Mapping, Nairobi.

From early 1990's, GPS took over as the principal technology for satellite positioning. In the last decade many survey organisations in the country have acquired GPS positioning technology for surveying and mapping purposes. GPS is thus slowly becoming the standard tool for geodetic positioning and surveying in the country. Attempts have also been made to use GPS technology for the monitoring of the geodynamic motions over the Kenyan Rift Valley system.

Geodetic positioning with satellite positioning techniques however requires that there is available, in the first instance, a geodetic reference system connected to the worldwide geodetic reference system. This reference system facilitates the transformation between the coordinates so derived from satellite positioning technology and the terrestrial system normally used for mapping. In Kenya, the geo-referencing framework is yet to be properly linked to the international geo-reference system. The consequence of this is that although there may be widespread use of GPS in positioning in the country, the full potential of GPS is not being realised because the derived coordinates are basically 'stand alone'. This problem is however already being addressed by Survey of Kenya through plans to establish a modern geodetic reference frame in Kenya.

In navigation, satellite positioning is yet to catch on properly within the country. There are a few cases where certain organisations have attempted to introduce the use of GPS in vehicle tracking and navigation, but most of these have gone hardly beyond the experimental stage. As indicated elsewhere already, there is no question that the use of GPS in vehicle tracking and navigation would have considerable scope in this country, especially with the numbers of vehicles being lost through theft everyday. The main reason for the lack of a functional GPS satellite vehicle tracking system is due to the lack of an appropriate network of GPS stations that can be relied upon to provide accurate coordinates for such a system.

The other satellite technology, remote sensing, arrived in this country in 1974, immediately after the launch of Landsat-1 (ERTS-A) in 1972. A small remote sensing laboratory had been set up at Survey of Kenya by USAID to spearhead the use of remote sensing in Kenya. This facility was subsequently relocated to KREMU (Kenya Range and Ecological Monitoring Unit) which is today's Department of Resource Surveys and Remote Sensing (DRSRS) in the Ministry of Planning and National Development. Moreover in 1975, UN Economic Commission to Africa established in Nairobi, a regional centre for surveying and mapping, whose activities focussed strongly on the application of remote sensing technology in mapping and environmental analysis within the eastern-central African region.

The use of GIS on the other hand has however picked up relatively well within the country. As has been indicated above, GIS is largely information technology based, and in most cases, with appropriate IT hardware and software, many organisations have been able to adopt GIS technology. The principal areas of application of GIS in this country are in environmental analysis, civil engineering project planning and implementation, agro-forestry, and epidemiology. However, because of the lack of a suitable geo-referencing system, the full potential of the use of GIS in the country cannot be realised. Many of the GIS products available in the country are not quite well geo-referenced and are therefore compromised in terms of accuracy.

7.4 Education and Training

Kenya has had one of the strongest programmes in education and training in surveying and mapping within the Commonwealth. Today surveying and mapping education and training is offered at the University of Nairobi, Jomo Kenyatta University of Agriculture and Technology (JKUAT), the Kenya Polytechnic, and the Kenya Institute of Surveying and Mapping (KISM). The University of Nairobi and JKUAT offer professional education and training from the Bachelor degree level through to Master's and Doctoral degree levels. Technician training on the other hand is available at the Kenya Polytechnic and KISM.

The beginnings of Surveying education in Kenya goes back to 1950, when the Government Survey Department set up a Survey Training School near Ngong to train European survey cadets for eventual deployment into the Survey Department. The training programme prepared candidates for qualifications of the Royal Institution of Chartered Surveyors (RICS). Already a year earlier in

1949, the Department had sent a number of African ex-servicemen for training at the Survey Training School, Entebbe, Uganda. This in fact was the first batch of Kenyans of African origin to be trained in surveying and mapping.

8

The Surveying Programme at the University of Nairobi

8.1 A Historical Perspective

The surveying programme at the University of Nairobi is one of the oldest on the African continent. The Royal Technical College of East Africa (RTCEA), the predecessor of the present University of Nairobi, was founded in 1956 with six Departments, namely: Architecture and Art, Arts, Commerce, Domestic Science, Engineering, and Science. The surveying programme was then one of the programmes in the Department of Commerce alongside Economics, Accounting, Banking, and a programme for training Company Secretaries. The Surveying programme then prepared students for the professional examinations of the Royal Institution of Chartered Surveyors (RICS) of Britain in the areas of valuation surveying, quantity surveying, and land surveying.

