4D Geo-referenced Database Approach for GIS

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SUMMARY

Since developments of computerised information systems practically used in the market, many things has been swiftly and progressively changed in surveying profession; because the volubility of the positioning/spatial information has been well understood by the other professions who deal with the information systems. In fact, at the beginning, information systems have been developed without any spatial information of the other information. However in a short time system developers have been realised that information integrated with its geospatial information provide precise results for strategy developments and decision making. That was also the demands of the systems' users. This is truth that in that case it is possible to support query results with graphical visualisation geographically. Therefore information systems have been began integrating with maps and hence applications of Geographic Information Systems have been started.

As is very well known that position information can be in different forms; two, three or four might be five dimensions (D). Nowadays most geographic information systems are integrated with 2D maps and the third dimension is integrated as their attribute information. However the latest generation of GIS systems are designed using 3D geospatial infrastructure and the fourth dimension is used as attribute information. In fact, in close future 4D geospatial infrastructure will directly take the place of the pervious/current systems. Since geospatial information are changing by time due to the natural motion of the earth, tectonics, landslides and etc. This is the nature. Therefore all connected information to the geospatial information is also changing by time. As a results new demands soon will indicate, might have already been, the GIS supported with 4D geospatial infrastructure. Since the geospatial data are collected in an instant of time in 3D. This 3D geospatial information is digitally frizzed in that instant. In fact it is not frizzed; from the time it has been collected it starts changing the location. Therefore GIS systems should be sensible for such changes to provide query results for the time of query made. In other words the query results should geometrically/graphically be visualised for the time that query indicates. Therefore in 4D GIS, geospatial infrastructure should be supported with a geospatial model that has parameters changing by time.

In this paper necessity of 4D geo-referenced databases for GIS is emphasized. Thereafter the designing approach of such geo-database will be explained and discussed. Finally all over vision of 4D geo-databases for GIS is explained on sample problems and discussed.

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1. COMPONENTS OF GIS

As is well known the technology of Geographic Information Systems (GIS) is not very old. However the use of GIS without its technology is very old since it is part of human nature. All intelligences have self-system that handles all type of information for decision making to remain their life. Therefore the technological GIS might be the prototype of these individual intelligence systems.

Today, when Geographical Information Systems is concerned following five main components are considered.

Hardware	: Where GIS software is run
Software	: The hardware and data is controlled, organized and used
Data	: Without it no GIS is concerned, since it makes GIS meaningful
People	: Why GIS for? Creator, builders and users
Method	: Way of using and benefiting from data

Certainly each of these components is individually very important. However, among these five the most important component is the data component regarding the concept of this paper. Since the sprit of GIS is directly depends on data availability, manageability and quality. The most important data of GIS is base maps, since they make the information systems geospatial. In other words they provide geospatial characteristic to information systems. All other information placed into the system is directly or indirectly related with geospatial information that comes or integrated with these base maps.

Base maps come from several different sources such as digital maps, digitized paper maps, rectified and oriented remote sensing images, etc. In other words base maps integration makes Information Systems to Geographical Information Systems and geodetic infrastructure pins base maps onto the earth surface. The topology of mapping process of these base maps is not really taken care of and used within GI Systems. Mainly topology of all other information are formed based on graphical information appeared on these maps; but in fact graphical information on these maps has its own topology regarding way of mapping process that might be very beneficial for decision making for some queries. In order to explain the meaning of topology of mapping process, brief paragraphs as a reminder have been prepared in sections 2 and 4.

While over viewing of GIS components, emphasizing on overall geospatial structure of GIS might also be beneficial. In order to establish a GIS, firstly reliable geodetic infrastructure, which has integration with global geodetic infrastructure, has to exist. Moreover, base maps based on this geodetic infrastructure have to be available. Thereafter Land Information Systems, Urban Information Systems and Specific Geographical Information Systems should be considered respectively, see Fig. 1 (Celik et al, 2003). They might all individually be called as GIS. However the best is to have all these in this order since in fact one can carry the other. If a country or a group of country has such systems in this order, it can manage and generate most efficient solution to almost all kind of problems and serve its citizen in most efficient way. There are surely more to say about establishing such systems such as way of providing online geospatial data to GIS users; however this does not directly touch on the topic of this paper.

