APPLICATIONS OF SATELLITE TECHNOLOGY IN THE SUGAR INDUSTRY

FANIE FERREIRA[1] AND FERDI SCHEEPERS[2]

[1] *GeoTerraImage, PO Box 73382, Lynnwood Ridge 0040, Tel: (012) 348-4586/7, Fax: (012) 348-4588, E-mail: fanief.gti@geospace.co.za*
[2] *Satellite Applications Centre, CSIR, PO Box 395, Pretoria 0001, Tel: (012) 334-5000 Fax: (012) 334-5001, URL: www.sac.co.za, E-mail: fscheep@csir.co.za*

Abstract

New and exciting geo-spatial applications are being made possible by recent advancements in the information and communications industries. Many of these applications rely on the innovative use of several technologies, including remote sensing, global positioning systems (GPS), and telecommunication, all of which require satellite technology to be feasible and accessible globally. In addition, personal computers and geographic information systems (GIS) provide the desktop environment needed to access and process data, to analyse results, and to execute optimisation algorithms or decision support tools. In this paper, two such applications pertaining to the sugar industry, and the technologies that support them, are discussed: precision farming and crop area estimation.

Biographies

Fanie Ferreira is a GIS and Remote Sensing Specialist and a co-founder of GeoTerraImage. His research interests include the application of geo-spatial techniques in both commercial and subsistence agriculture and associated rural settlements. Fanie received his BSc (Agric) degree from Stellenbosch University in 1984. He completed a post graduate diploma in Terrain Evaluation at Potchefstroom University in 1987, and received a BSc (Hons) degree in Geography from North West University in 1996.

Dr Ferdi Scheepers is manager of Geo-Information Projects and Applications (GIPA) at the Satellite Applications Centre of the CSIR. His research interests include 3D geo-spatial analysis and visualisation, virtual reality, computer graphics and animation, and computer art. He received the BSc (Hons) and MSc degrees in computer science *cum laude* from the Rand Afrikaans University, in 1984 and 1988, respectively. In 1989 Ferdi started graduate studies at The Ohio State University in Columbus, Ohio, USA, where he obtained an MS degree in 1991 and a PhD in 1996, both in computer and information science.

1. Introduction

The information and communications industries have experienced major technical advancements in recent years. Computers now have processing power, memory sizes, and storage capacity suitable for advanced applications, cell phones are part of our daily lives and communication links via satellites are commonplace, and the Internet provides immediate access to global information.

These technological advancements are creating exciting opportunities for new applications that were not possible previously. Increased utilisation of technologies for communication, data capture, and information dissemination is stimulating the development of new applications, many of which are based on the combined and integrated use of various technologies.

In this paper two such applications are described: *precision farming*, a modern farm management practice that relies heavily on the integrated use of advanced technologies, and *crop area estimation*, a methodology that provides important information on crops, including crop statistics and expected crop yields.

1.1 Precision Farming

Traditional farm management practices regard an agricultural field as a homogeneous unit. Individual fields are managed uniformly without accounting for variations in soil fertility and topography. These variations are exacerbated by the ever-increasing sizes of fields that result from mechanisation.

Precision farming seeks to improve farm management practices by taking soil and terrain variations of individual fields into account. Agricultural fields are not treated as homogeneous units, but are managed according to localised needs. Based on apparent variations, potential zones can be identified and managed separately to optimise overall profit. Thus, precision farming provides a framework by which more accurate sowing, irrigation, and fertilisation activities can be planned and executed.

Precision farming relies on the innovative use of several technologies, including remote sensing, global positioning systems (GPS), and telecommunication, all of which require satellite technology to be feasible and accessible globally. In addition, personal computers and geographic information systems (GIS) provide the desktop environment needed to access and process data, to analyse results, and to execute optimisation algorithms or decision support tools.

Of course, any application that depends on several advanced technologies and systems must be evaluated from an economic perspective to ensure sound investment returns through increased productivity or recurrent savings.

