Geomatics and Digital Earth

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Abstract In this paper, the conception of Geo-Spatial Information Science (Geomatics) and Digital Earth are introduced. The former is created along with the information revaluation. Vice president of America Al Gore presents the latter. The formation, basic theory and technical system of Geomatics are discussed. And the key techniques and applications of Digital Earth are also discussed. After the relationship between them is analysed, we present that National Spatial Data Infrastructure (NSDI) is the fundamental construction of Digital Earth. The development of Digital Earth brings opportunities and challenges for development of traditional surveying and mapping.

1. Geo-Spatial Information Science

Geo-Spatial Information Science (Geomatics) is a comprehensive and integrated information science and technology, which is used to acquire, measure, analysis, store, manage, display, diffuse and apply the data related to earth and spatial distribution. Global Position System (GPS), Geographic Information System (GIS), Remote Sensing (RS) and other spatial information technologies are it's main contents. Computer and communication technologies are its major technical support. Geomatics is a new developed science represented by "3S" technology including communication and computer technology. It is the foreland of earth science and the important composition of earth information science as well as the mathematics basis of the Digital Earth.

1.1 Formation of Geomatics

With the rapid development of society and economy, the global change, which is caused by human beings activities, become the focus of the people over the world. According to the history of recent centries, the affection of human beings activities to entiroment is going to the bad direction. With the speedy increasing of world population, the large amount of resouce consuming and the entironment deterioration are obvious to all people. Since the earth and its enviroment is a vast complex system, for conquering the above problems, it is a necessary to understand the earth in the view of macrocosm. While the human beings society steps into the information epoch, the research of earth science problems need to be based on information science. Furthermore, it needs to found the scientific hierarchy of earth information science via the modern information technology. Geomatics, which is the major subbranch of earth information science, will provide the mathem-atical basis, spatial information framwork and inform-ation processing method for earth science problem research.

In generally, the geo-spatial information is a sum of spatial distribution and temporal change as well as its interaction of the substance feature within every layer of earth system, which are acquired via the sensors taken in spacecraft, aircraft and car as well as terrain remote sensing. Geomatics is the frontier and cross science of information science and earth science. It has to do with the research of regional and global change. Furthermore, it is the basic section for solving the problem of social sustainable development.

With the development of Global Positioning System (GPS), Spacecraft and Aircraft Remote Sensing (RS), Geographical Information System (GIS) and Internet technology, et al, as well as their intersection and permeating, the integrated technical system of geo-spatial information is formed gradually. In the last twenty years, the composite applications of the spatial information technologies have developed much quickly. It makes that the human beings can acquire the geometrical and physical information of earth's surface and its environment rapidly and continuously, which will form the data flow and information flow of geo-spatial information, thus Geomatics is born.

Geomatics not only includes the whole contents of surveying and mapping, but also shows the intersections and permeating of multi-subjects. Especially, it much emphasises the application of computer technology. Geomatics is not limited in data collecting, it emphasises more to the whole process from data acquisition, processing, analysis, management, storing to visualisation and promulgation of geo-spatial information. These characters express that the subject of surveying and mapping will attain the intersection of

multi-subjects from a single subject. The technique of surveying and mapping has made a great progress in data acquisition from collecting the regional data via topographical surveying instruments to collecting the global data via the sensor taken by spacecraft, aircraft and car, from single type of static data to real time spatial temporal geo-spatial information. In the mean time, the composite application of spatial data and other professional data have also made a great progress, its applications will cover many fields, for instance, environmental monitoring and analyse, resource investigation and exploitation, disaster monitoring and appreciating, modern agriculture, urban development and intelligent traffic, et al.

There are two key factors in promoting the Geomatics forward. One is the technical support of quick development of spacecraft, aircraft, computer and Internet. The other is that the global change and social sustainable development have become the focus of human beings gradually. Since Geomatics is the major technical support for solving these global problems, it should be the field to be developed firstly. In detail, the theoretical frame of Geomatics is consummated step by step, the technical system of Geomatics is formed gradually, its application fields become widely further, and the industrial department is forming in global range.