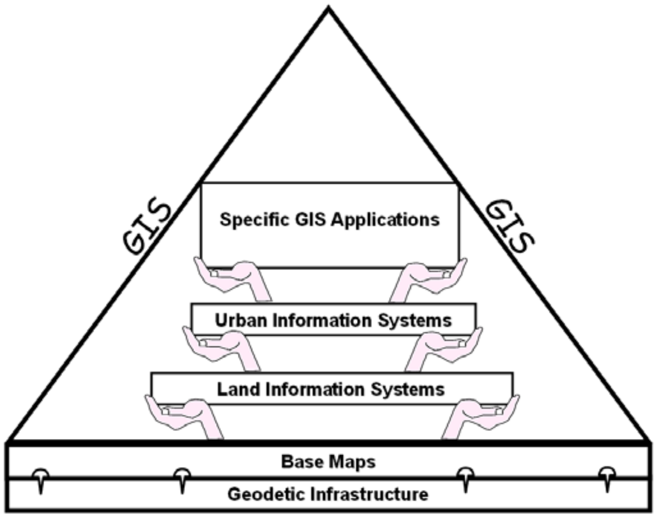

Figure 1: Structure of GIS concept

2. HOW TO PRODUCE MAPS

There are several techniques to produce maps, conventional, GPS, photogrammetric, remote sensing and etc. Whatever the techniques are used the common point is to use geodetic control stations and networks; in other words is to establish a geodetic infrastructure.

As is well known by the Geomatics Engineers, before starting map making a geodetic control network is established. In fact, almost all over the world a higher order geodetic network generally exists in national, international or both levels. Therefore the fist step is usually to condense the geodetic control network to establish a geodetic infrastructure for mapping process. Condensing process remains until comfortable detail survey is to be carried out by using any type of geodetic equipments. The main goal is to achieve sufficient and reliable results for detail survey. Since the results of detail survey provides the measurable picture of present status of mapping field. Having produced maps, in most cases especially for the other professions, the existence of control networks is not very important until the staking out survey is necessary.

However location or coordinates of all detail points surveyed directly depend on the control stations and hence the network. This means that in any instance of time if the physical location of control station is changed by the impact of any natural effects such as earthquake, crustal movements or landslides the locations of detail points might also changed. The geometrical relations between detail points and control stations and networks in any order are called as topology of mapping process in this paper. Therefore if the topology of mapping process is taken care of within the GI Systems foreword prediction and backward analysis by time might be made for decision making. Since, to use of topology of mapping process makes base maps dynamic by time.

Unfortunately, in today's technology base maps are used as stable geospatial information provider rather then dynamic geospatial information provider; however they might be used as dynamic geospatial information providers if the topology of mapping process is taken care of, and hence more beneficial query for future and past might be carried out for better and smart decision making process.

3. EVERYTHING IS MOVING WITH EARTH BY TIME

Finding a fix point somewhere in space would make the things much easier for Geomatics Engineers; but unfortunately nothing stable and furthermore everything is moving. The only way of having a fix point in space might be frozen the time and defining the location of point for that instant of time.

Due to the dynamics of earth all objects on and in the earth is moving. Moreover tectonic activities cause partial movements on earth. The continents that are the large areas are moving towards each other. Hence their activities cause also changes in smaller areas. These changes might suddenly or gradually be occurred due to earthquake or self-movements of faults by time respectively. Geomatics Engineers establish control stations on surface of the earth for making maps. Therefore the locations of these control stations also change regarding these actives.

Especially, by means of space based techniques global, regional and local movements of earth can continuously be determined and hence monitored. These researches are mainly carried out by the aid of international cooperative work of earth sciences and specifically by the science of geodesy. This is a grate advantages that the distortion and deformation of geodetic network can be determined by time. For instance International GPS Services (IGS) has many permanent Continuously Operating GPS Reference (CORS) stations to monitor such activities on earth (Anonym, 2004a). Additionally such scientific works have been turned to international cooperative activities, and as a result global geodetic frames are formed such as International Terrestrial Reference Frame (ITRF) and European Reference Frame (EUREF). Beside scientific activities most countries' geodetic control networks are also established part of these global networks. This is also another great advantage since effects of tectonic movements might be eliminated, minimized or taken care of by developing a mathematical model in small areas.

These demands occur due to the force of globalization request. The best tool is global and reliable geodetic infrastructure existence to establish an efficient GIS. Since fast, compatible and reliable information circulation is heavily requested in global level. In that case geodetic reference system used in different countries must be unique or transformable to unique geodetic reference system in global level for geospatial data compatibility.

Generally developed countries whose national geodetic control networks integrated with the global network periodically observe their national geodetic networks to obtain coordinate differences at national control stations by time. Thereafter velocity of each component of coordinates of geodetic control stations is computed using coordinate differences. Today, these are mainly used for updating maps and in scientific researches. However these might also be used to produce dynamic base maps or in other words digital base maps that can be queried by time for GIS applications. Way of using this aspect is explained in section 4.

4. WHY 4D GEO-REFERENCED DATABASE DESIGN IS NEEDED?

Most GIS applications are currently considered as 2D. The third dimension also exists in the system; but it is not part of coordinates, it is an attribute of objects as graphics that are constituted by group of coordinates. This is certainly beneficial for 3D query, analysis and decision making; however this is indirect benefit of 3^{rd} dimension. Nowadays, when 4D is concern temporal GIS comes up as the topic; since, in that case, the 4^{th} dimension is time. However temporal GIS mainly focus on changes of semantic data by time (Wachowicz, 1999). This might be explained with some examples. For instance, to monitor decreasing of number of buildings for seeing improvements of a settlement within a region or changes geometry of cadastral parcels due to cadastral applications or changes of road geometry due to reconstructions and so on.