1.2 Crop Area Estimation

Several technologies are also employed to obtain information on crop statistics. Satellite imagery can be used to determine the area planted under different crops, to verify that specific crops have been planted, and even to estimate expected crop yields. Through field verification of specific crops (maize, sugarcane, etc.) using GPS technology, satellite image classification algorithms can be calibrated to perform crop type classifications. Once classified, the area and extent of specific crops can be determined. By integrating historical information on average yield, or through the use of prediction modelling, crop yield estimation is possible.

Information gathered in this manner is useful for grain millers, silo managers, and sugar mills as it allows them to plan processing, distribution, and marketing activities. If the supply of grain or sugarcane is expected to be below demand, additional delivery can be procured well in advance. Similarly, if oversupply is imminent, marketing and distribution plans can be initiated.

Information on crop statistics and expected yields is also important in a variety of global and regional activities, including international price determination, crop monitoring and verification, and food security. The Foreign Agricultural Service (FAS) of the United States Department of Agriculture gathers information on worldwide crops and provides estimates of expected crop yields. The futures market in Chicago uses this information to determine international crop prices on a monthly schedule. Similarly, the Joint Research Centre of the European Union (EU) provides crop statistics to the EU, derived mainly from information provided by a programme called MARS (Monitoring Agriculture with Remote Sensing). Organisations such as the Food and Agricultural Organisation (FAO) use information on global crop expectations to monitor food security across the globe and to advise on relief measures.

2. Satellite Technology

An artificial satellite is an object placed into an orbit around the earth for scientific research, earth applications, or military reconnaissance. Since the launch of SPUTNIK 1 by the USSR on 4 October 1957, several thousand satellites have been placed in orbit. Most of these satellites were built by the United States and the USSR, but the European Space Agency, and many individual countries including Canada, China, France, India, and Japan, are now actively engaged in satellite technology.

Satellites are placed into orbits at different altitudes and with different inclinations depending on their purpose. Meteorological and telecommunication satellites are generally placed in geo-synchronous (GEO) orbits, 35 840 km above the surface of the earth. These satellites orbit in the same direction as the earth's rotation and at the same angular velocity; consequently, GEO satellites hover over the same geographical point on the globe and would appear to be stationary to an observer on the ground. Navigation satellites are placed in an orbit of approximately 22 000 km with a 55-degree inclination to the equator. The ground track of these satellites is repeated every 24 hours with a four-minute shift. Newer constellations of communication satellites, especially those for cellular networks requiring landline quality transmissions without propagation delays, are placed in low earth orbits (LEO) up to an altitude of 1 500 km. LEO satellites enhance the quality of service to low-power mobile cellular and vehicle-mounted equipment without requiring expensive and dedicated antennas that point towards the satellite. Most earth observation satellites orbit at lower altitudes ranging from 700 km to 1 000 km. These usually have near-polar orbits to ensure regular, global coverage. Near-polar orbits can be designed to be sun-synchronous to ensure similar illumination conditions at the same latitude and at the same time of the year.

2.1 Communication Satellites

One of the most important technological applications of satellites is the relay of radio signals around the world for communications purposes. Using receivers, amplifiers, and transmitters, as well as the technique of multiplexing, communications satellites can simultaneously relay many telephone and television signals. A constellation of satellites spanning the globe is needed for worldwide communication.

The development and deployment of a constellation of satellites can run over decades and cost billions of dollars. This enormous cost makes it essential for consortiums to be formed to support ventures of this nature. Some of the leading programmes that provide cellular and Internet communication via satellites, such as Iridium, Globalstar, and Teledesic, are all consortiums of worldwide partners.

Iridium is a global network for cellular communication that consists of a constellation of 66 LEO satellites orbiting at 780 km, close enough for telephonic and paging communication from handheld instruments. The Iridium network integrates land-based phone lines and local cellular coverage with satellite communications. The multi-mode capability of the Iridium phone makes it possible to use only one instrument for cellular or satellite access and allows the telephone to work as a typical cellular telephone (in areas where compatible cellular services exist) or as a satellite telephone (Figure 1).