Shortly after its establishment, the College was reorganised into Faculties. In this rearrangement, Surveying was now established as an extra-Faculty Department. In 1960, the Department of Surveying split into two: Quantity Surveying and Land Surveying. Quantity Surveying moved over to the Faculty of Architecture and Art while Land Surveying joined the Faculty of Engineering as the Department of Land Surveying. The Department of Quantity Surveying soon afterwards became the Department of Land Development, and even much later, split further into the two Departments of Land Development and the Department of Building Economics and Management in the Faculty of Architecture, Design, and Development. In the recent restructuring of the University, the two Departments have been brought together as the Department of Real Estate and Construction Management in the School of the Built Environment.

In 1964 the Department of Land Surveying introduced the degree programme in Land Surveying to replace the RICS professional examinations programmes. The first group of seven students on this programme graduated with the degree of Bachelor of Science (Surveying) in 1967. This land surveying degree programme was pegged at the level of the written examinations of RICS, so that graduates from the programme would be exempted from the written examinations for the associate membership of RICS. For virtually the entire period that the surveying degree programme has been in existence, however, it remained relatively traditional; focussing on the traditional areas of surveying, namely: cadastral surveying, topographic mapping, engineering surveying, and trigonometric surveying.

The Chair of Surveying in the University of Nairobi was first occupied in 1971 with the appointment of Professor Lawrence Pentecost Adams as the first Professor of Surveying in the University of Nairobi. Prof. Adams had originally joined the Department as Lecturer. He also became the first person to graduate with the degree of Doctor of Philosophy (PhD) in the Faculty of Engineering with a thesis on the application of photogrammetry in cadastral mapping and land registration. The cadastral mapping and land registration system adopted in rural Kenya, under the Registered Land Act (RLA) in fact has its foundation in Prof. Adams' work. In 1972 Prof. Adams moved over to the University of Cape Town as Professor of Photogrammetry and Surveying. At Cape Town, he founded a pioneering research group in the area of application of photogrammetric techniques in biomedical engineering.

The next occupant of the position of Professor of Surveying in the Department was Professor Raouf Shawky Rostom. Prof. Rostom joined the Department in 1976. He brought with him extensive experience gained in teaching surveying and civil engineering in his native country of Egypt and other parts of Africa. Prof. Rostom oversaw the development of the Department through the eighties before taking up the position of Professor of Civil Engineering at Jomo Kenyatta University College of Agriculture and Technology at Juja in 1993. In 2001 Prof. Rostom returned to the Department and continues to serve as Professor in the Department.

8.2 Current Status and Future Directions

Since it started offering the degree programme in 1964, the Department of Surveying has graduated about 700 students with the degree in Surveying. For many years the University of Nairobi was the only place where one could study Surveying at University level in East Africa. In fact by 1977, the number of graduates from the Department was almost equally balanced amongst the three

East African countries of Kenya, Uganda, and Tanzania. The programme also attracted students from as far as Pakistan. Today there are equivalent Surveying programmes at the University of Dar-es-Salaam and at Makerere University.

Until into the 1990's the teaching of Surveying at the Department of Surveying was basically focussed on the measurement and mapping of land. In a way this is also the interpretation of the discipline in most Universities. Graduates of the Department were thus traditionally trained to work with organisations dealing in land measurement and mapping. Most graduates from the Department in those days thus found employment with national survey and mapping agencies (e.g. Survey of Kenya), public works departments, local authorities, and private land survey and civil engineering firms.

However, the major technological developments that have taken place in the discipline in the last decade have completely transformed the practice and teaching of the discipline across the globe. As has been indicated elsewhere in this lecture, the discipline of Surveying has transformed itself dramatically in the last ten years from one that was measurement intensive to one focussing on the management, analysis, and utilisation of geo-data. This has expanded considerably the scope of application of expertise in the discipline. In particular, the modern technologies of Global Positioning System (GPS), Geospatial Information Systems (GIS), and remote sensing have opened up new opportunities for persons with expertise in surveying and mapping.