1.2 Theoretical Basis of Geomatics

The core of theoretical frame of Geomatics is the geo-spatial information mechanism. It is an important theoretical support for Geomatics. Through the research of transmitting process and physical mechanism of the information among layers within the earth, it uncovers geometrical morphology and spatial distribution as well as change of the earth. The main contents include a series of basic theoretical problems such as the benchmark and standard, temporal spatial change, recognition, uncertainty, interpretation, representation and visualization, et al.

The benchmarks of geo-spatial information includes geometrical, physical and time benchmark, it is the fundament for determining the geometrical morphology and spatial distribution. The reference coordinate system is defined based on the earth's rotation, the earth's rotation vector changes in periods depending on the process of earth dynamics. On the other hand, the movement of regional crust and global block influences the surface base stations used as the reference frame. So, the links between regional reference frame and the global reference frame and the effectiveness of earth dynamics are the basic research problems of the intersection of Geomatics and earth dynamics.

- *Standards of Geo-spatial information*

Geo-spatial information has four properties, which are location property, qualitative property, relationship property and time property. The acquisition of these properties mainly depends on spacecraft and aircraft remote sensing sensors. The acquired signals by different sensor lies on the reflection and radiation rates, which are affected by complex earth's surface and atmosphere. The promise of the geo-spatial information industry is the information standardisation, which is a powerful method forcing the newly results of geo-spatial information into the productivity much quickly, and the level of standardisation will influence the economical and social benefit of these industries. The main contents include spatial data acquisition, storing and format transformation standard, spatial data quality and accuracy standard, spatial information classification and encoding standard, spatial information safety and service standard, et al.

- *Temporal Spatial Changes of Geo-Spatial Information*

Earth and its environmental is a vast temporal spatial changing system, one property of it is that temporal spatial scale may change in more than ten grades for these phenomenon evolved and changed in temporal spatial scale. The research of spatial temporal theory of geo-spatial information will uncover following two aspects. One is the research of the rules and properties of temporal spatial changes, and to describe them formally, at last these works will form the theoretical foundation of Geomatics. Thus, it makes the earth science from static description of spatial feature to multi-dimensional and dynamic description and analysis of the process. On the other hand, the composite of different spatial and temporal scale would solve the link, share, integration and change monitoring for different earth science applications.

- *Recognition of Geo-Spatial Information*

The geo-spatial information is saved at the interacted and related elements of the earth, which divided into different layers. The location, morphology, organising, arrangement, distribution, relationship and restriction relation for each element may be recognized. By the morphology analysis in static state, reason analysis in appearance, process analysis in dynamic state, mechanics analysis in evolvement and simulation analysis in time series, the recognition and reasoning of earth morphology can be made, thus, the earth space can be

recognized well.

- *Uncertainty of Geo-Spatial Information*

Due to the geo-spatial information is an abstract and appropriate description of earth phenomenon based on the measurement, there is uncertainty, of course. Also the uncertainty will change with the change of time. It makes the management of geo-spatial information much difficult and complex. In the mean time, these errors will affect the results of information processing and analyzing. The contents of spatial information uncertainty include uncertainty of location, uncertainty of spatial relationship, uncertainty of time field, logical unconsistence and data unintegrality, etal.

- *Interpretation and Inversion of Geo-Spatial Information*

Via the qualitative interpreting and quantitative inversion of geo-spatial information, the present statue and rule of spatial temporal change will be uncovered. From the phenomenon to the nature, to answer the earth science faced important questions such as resources, environment, disaster, is the final goal of Geomatics. The interpreting and inversion of geo-spatial information will involve wide earth's subjects.

- *Representation and Visualisation of Geo-Spatial Information*

Because the geo-spatial information is stored in the computer in digital format, for using and understanding the information better, it is necessary to research the representation and visualisation of information. It mainly involves multi scales representation in spatial database, digital map auto-generalization, graphic visualisation, dynamic analogy and virtual reality.