Globalstar is a consortium of international telecommunications companies planning to create a satellite-based, wireless telecommunications system designed to provide voice, data, fax, messaging, and other telecommunications services to users worldwide. Subscribers will be able to make or receive calls using hand-held or vehicle mounted terminals similar to today's cellular phones. Calls will be relayed through Globalstar's 48 satellites orbiting at 1 500 km to a ground station and then through local landlines and cellular systems to the end destinations. This system will provide global roaming and cellular connections almost anywhere on earth (Figure 2 & 3).

Teledesic is planning a global *Internet-in-the-Sky* network that will consist of a constellation of 228 LEO satellites (Figure 4 & 5). The network will provide affordable fibre-optic like connectivity optimised for fixed-site terminals, and services such as computer networking, broadband Internet access, and digital data exchange.

2.2 Navigation Satellites

Navigation (or global positioning) satellites provide the means to pinpoint any location on the earth (longitude, latitude, and altitude) with high accuracy (Figure 6). Initially designed and developed for military applications, global positioning systems (GPS) are now being used in a variety of applications, including:

- Air, naval, and ground navigation (Figure 7)
- Air and naval traffic control for increased safety
- Emergency search and rescue operations
- Ground transport monitoring
- Land surveying for cadastral applications
- Capturing of geographical data, including line, point, and area features
- Precision farming and yield mapping

The American GPS, operated by the US Department of Defence (DoD), consists of 24 active satellites orbiting at an altitude of 20 200 km (Figure 8). Signal distortions are integrated into GPS signals to prevent non-military users from acquiring high accuracy information instantaneously. The DoD, and specifically selected and approved users, employ specialised cryptographic equipment to access undistorted signals, ensuring instantaneous 20m accuracy. This represents an advantage to US military forces in live combat situations when firing rockets and missiles at specific targets.

Some civilian applications, such as emergency search and rescue operations, do not require sub-100m accuracy. For applications requiring higher accuracy, captured GPS data can be post-processed to the required accuracy, either through using very sophisticated GPS equipment that can receive and process GPS signals from five or more satellites, or through a process called *differential correction*. With differential GPS, time-coded recordings of GPS signals in the field are compared to time-coded GPS signals recorded at a base station. As the exact location of the base station is known, inaccuracies of the recorded values at any given time can be quantified and used to correct the field observations. With these techniques, sub-metre accuracy is possible.

2.3 Earth Observation Satellites

Remote sensing is a technique for obtaining information about objects from a distance. Viewing earth in this way reveals interesting features that are difficult to detect from ground level. It also gives us an invaluable global perspective of earth that would be impossible to obtain otherwise. Earth observation is remote sensing from satellites (or aircraft).

Onboard instruments called *sensors* are used to obtain information about objects and features on the earth's surface. Sensors sample reflected or radiated energy at square areas on the earth's surface. Rows and columns of samples resemble the grid pattern of a spreadsheet. Usually, each sample (corresponding to a cell in the spreadsheet matrix) has a value from 0 to 255. A panchromatic satellite image can be formed from a matrix of samples by assigning shades of grey to the different values. For example, a black pixel would represent 0, a white pixel would represent 255, while values between 0 and 255 would be represented by pixels with shades of grey varying from black to white.

The emergence of commercial earth observation has been dominated by two satellite systems in the past decade, the US Landsat and the French SPOT. Recently, many alternative systems have been introduced, including ERS of the European Space Agency, India's IRS, and Canada's Radarsat. In addition, systems like NOAA and Meteosat have been operational for many years, providing meteorological and surface temperature information globally.

Sensors on earth observation satellites measure reflected or radiated energy in different regions of the electromagnetic spectrum, both inside and outside the visible spectrum. These regions of measurement are called *bands*. For example, the Landsat Thematic Mapper (TM) sensors collect data in the blue, green and red regions, in bands 1, 2, and 3, respectively. They also collect data from outside the visible spectrum, in the near-infrared (band 4), the mid-infrared (bands 5 and 7), and the thermal infrared (band 6) regions. By combining data from three different bands, colour satellite images (also called multispectral images) are formed.