Many organisations locally have just come to realise the potentials of the modern geospatial technologies of GPS, GIS, and remote sensing. These have opened up many employment opportunities for graduates of the Department. Today, besides the areas concerned with traditional surveying and mapping, the expertise of our graduates in geospatial technologies are being asked for in many areas within the natural, built, industrial, and business environments. We have for instance graduates working in environmental management, medical research (epidemiology), transport and fleet monitoring, banking (use of GIS in marketing), refugee settlement and management (use of GIS, GPS), and agro-forestry.

In order to respond to these modern technological developments, the Department of Surveying at the University of Nairobi has recently completely re-engineered its undergraduate programme and introduced a programme in **Geospatial Engineering** in place of its traditional programme in Surveying. The Geospatial Engineering programme aims to produce graduates with dedicated skills in the application of geospatial technology in the solution of engineering problems.

At the Department we have adopted the following definition for Geospatial Engineering:

> ***"The professional discipline concerned with the measurement, analysis, and graphic representation of dimensional geo-spatial***

relationships, as well as with the design, construction, maintenance, and the use of geo-spatial databases. It has its roots in surveying and mapping and encompasses the specialisms of geodesy, surveying, topometry, hydrography, geoinformatics, and navigation."

The new programme in Geospatial Engineering was already implemented with effect from the academic year 2004/5. The programme aims to fulfil requirements for recognition of its graduates by both the engineers' and surveyors' professional bodies in Kenya.

The Geospatial Engineering programme covers the following as the broad core areas of study:

- **Geodesy and Geodynamics**
  Geodesy is the study of the geometry of the earth including its gravity field. The study of geodesy deals generally with the determination of the figure and size of the earth as well as with the study of the earth's gravity field. Geodynamics on the other hand is concerned with the study of the dynamics of the solid earth including the study and monitoring of plate tectonics, earthquakes, and volcanic eruptions. Geodetic methods are core to the study of geodynamics. Geodesy and geodynamics form the scientific foundation on which various aspects of geospatial engineering are based.

- **Positioning and Navigation**
  Positioning is about the determination of position of a point on or near the earth's surface. Positioning is closely allied to navigation, which is concerned with the determination of the position of an object in motion. Both in positioning and in navigation, one requires well-established reference coordinate systems, in four-dimensional space, which comprises the definition of position in terms of place and time. The reference coordinate system provides a reference with respect to which the location of the point or object is to be given.

- **Topometry and Measurement Systems**
  Topometry is simply the measurement of topography, taken in its broadest sense to cover the measurement of topography of any object. Topometric measurements rely on sophisticated measurement systems ranging from those required for precise, industrial, metrology to satellite positioning systems for the measurement of the topography of the earth and the planets. Topometry thus finds application in the measurement of topography of small artefacts such as bolts and nuts to the measurement of the topography of the earth and even of other planets as well as in such areas as in the design and construction of robots, biomedical engineering, civil engineering design and construction, machine guidance and control, precision industrial

  measurements, and the modelling of the environment. The instruments used in Geospatial Engineering are almost exclusively sensor based. Thus this aspect of the discipline covers also the understanding of the working principles of geo-spatial sensors and instruments as well as with their design and construction.

- **Geoinformatics and Visualisation**
  Geoinformatics is concerned with the application of modern computer information systems to the analysis of geo-spatial phenomena and systems. It comprises particularly the disciplines of cartography, photogrammetry, remote sensing, and geo-spatial information systems (GIS). Spatial data visualisation (SDV) on the other hand is concerned with the manipulation of graphic representation of geo-spatial data as to be able to realise three-dimensional visualisation of such data. Through SDV one is in a position to create virtual reality models of geo-spatial systems and objects.

- **Land and Infrastructure Management**
  This is a traditional area of land surveying which is concerned with policy issues in land management on one hand and the management of infrastructure on the other hand. It covers surveys for land management and the design, development, and use of land information systems (LIS) including digital and three-dimensional cadastres. Facility management on the other hand is a modern area of professional practice concerned with the application of information technology in the management of infrastructure. In both these cases, the question of 'location' is of critical importance, hence the consideration of this as an integral aspect of geo-spatial engineering.

Further, the Department is currently working on an undergraduate programme in ***Geospatial Information Technology*** to be implemented jointly with the School of Computing and Informatics. The intention in this programme will be to produce persons with expertise in the application of information technology (IT) in geospatial systems. The spectrum of the expertise of the graduates from this programme would cover from geospatial software development and systems to applied geospatial technology.