1.3 Technical System of Geomatics

The technical system of Geomatics is a sum of techniques and methods from spatial data acquisition, processing, management, analyzing, representation, transmission, to application, it is the technical support to implement the functions from data collecting to application. And it can also meet the needs of the human beings in the fields such as automation, uptodate, detail and reliability. The technical system of Geomatics is an important component of Geomatics, its foundation depends on the development of basic theory and related technique of Geomatics, they can include the following parts:

- *Global Positioning System (GPS)*

GPS is a modern positioning method, which has substituted the original optical and electrical measurement instruments in many fields gradually. Since 1980, especially after 1990, the integration of navigation and modern communication technique brings out the revolution in positioning technique. The three dimensional coordinates determination via GPS has extended from land and near sea to whole sea and out space, from static state to dynamic state, from single point to regional or wide DGPS, from post-processing to real time positioning and navigation. The absolute and relative positioning precision is extended from meter to 0.001 meter. Thus, the application fields have widely extended.

- *Remote Sensing (RS)*

The development of remote sensing mainly is expressed in multi-sensors, high resolution and multi-tenses. The 1.0 to 3.0 meters RS systems have been developed in foreign countries. Russia sells the 2.0 meters resolution spying satellite image in public, which was been kept secret by military. In the field of image processing, the intelligent expert system has been started to use. The RS information application has been researched from single image analysis to composite analysis of multi-tenses and multi data sources, from static analysis to dynamic monitoring, from qualitative investigation to computer aid quantitative mapping for resource and environment. In recent years, due to the mobility and high resolution of aircraft RS, it becomes an important developing aspect of RS.

- *Geographical Information System (GIS)*

With the proposing of the Digital Earth, the human being's knowledge on it has deepen gradually. It is a major direction from 2D GIS to multi dimensional and dynamic GIS as well as Web GIS for geographic information system, this is also the needs of GIS theoretical development and many applications such as resources, environment, urban, etc. In the aspect of technique, one direction is to develop Client/Server structure, that is to say, the users can get the data and program from the server. The other direction is to develop the Internet GIS or Web GIS, which can realize the far distance finding for various spatial data including image and graphics, and implement the composite analysis among these data. This makes even more link between GIS and information highway via modern communication technology.

- *Data Communication*

The data communication technology is the important fundament of modern information

technology. In some extent, the development of geo-spatial information technology depends on the development of modern communication technology. During the development process of GPS, RS and GIS, the high speed, huge storage, and high reliability data communication is necessary. Now, the communication technology is developing very quickly, especially in some new fields such as the wide-band web, multimedia communication, satellite communication. This creates a wonderful environment for the development and application of the data communication technology.

2. The Digital Earth

The Digital Earth is described by vice president of America Al Gore in his report "Digital Earth-----Understanding our planet in the 21st Century" in detail. It is understood as a united digital reconstruction and recognition of real earth and its related phenomena. The kernel of it is to process the natural and social problems related to whole earth by use of digital method, to make good use of resource, and to make that people could get their required information about earth through certain methods. The characteristics of the Digital Earth are vast geograhic data, multi resolution and three-dimensional description. In generally it is vitural earth.

2.1 Key Technology of the Digital Earth

The key techniques of the Digital Earth presented in Al Gore's report are computational science, vast storage, high resolution satellite image, broadband networks, interoprability and metadata, which can be summarised in follow four points:

- *High Resolution Satellite Image*

Now, in the researching and launching of high-resolution remote sensing satellite, there are drastic competitions among worldly countries. Lots of developed and developing countries such as America, French, India, et al, invest large amount of money and person. The 1.0 meter resolution satellite image will be the highest resolution peaceful using earth image obtained by human beings, which is satisfy the requirements of different applications including larger than 1 to 10 thousand scale mapping, agriculture, natural resource, environment, traffic, military, etc. It is the basic spatial data for creating Digital Earth and the framework and carrier of non-spatial data, which forms the spatial positioning of the Digital Earth. The related spatial information acquiring methods are radar satellite technique, small satellite technique, and satellite, aircraft and terrain base integrated data acquiring system as well as data processing techniques.

- *Broadband Networks and Data Standards*

A large amount data of the Digital Earth distribute in different databases over the world, which is maintained by different organisations. These data should be connected by high-speed network such as ATM technique. The next generation Internet with 10^{15} information unit may realize rapid transformation of the variety of vast data including image. At the same time, the united data transformation standards are the important basses for the Digital Earth implementation. Otherwise, the interoprability and transformation among different databases could not be realized.