The fraction of energy reflected by an object determines its spectral reflectance. Different objects reflect energy differently, and the reflectance of each object varies with wavelength. Objects can therefore be characterised by the way they reflect energy, or by their spectral reflectance *signature*. For example, water bodies can be identified and outlined easily by using infrared bands. Water absorbs energy at infrared wavelengths, so the absence of reflected infrared light is a strong indication of the presence of water. Near-infrared bands are especially sensitive for green vegetation such as agricultural crops in vegetative stages.

In 1967, NASA initiated the Landsat programme, considered to be a pioneering effort in terms of unmanned satellites at the time. The first Landsat satellite was launched in 1972. It was technologically advanced because data was recorded as digital numbers and could be transmitted to earth. An onboard recorder also allowed data to be recorded in areas where no direct receiving stations existed, for downloading and archiving at a central receiving station in the USA during over flight. Landsat TM imagery has pixels representing a 30m square area in multispectral mode, and 15m in panchromatic mode.

The French Space Agency (CNES) started to develop the Spot programme in 1982 in collaboration with Sweden and Belgium. Since the launch of Spot 1 in February 1986, four satellites have been launched, of which three are still operational. The Spot satellites have high-resolution visible imaging systems that operate in the multispectral and panchromatic modes to provide imagery at resolutions of 20m and 10m, respectively. These satellites have pointing capabilities that increase the system's *revisit* flexibility (coverage over the same geographical area every five days) and allow SPOT to acquire stereo imagery useful in creating digital elevation models.

3. Geographic Information Systems

Along with earth observation, the technology of geographic information systems (GIS) is one of the leading technologies that enable questions about spatial and temporal dimensions to be answered. A GIS is designed for assembling, integrating, and analysing spatial information in a decision-making context. These systems evolved from a requirement to integrate and manipulate diverse data sets for common geographic areas by using co-ordinates as the basis for the information system.

GIS is a discipline that has developed from advancements in digital cartography, database technology, and computer processing and storage capacity to handle large files of geographical data. Further advancements that are stimulating even more progress in GIS technology include the availability of desktop computers with powerful processors and inexpensive storage, high-quality plotters, and user-friendly GIS, image processing, decision support, and visualisation software.

A GIS is like a configurable (or intelligent) map that allows thematic information layers with a variety of different features such as geology, roads, contours, vegetation, land parcels, field boundaries, electrical power lines, to be stored using a common geographic co-ordinate system. A common reference system for multiple geographic data sets allows the GIS user to combine any or all of the layers and to analyse spatial relationships between them or to create new information. A GIS also presents an excellent environment for the optimal use of GPS data and for thematic feature coverages extracted from satellite imagery.

4. Applications in the Sugar Industry

The applications of satellite technology in the Sugar Industry mainly relate to the farm management practices and crop area estimation for a specific district or region. Earth observation and navigation satellites are at the root of these applications. These types of satellites provide the primary input data, which together with other data sets, can be assembled, integrated, and analysed in a GIS.

4.1 Precision farming

As a management support tool, precision farming can assist farmers in the following ways:

- In supplying practical field information
  - to identify the location and extent of problem areas in a field, and
  - to identify soil potential zones for management purposes.
- In supporting management decisions
  - to manage and optimise input costs, and
  - to increase net farm income.

Satellite images have inherent characteristics that make them suitable for application in field-level farm management. In the case of the Spot satellite, a colour image (Xs) has a 20m interval, which means that the satellite is recording one value for every 20m x 20m square area in an agricultural field. Secondly, the sensor on the satellite is extremely sensitive to photosynthesising vegetation and when combining some of the data channels, a vegetation index can be derived.