The concept of this paper is different than these applications. The concept is here; changes of base maps geometry by means of natural dynamics of the earth. Today these changes are not integrated to GIS, they mostly are omitted. However if the topology of mapping process is used or functioned, in other words if dynamic base maps are used, much more realistic query and analysis might be made and hence better decision making process might be carried out. Since in that case changes of topography and changes of objects exist on the topography might be monitored within the GI System. This is meaningful especially for the countries whose lands are under the effects of tectonic activities, landslides, tides and etc. because in that case these changes might be monitored in forewords and backwards of time. For instance Turkey is an earthquake country whose 92% of lands are under the effects of tectonic activities. Position of control stations, which are especially located on opposite sides of the faults, changes almost 2 cm per year (Anonym, 2002). This means that geometry of detail points observed based on these control stations to produce base maps naturally changes. These physical changes might be reflected to base maps, since the information of location changes of control stations is available as velocity of coordinate changes from the national geodetic control survey.

This situation might be handled as follows. As is previously mentioned, coordinates of all detail points on base maps are produced based on control stations that are varies in several different types and orders; in any case coordinates of lower order control stations is always produced based on higher order ones. Therefore any coordinate changes of higher order control stations will cause coordinate changes on lower order control stations and hence on detail points.

Assume that in the database of a GI System all available coordinate and coordinate velocity information of various order control stations Eq. (1) are stored,

$$X_o, Y_o, Z_o, v_x, v_y, v_z \qquad (1)$$

Additional to this information topology of mapping process must be kept in the system to reproduce base maps for the time that query is carried out. In fact the beginning time (t_o), which indicates the time of coordinates (X_o, Y_o, Z_o), must be known by the system. The time t_o is generally indicated within the system as part of datum information such as ITRF96. The 96 is there the time (epoch) of the geodetic datum. If this information is available in the system when a query is made for any instant of time (such as for time t_i) base maps might be prepared to view current status of the working field regarding the positional changes and topology of mapping process. In that case, for instance, the coordinates given in Eq. (1) are turn to Eq. (2) for the case of linear velocity relationship existence.

$$X_i = X_o + (t_i\text{-}t_o)\ v_x\ ; \qquad Y_i = Y_o + (t_i\text{-}t_o)\ v_y\ ; \qquad Z_i = Z_o + (t_i\text{-}t_o)\ v_z \qquad (2)$$

However nonlinear velocity case might also exist. In that case velocity should be used as a function of time differences, hence the coordinates given in Eq. (1) are turn to Eq. (3)

$$X_i = X_o + (t_i\text{-}t_o)\ Fv_x(\Delta t); \quad Y_i = Y_o + (t_i\text{-}t_o)\ Fv_y(\Delta t); \quad Z_i = Z_o + (t_i\text{-}t_o)\ Fv_z(\Delta t) \qquad (3)$$

The other case might be velocity model that is valid for the working field. In that case the new position of any control stations and detail points might be generated using this model for the working field and hence base maps are reproduced with these generated coordinates at the time of query process carried out.

In order to realize such applications within GI Systems database might be designed to fit the requirements. In fact the main issue is here to design a geo-referenced database that means the coordinates and velocities are the fundamental components of the database. Moreover base maps might exist in the system with its topology of mapping process. In other words advantages of dynamic digital maps existence should be taken. Therefore database architecture should be designed and then established to realize such process.

5. DISCUSSIONS

This approach looks has a very simple algorithm. In fact it is not. Since the dynamics of the earth is not simple, not linear and not easily understandable. However in close future demands from GI systems will appear on similar approach. Database design architecture of Oracle 10g version has realized a part of this crucial step (Anonym, 2004b). GI Systems develop with a great acceleration every day and sooner or later these systems will turn to artificial intelligence. In that case these systems will response such requirements of users, such as he/she would like to buy a land on coast of Bodrum/Turkey. What will the land status be in 50 or 100 years time? Will the land be covered by sea or coast line will move several hundred meters away from the land he/she buys? There might be much more crucial problem, for instance he/she needs to decide to change of using land in different type such as for improving the city. What will it be in far future on this land? Nowadays, there might be several different way of sorting out such problem; but one of them is not querying a GI System; however in close future the answer of these questions will be requested from GI Systems. The answers of these questions lie under the use of dynamic digital base map for GI Systems. Therefore way of using dynamic digital base maps should be considered and hence database design should be developed for implementing 4D geo-referenced data base and the topology of mapping process. Moreover, in order to develop much realistic positional velocity functions CORS networks should be condensed and periodical geodetic survey should be carried out in national and international geodetic networks.

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BIOGRAPHICAL NOTES

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