- *Spatial Information Technology and SDI*

Spatial data is defined as those data describing phenomena directly or indirectly associated with a location and time relative to the surface of the Earth. The Spatial Data Infrastructure (SDI) is critical to the attainment of sustainable development in both the developed and developing countries of the world. SDI encompasses the policies, technologies, standards and human resources necessary for the effective collection, management, access, delivery and utilization of spatial data.

- *Science Computation*

Science computation enable us break through the limitation of experiment and theoretic science, the modelling and simulation abilities enable the more thorough exploring of all collected data about the planet.

- *Vast Storage and Metadata*

Due to the requirement of storage for more than 10^{15} byte information in the Digital Earth, vast storage ability is the basic condition for the Digital Earth implementation. The continuous development of various data compress techniques for different data types such as image, multimedia, made possible for rapid moving of vast digital image in network. Also, with the development of laser technology, the storage space of medium is increased in times. On the other hand, in order to find the needed data in vast data rapidly, the creating of metadata is necessary, which is data about data. Throught these data, the name, position, attribute and other information about data could be understood, thus, the time for finding needed data is reduced.

- *Virtual Reality Technique*

Virtual reality technique is an important technical

method for the Digital Earth implementation. A realistic equal sensing world with seeing, hearing, feeling and tasting is generated in computer. Users may make observation and manipulation to this virtual entity directly by use of his ability and wisdom. On the other hand, it is a user interface, in which users can not only observe data but also interact with data. And, this observation has the spatial property from inside to outside or from outside to inside. Comparing with visualisation calculation, there are much difference, in which just from outside to inside observation can be permitted.

Virtual reality modelling language (VRML) is web and object oriented three-dimensional modelling language, which is also an explain language. It not only supports three-dimensional representation of the data and process, but also makes the users coming into the virtual world with realistic seeing and hearing. Furthermore, the representation of the Digital Earth is implemented, and through the Digital Earth variety of earth phenomena researching and human daily applications are realized.

2.2 Applications of the Digital Earth

Within human beings contacting information, 80 percent has to do with position and spatial distribution. Geo-spatial information is the car and goods in information highway. The Digital Earth includes not only high-resolution satellite image of the earth but also digital map, economic, social and demographic information. The applications of it are as vice president Al Gore say “limited only by our imagination”. In other words, the applications of the Digital Earth will go beyond our imagination. Here are some real applications depending on our understanding.

- *Global Change and Sustainable Deve-lopment*

Global change and sustainable development have become the important issue for the people all over the world. The digital representation of the earth provides the useful condition for these problems researching. The process, rule, affection and countermeasure of global change can be simulated and emulated in computer by using the Digital Earth, and the ability of human beings dealing with global change can be improved. The Digital Earth may be widely applied in the researches of global climate change, sea level change, hungriness, zoology and environment change, land use change monitoring. Furthermore, the problems related to society sustainable development could be analysed and predicted by using the Digital Earth such as natural resource and economy, population and society development, reducing and preventing natural disasters, etc.

China is a developing country with large population, limited land resource, lots natural disasters. The feeding of more than one billion persons is very important issue. After twenty years high-speed development, the contradiction between resource and environment is much more serious. Flood in 1998, flow stopping in Yellow river, plowland reducing and hungriness increasing have caused more and more attention of the society. The efficient measures must be taken in order to increase the monitoring and protecting of land and water resource, and the monitoring, predicting and preventing of the natural disasters, especially flood. Avoiding the road that the third world countries and some developed countries walked, the Digital Earth can make a good use in these aspects.