Given the systematic and evenly distributed data recorded by satellites, the vegetation index provides a picture of the condition of a crop across a field. Variation in soil properties across the field is translated into vegetation growth and vigour, which actually represent yield potential zones. These zones can be mapped from the satellite imagery and used as a means to identify low, medium and high potential zones.

In Figure 9, an example in the Komatipoort vicinity shows sugar cane under centre pivot irrigation. The image on the left is the original Spot colour image (Xi) recorded on 13 June 1998, with an image representing its vegetation index on the right. The variation of colour within the perimeter of some of the centre pivot fields show certain parts of the field to be growing better than others, indicative of the presence of potential zones.

The circular variations in the fields point to irregular irrigation, while the yellow areas at the top and bottom are known to have been water logged when the image was recorded. Thus, potential problem areas can be identified from satellite imagery and then verified in the field. One way of doing this would be to determine the geographical positions of problem areas on the satellite image and to use a GPS in the field to find the locations in question.

4.2 Crop area estimation

Satellite imagery is valuable in estimating the area planted under a specific crop. The MARS programme of the EU used a total of 168 images during 1998 across 14 countries, covering 60 sample sites, to determine area planted under a certain crop. Spot provided 128 (76.2%) of these images, emphasising the fact that the constellation of three Spot satellites is very effective for monitoring crops at regular intervals.

The Pongola area south of Swaziland and along the Pongola river is a well known sugar producing area. A Spot colour image (Xs) covering this area, dated 4 May 1998, was classified to determine the total area of arable land, the area under sugar cane, and the harvested and unplanted areas. Calculations show that the total area of arable fields was 22 124 hectares of which 7 820 hectares were under sugar cane at the time of image acquisition, and 14 304 hectares were harvested and unplanted fields. In this case, the image could be used to quickly assess the cropped area, providing information that is useful for the planning of processing and marketing strategies.

GPS instruments have two possible applications in crop area estimation, firstly in the calibration of classification algorithms to determine crop types, a technique that is commonly known as *ground truthing*, and, secondly, to control the variable application of farm inputs such as fertiliser in different potential zones. In the USA, for example, farm machinery is increasingly being equipped with GPS instruments that are being used for yield mapping or the variable application of fertiliser or seed. Such applications are based on known soil potential – as the machinery moves across the field, the position is relayed to a GIS to establish the potential zone, and the variable applicator equipment is instructed to apply the correct amount for each potential zone.

Communication satellites provide further application opportunities for farmers, especially in remote areas where it is difficult to create regular infrastructure such as telephonic landlines. Constellations of satellites deployed to provide telephony services via satellite create the opportunity for farmers to be 'connected', no matter where they are located. In addition, the satellite constellations designed for Internet access anywhere in the world will make it possible for farmers to acquire information on global trading activities, including commodity prices and supply and demand situations on the international market, irrespective of geographical location.

5. Conclusion

The rapid development and improvement of satellite technology provides opportunities for the sugar industry that were not possible previously. Earth observation satellites provide a means for farmers to manage their operations more effectively and profitably while also creating the potential to monitor crops and to estimate cropped area for specific regions at a given time. Communication satellites make it possible for people to be in contact with each other from anywhere on earth, whether telephonically or through the Internet, and as such has the potential of putting farmers into contact with the rest of the world.

6. Bibliography

Rapid technological developments and new applications are often associated with a lack of published material. However, the Internet provides an excellent source of information – interested readers are invited to visit the following web sites for more detail on the topics of this paper:

Blackmore, Simon. Precision Farming; An Introduction
http://www.silsoe.cranfield.ac.uk/cpf/papers/abstract.htm

Dana, Peter H. Global Positioning System Overview
http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html