In the next stage of its development, the Department is moving into the area of applied space science and technology. In its current curricula the Department already covers extensively the technologies of remote sensing, Global Positioning System (GPS), and Geoinformation Systems (GIS). These areas of study already constitute an important core of any curriculum in space science and technology. The programme on ***space science and technology*** shall focus on satellite positioning and navigation systems, satellite remote sensing, satellite communication systems, application of satellite technology in atmospheric science and meteorology, and geospatial information systems. Naturally the Department will need to work in partnership with other Departments and units in the University in order to fully realise the implementation of this programme.

At the postgraduate training level, the Department introduced its first formal Master's degree programme, offered by coursework, examination and thesis, in 1988. Up to this time the Department had admitted students for the Master's degree on an ad hoc basis and had such students largely study for their MSc degrees by research and thesis alone. The Department has also recently introduced a taught MSc programme in geospatial information systems (GIS.), on which the first batch of students have just started their programme of study. The Department is also working on MSc degree programmes in *geodetic science*, *geospatial measurement systems*, and *geoinformatics and geo-visualisation*. The Department will also be looking into the possibility of mounting a Master's degree programme in *land and infrastructure management* jointly with the Department of Real Estate and Construction Management.

In its objective to be a distinguished centre for higher learning in the geospatial and space sciences and technology, the Department of Surveying has had its name changed to the ***Department of Geospatial and Space Technology*** in the recent restructuring of the University of Nairobi. It is expected that within this framework the Department will eventually establish Professorial Chairs in *geodetic science*, *geospatial measurement systems*, *geoinformatics and geo-visualisation*, *land and infrastructure management*, and *space science and technology*.

9 Conclusion

9.1 Summary

In this lecture we set out on a review of the discipline of Surveying. We traced the historical development of the discipline from the rope-stretchers in antiquity to the modern times of e-mapping. In this we noted that the discipline had its origins right from the beginnings of civilisation in the Near East. From relatively primitive concepts we saw how the art of land and earth measurement became relatively advanced in ancient Egypt. We noted that all the three broad subject areas of Surveying, namely, geodesy, land surveying, and cartography had their formal origins in Africa, along the Nile valley in Egypt.

We presented the principal objective of the discipline of Surveying as being about the location of objects and phenomena and their geometric description within geo-space. We presented the discipline of geometry as the foundation of the discipline. Geometry itself has been defined as the quantification and mathematical description of space. To this extent we looked at the concepts of space and time in terms of philosophies surrounding their nature from the early Greek philosophers Zeno, Plato and Aristotle through to Copernicus and Kepler, Newton and Leibniz, Laplace and finally to Einstein's relativity.

The discipline of geometry was considered to have developed out of the practical need to measure land by the rope-stretchers of Egypt. We traced the development of geometry in the first instance from Pythagoras to Euclid. We saw how the desire to solve the problem of the fifth postulate of Euclid led to the discovery of non-Euclidean geometry of curved spaces by Gauss, Bolyai, and Lobachevsky, and the subsequent further development by Riemann and Hilbert. We saw how the desire by Minkowski to formulate Einstein's special relativity in non-Euclidean geometry created the foundation for the subsequent development of the theory of general relativity.

as in industrial metrology and analysis of deformation of engineering and other structures.

Navigation has been a traditional area of application of geodetic knowledge and mapping, and is today one of the fastest growing areas of application of geospatial technology. We considered the development of the technology of navigation beginning with the primitive methods of way finding by identifying objects along the way. We saw how navigation technologies subsequently got improved through the use of astronomic methods and the magnetic compass. We saw how the use of technologies based on the electromagnetic wave signal revolutionised the technology of navigation towards the middle part of the twentieth century. We pointed out that the principal tool for navigation today is GPS and its variant technologies. In all this we gave special consideration to the longitude problem and how it was eventually solved.

Perhaps no aspect of the discipline of surveying has attracted as much widespread application today as geoinformation systems technology. We traced the development of geospatial (geographic) information systems (GIS) from its early days in Canada and USA to its current widespread application in the analysis of geospatial phenomena. Within the framework of geoinformatics, besides GIS, we looked at remote sensing, digital or electronic (e-) mapping and cartographic visualisation. We argued that the driving force behind the popularisation of the application of geospatial technology lay in digital technology.