- *Applications in Politics, Economy and Military*

The Digital Earth has wide applications in the present world’s politics, economy and military. For example, the digital earth could be used for solving the disputes among the countries such as boundary determination. The Digital Earth could be used for keeping the society stability and fighting crime such as analysing the modes of crime, rate of crime and police assignment et al via the GIS. Through the integration of GIS and GPS, the attempering and directing of police car is implemented, as well as tracking and defending of the important cars. The Digital Earth could be used for predicting the natural disaster and conducting reconstruction after the disaster such as predicting and conducting in earthquake. The Digital Earth could be used for the urban and rural area planning such as the design of the scope and functions of the urban, land use monitoring. The Digital Earth could be used for improving the productivity of the agriculture and industry such as conducting the prevention of the worm disaster and field works in the farm via the RS image and GPS. Especially, the Digital Earth is very useful for the development of the world information industry, it is a basic carrier for storing the information in the Internet. All types of the information related to social departments should be put on the Digital Earth, this will form more than ten billion U.S. dollar newly economic rising in the world. And it will produce very large influence in world further politics, economy and military.

In the economy globalisation age, the spatial distribution, dynamic change and reasonable layout of work force, capital, production and market are significance. Through the government action for the Digital Earth to improve the economy information forming procedure, it is much favourable for our socialism market economy forming and developing.

The Digital Earth is the continuation and development of “Global War” at the late cold war age. It also is the continuation of America’s global strategy. It is the new generation of the electronic map and geographical information system, which is obvious to have a great value in the military, this is proved in the war between Iraq and America, and the war in Yugoslavia in recent. Especially, since the Digital Earth is a peace and war combined, military and civil combined systematic engineering, the construction of national Digital Earth project is suitable for the direction of our national defence.

3. Relationship Between Geomatics And Digital Earth

The Digital Earth is not only a new conception but also a complex systematic engineering. Nevertheless, most of its concerning theories, technologies and applications directly connect with the current technical works. It is a systematic point of view from higher level in integrating and applying existing and developing theory, technique, data and capacity. It serves the society in a way of more extensity, density, efficiency and economy. The clarity of the relationship between the Digital Earth and current theory, technique and application in earth science is helpful for reading the Digital Earth in depth and grasping the direction and aim of earth science.

3.1 Geomatics is the Mathematical Foundation of Digital Earth

In the Digital Earth, the globe is described in digitized format. Spatial information dominates the whole data set. The problems investigated in Geomatics like spatial information benchmarks, standards, spatial-temporal changes and uncertainties comprise the most fundamental theories about geo-spatial information, which however is also the basic theory of the Digital Earth. The ultimate realization of the Digital Earth depends on the breakthrough of some theoretical problems and their perfection. Examples are the definition of the earth shape in the Digital Earth, the establishment of the geometric benchmark and geometrical transformation as well as projection of the Digital Earth, the formation of the exchange standards of various data, the definition and description of the spatial-temporal evolvement of natural phenomenon, and the description of uncertainties and its propagation, etc.

3.2 Geomatics is the Spatial Information Framework of Digital Earth

In the Digital Earth, various types of complex information about society, economy and culture etc. are indexed and organised by spatial information. The spatial information is the carrier of other types of information. The organisation mechanism and management scheme of spatial information investigated in Geomatics proposes a robust spatial information framework for the construction of the Digital Earth. Digital Geo-Spatial Data Framework is the kernel of Spatial Data Infrastructure (SDI). It contains the most fundamental spatial data set including digital orthogonal image, digital elevation model, road system, water system, administrative boundaries, public cadastry and labels of place name etc. This spatial data framework provides not only the most fundamental and public data set for the researching and observation of the real earth and geographic analysis, but also a geographic coordinate reference for the users of the Digital Earth to append information relevant to spatial position. Thus we can locate, organise, integrate and adopt various data of more than one temporal and spatial scale in the Digital Earth efficiently.

3.3 Geomatics Offers Technical Support to Digital Earth

The technologies of "3S" and communication, which comprise the technical system of Geomatics, are the most important measure to acquire, handle, analysis, represent and transmit spatial and non-spatial information of the earth surface and nearby space. The continuous improvement of these technologies guarantees the construction of the Digital Earth. The researching and launching of high resolution remote sensing satellite and the techniques of spatial data collecting, processing and analysis with satellite, aircraft and terrain base integrated ensure the real time update and extraction of geo-spatial information. The development of distributed spatial database technique offers an efficient way to manage video and image data of huge volume with spatial data. Particularly the object-oriented technique enables the spatial database with ability of constructing and describing complex object. Almost all real-world complex entities can be expressed as object that reduce the I/O visiting and improve operation efficiency. The spatial dataware and data mining techniques assemble the data from different databases, with different spatial and temporal scales according to certain subject, and mine the knowledge users required. Thus to realize the unification of data oriented and analysis oriented analysis. The Web GIS technique develops from single computer to Client/Server structure, then to Browser/Server structure indicates the new generation of Web GIS. It offers the convenience for geo-spatial information querying and application