ESA
http://nng.esoc.esa.de/

Geoweb
http://www.ggrweb.com/

Globalstar
http://www.globalstar.com

Iridium
http://www.iridium.com/

Teledesic
http://www.teledesic.com/

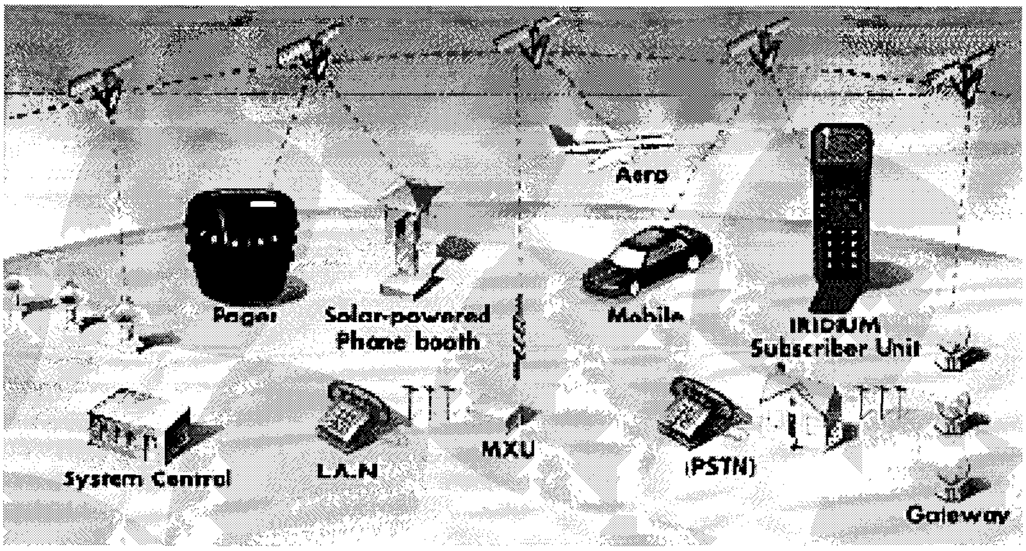

Figure 1:
A diagrammatic representation of the Iridium communication network incorporating landline infrastructure. (Source: http://www.iridium.com/)

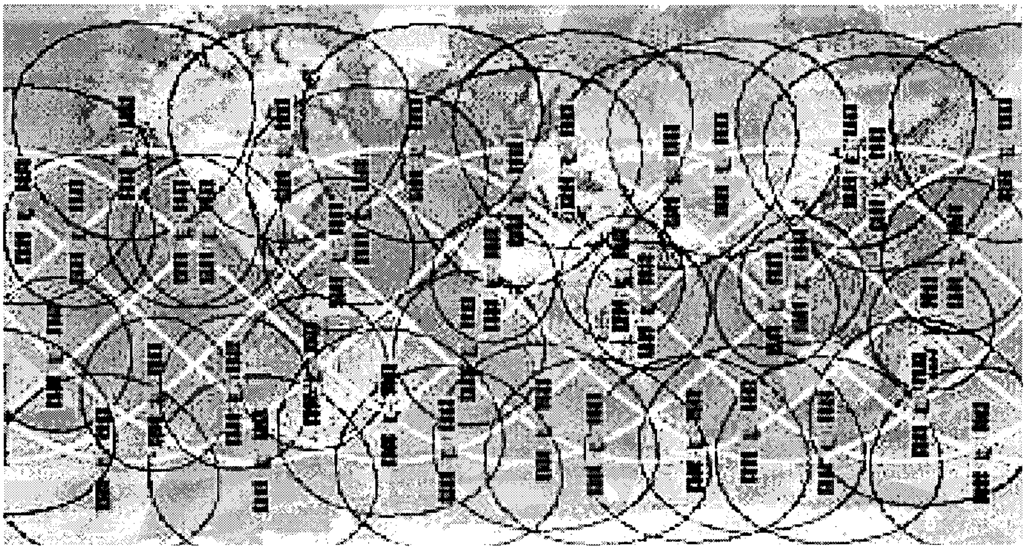

Figure 2:
A diagrammatic representation of the Globalstar satellite coverage. (Source: http://www.globalstar.com)