We pointed out that, due to the foundation provided by the technologies of GPS, GIS, remote sensing, digital mapping, and telecommunications, the new horizon of application of geospatial technology in location based computing and systems was fast opening up. We pointed out that this is the area with the greatest potential for application of geospatial technology in the near future. The combination of the use of the technologies of GPS, digital mapping, GIS, and telecommunications was already finding widespread and innovative applications in the physical, built, industrial, and business environments. It was observed that this trend was set to continue at even a much more extended level.

Having looked at the historical development of the discipline, areas of its application, and its current level of development, it was time to extrapolate the current developments into the future. We started this by discussing the current apparent crisis of identity in the discipline. We discussed how the development of modern technologies had completely changed the face of the discipline to the extent that its description by the term 'Surveying' could no longer be considered adequate or even appropriate. We presented the view that descriptions based on the term 'geospatial' were being found more appropriate as representative of the discipline.

It was pointed out that the future of the discipline shall continue to be defined by the modern technologies of information technology, communication systems, and space technology. We indicated that satellite positioning technology (e.g. GPS), digital mapping, GIS, remote sensing, and developments in precision metrology shall continue to dictate the areas of application of geospatial technology. The one area of application that is sure to redefine the scope of the discipline is Digital Earth as viewed within the broad area of e-mapping. The Digital Earth concept is bound to provide a major direction in the development of spatial technology and application in the future, and that the Digital Earth concept shall do with maps what the Internet is currently doing with text.

We next moved over to look at the practice of geospatial technology in Kenya. We traced the development of the practice of surveying and mapping in Kenya. We saw that the formal introduction of surveying and mapping in this country was through the surveying work for the Kenya-Uganda railway line towards the end of the nineteenth century. It was observed that subsequent development of the discipline in Kenya was propelled by, on one hand, the need to survey land for colonial settlement and to alienate African land, and on the other hand to map out the country for efficient governance by the then colonial government. Finally we speculated on the future development of the practice of geospatial technologies in this country.

Finally we came home to look at our own Surveying programme at the University of Nairobi. We traced the development of the programme at the University of Nairobi starting with the introduction of surveying education at the Royal Technical College of East Africa, Nairobi. We looked at the current status of the programmes in the Department and gave indications on some efforts the Department was making on its curricula to continue keeping its programmes relevant. It was indicated that, in line with the general development of the discipline worldwide, the future of the discipline of Surveying at the University of Nairobi was quite bright.

9.2 Concluding Remarks

In this lecture I have tried to communicate the position that in broad terms, the discipline of Surveying was about the geometric measurement and geo-graphic representation of our world. The world was considered to comprise the physical entity of the Earth with phenomena and events that take place within it. The principal objective of the discipline was interpreted to be that of locating these events and phenomena within the four-dimensional space-time of our world. It was argued that every event within this space-time can be uniquely located and described in the first instance on the basis of coordinates such as (x, y, z, t) in which (x, y, z) is taken to represent the pure three-dimensional Euclidean space while (t) is the time coordinate.

It will be recalled that I started on this lecture by posing the question: "Where in the world are we?" At that time, I described our location basically in qualitative terms. Throughout the lecture I have however insisted that location is best described in quantitative terms; in terms of coordinates, that is. Further, I have argued that the principal specialised, unique, expertise that the surveyor possesses is the ability to work with coordinates to produce practical, useful, results.

In this spirit, I can now state that, at the beginning of our lecture this afternoon, our location in terms of physical coordinates, being astronomic latitude, astronomic longitude, height above mean sea level, and time, was:

Latitude:	**01° 16' 48.234" S**
Longitude:	**36° 48' 56.055" E**
Height:	**1,672.96m AMSL**
Time:	**13hrs 00min 00sec UT**

Ladies and Gentlemen: I am most grateful to the University of Nairobi, and specifically to the Vice-Chancellor, for granting me this opportunity to give my inaugural lecture and for availing financial support towards the lecture. I also wish to thank the Deputy Vice-Chancellor (Academic) and the Academic Registrar for facilitating the process that has made it possible for us to be gathered here today. Many other people assisted in various ways towards the realisation of this lecture; I wish to thank you all. I wish particularly to appreciate the support of my wife and family during the course of the preparation of the lecture. This lecture however could not have taken place without your participation; I wish to record my most warm appreciation to you for taking your time out this afternoon to come and listen to me.

Ladies and Gentlemen: THANK YOU!

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