at Internet. The development of virtual reality technique and its application in geo-spatial information representation create condition for ordinary person's operation, which transfers the abstract data to visible, operable, and satisfies the vary requirements.

4. NSDI is Fundamental Construction of the Digital Earth

The National Spatial Data Infrastructure (NSDI) was first put forward by the U.S. government in the title of President Executive Order in 1994. It is a national spatial data framework built for geographic reference in National Information Infrastructure (NII) (also called information highway). It makes that we can precisely express, describe and query spatial data concerning geography and earth position in Internet.

NSDI is a part of National Information Infrastructure. It is the bridge between information highway and the Digital Earth. NSDI principally involves spatial data harmonising, mechanism and institution of managing and distributing spatial data, spatial data clearing house, spatial data exchange standards and geo-spatial data framework. Spatial data infrastructure has great much to do with the Digital Earth. On the one hand, spatial data infrastructure including spatial data framework, is the most basic part of the Digital Earth, on the other hand, the connotation of the Digital Earth has far exceeded the contents of spatial data infrastructure. What's more, the key techniques of the Digital Earth also play key role in NSDI. That is the reason why we deem that the Digital Earth is a comprehensive conception based on information highway and relied on spatial data infrastructure.

Spatial data infrastructure contains only the framework of geo-spatial data produced by specialised departments. Though they might be utilised extensively, its capacity is definite. The Digital Earth is an open system. Citizens of the Digital Earth, including industry departments, enterprises, farms, stores, banks, education units, government sections, and even natural persons, are allowed to enrich it by arbitrarily appending information of themselves. It is a full-functional approach and an all-new way of contacting and connecting with others of the world. All the citizens are information provider and information receptor on his will. All behaviours other than concrete contact, we may refer as digital behaviour, can be implemented via Digital Earth. Real estate companies may emigrate to the Digital Earth by posting its information about building structure, surrounding environment, virtual furniture etc. into Internet. Touring companies join to the Digital Earth with textual, visual and aural information about hotel, resort spot and route plan. Even a virtual reality is built for the client to take a trying tour before the real journey. Readers are no longer needed to enter the library to borrow and return books. Museums, libraries and all other information provider serve for the client by the Digital Earth. But all these behaviours are carried out on the aid of spatial data infrastructure, that is to say, spatial data infrastructure is a pre-requisite construction of Digital Earth.

5. Conclusions

The Digital Earth is the necessity of global information procedure. It is long term strategic object, and will implemented by all human beings in great efforts. At the same time, the construction and development of the Digital Earth will expedite the step of global informing procedure, change people's life style in great extent, create much large social fortune, and make huge contribution for the development of human beings society.

Geomatics, which is as the theory and technology foundation of the Digital Earth, will get speedy development. On the one hand, the researching and construction of the Digital Earth will create suitable condition for the development of Geomatics. On the other hand, the development of Geomatics will supply the support in theory and technology for the Digital Earth construction.

There are a lot of excellent results in the fields of Geomatics after the long time great efforts in China, a group of famous scholars and mid-young academic cadremen are bring up. They make great contribution to the subject. But we must in consciousness, due to the large gap at sensor, computer, communication and comprehensive national power between developed countries and us. We will trail the international level in some aspects of information science for a long time. Therefore, we should play the advantages of ourselves and make great efforts to short this gap, make contribution for national economic construction and society development.

Finally, we will point out that Geomatics includes whole contents of modern surveying and mapping science. The scientists of surveying and mapping should take the flag of Geomatics and march into 21th century information society, make great efforts on the construction of the Digital Earth and the Digital China, make contribution in the development of information society at knowledge economy epoch.

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