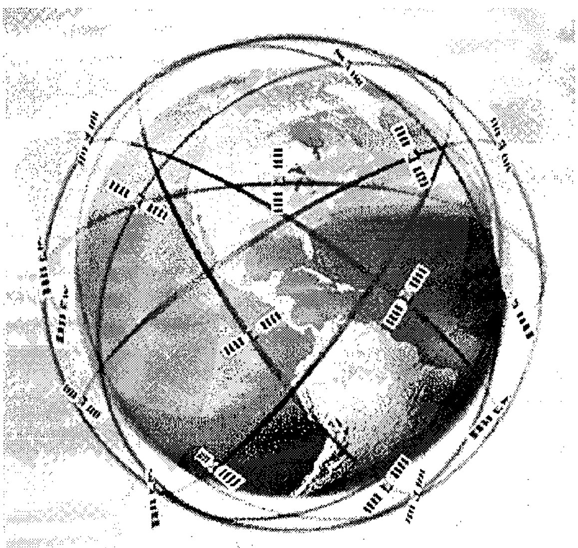

Figure 3:
The Globalstar Satellite Constellation (Source: http://www.globalstar.com)

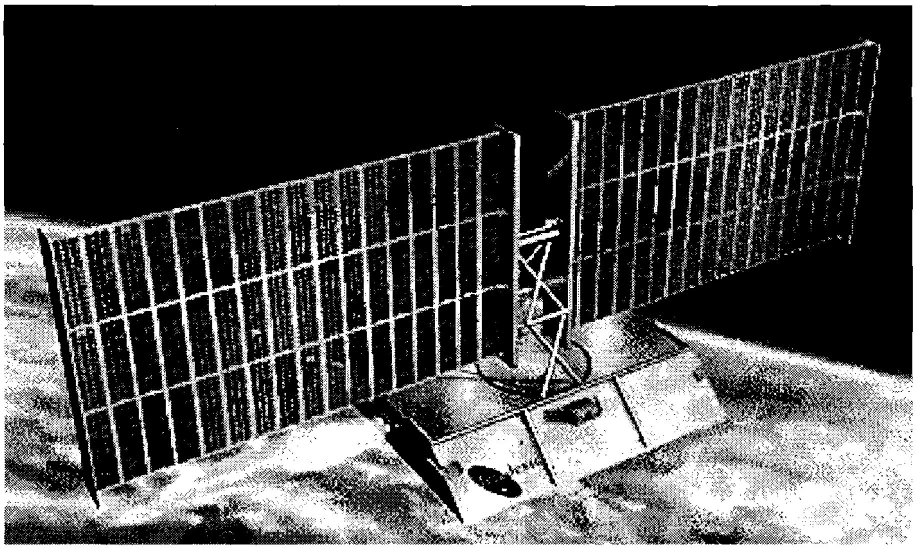

Figure 4:
The Teledesic Satellite (Source: http://www.teledesic.com/)

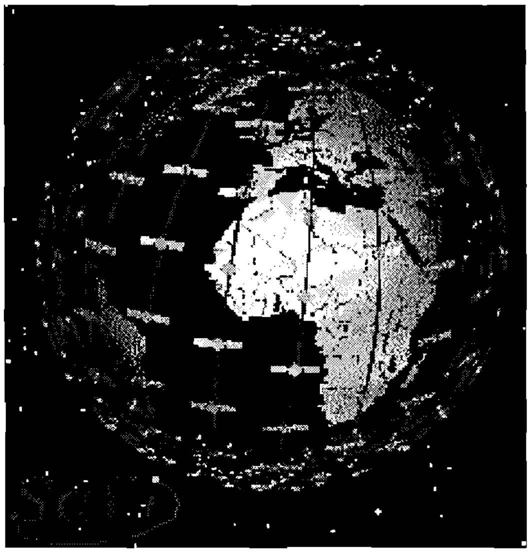

Figure 5:
A representation of the Teledesic Constellation of satellites (Source: http://www.teledesic.com/)

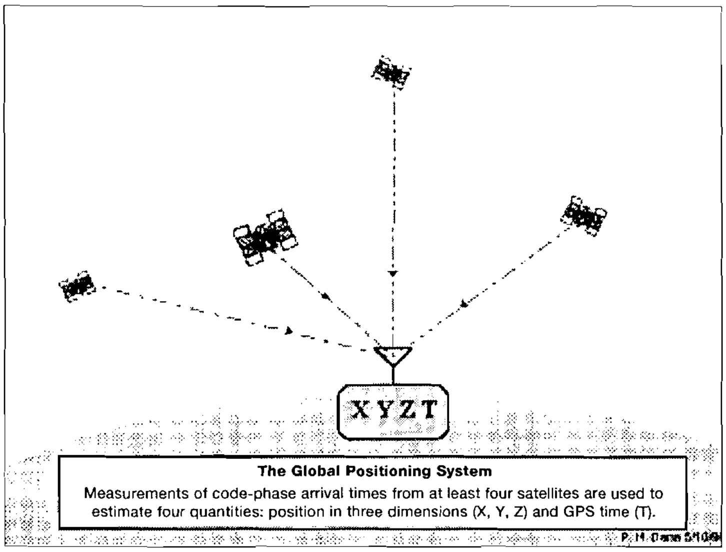

Figure 6:
A diagrammatic representation of four GPS satellites of the US Department of Defence calculating position. (Source: http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html)

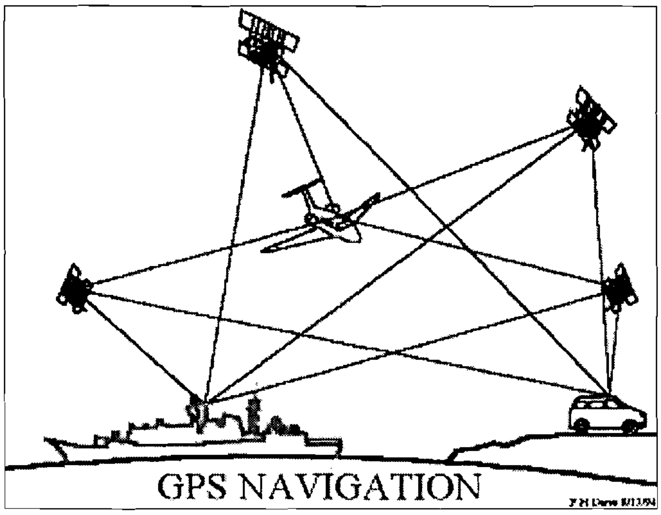

Figure 7:
A diagrammatic representation of four GPS satellites of the US Department of Defence calculating position for a naval vessel, motor vehicle and aircraft. (Source: http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html)

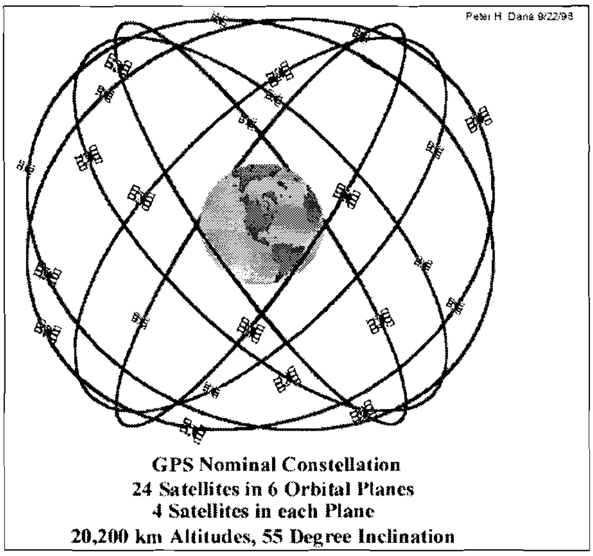

Figure 8:
The constellation of GPS satellites of the US Department of Defence. (Source: http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html)

Figure 9: A Spot colour image (Xi) on the left and associated vegetation index on the right.