CONTINENT-WIDE HIGH ACCURACY GPS NETWORK (C-HAGNET): A Backbone For 21st Century Geoinfomation For All

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ABSTRACT

Geodesy in the history of science is one of the oldest. It has a noble tradition in the development of the classical physical science. Great names like Gauss, Laplace, Bessel, Newton, and Euler have left their mark on science through their studies of geodesy. Geodesy has both scientific and practical objectives: the scientific aim of geodesy is the determination of the figure of the earth through its size and shape. The practical objective of geodesy on the other hand is based on the findings of physical geodesy to perform all necessary measurements and calculations which are required to determine locations of various geometric configurations on the surface of the earth together with some way of representing the results of these calculations on a flat piece of paper which we call a "map"; these maps now can be produced or converted into a digital form which we refer to as a "Geographic Information System (GIS) Basemap". The exact nature of the earth's shape and rotation has fascinated many great scientists, and this fascination pushed many scientists towards space technology. As a result, we have many imaging and positioning space programs today.

In the last thirty years or so, the advancements in space technology and computer facilities have made tremendous impact on geodesy and mapping sciences. For example, Very Long Baseline Intereferometry (VLBI), Lunar Laser Ranging (LLR), Landsat, SPOT, Doppler, Global Navigational Satellite System, GLONASS:Russian GPS, and NAVSTAR Global Position System (GPS) programs (just to name a few) have revolutionized our thinking and ability to capture information about the earth. GPS has revolutionized geodesy and mapping techniques in terms of accuracy and efficiency ; for example, the relative accuracy and efficiency of GPS techniques are about ten thousand, and six times respectively compared to the conventional surveying techniques. Although, GPS has made tremendous progress in terms of relative accuracy achievements, technology transfer has been very slow. Technology transfer to the developing countries has also been impeded by the high cost of GPS receivers and lack of proper training.

This paper will discuss the disadvantages of not having C-HAGNET for the future information for all. Additionally, this paper will discuss the benefits of the networks if established. For those continents where the high accuracy reference network is not available, this paper can be used as a guide for the establishment of high accuracy reference networks.

The resolution of the remote sensing satellites has come down to a meter level; if the C-HAGNET is designed properly, all the developing countries can have one meter resolution image maps within a short span of time. This will not only expedite the development work but truly provide geoinformation for all. This kind of project should be performed under the guidance of the United Nations.

1 INTRODUCTION

GPS has revolutionized geodesy and mapping techniques in terms of accuracy and efficiency (for example, the relative accuracy and efficiency of GPS techniques are about ten thousand, and six times respectively compared to the conventional surveying techniques). Table 1 gives the present day relative positioning accuracy standards for the GPS, notice that a highest order of geodetic network was class 1 or (C) a decade ago order B or better was not possible using the conventional surveying techniques.

Table 1: Geometric Relative Positioning Accuracy Standards by FGCC

Order	Base Error Mm	Parts per million (ppm)	Ratio (1:a)	Maximum allowable error for 200 km base line	Remarks
1 (or C)	**10**	**10**	**1:100,000**	**201.0 cm**	**Maximum accuracy obtainable by the conventional techniques**
B	8	1	1:1,000,000	20.8 cm	
A	5	0.1	1 :10,000,000	2.5 cm	
AA	3	0.01	1:100,000,000	0.5 cm	

Although, GPS has made tremendous progress in terms of relative accuracy achievements, technology transfer has been very slow. Technology transfer to the developing countries has also been impeded by the high cost of GPS receivers and lack of proper training.

Other geodetic and GIS problems facing nations due to lack of a common reference system, or continent-wide high accuracy reference networks (C-HAGNETS) can be listed as follows:

(a) INTEGRATION PROBLEMS

If densification efforts employing GPS surveys is pursued, the integration of "new" GPS data with "old" traditional survey data (Order 1) becomes a difficult problem at best.

(b) ACCURACY

When performing GPS surveys, one must consider that by definition, known control points should be one order of accuracy better than the method used to perform the survey.

GPS surveys are easily capable of providing relative accuracy at 0.1 ppm in differential mode. However, in differential GPS surveys, the coordinate system and the absolute accuracy of the base or known station/stations will determine the absolute accuracy of the new stations.

In the absence of high accuracy reference network (i.e., lack of existing high accuracy control stations), the accuracy achievable by GPS can not be utilized in the countries in Africa, Asia, South America, and Eastern Europe.

(c) EFFICIENCY

When employed properly, GPS can essentially replace expensive and inefficient conventional methods of ground control establishment.

(d) COST EFFECTIVENESS

Geodetic control points serve as "back bone" for all maps produced by conventional, photogrammetric, or remote sensing methods. Traditional field surveying constitutes about 30% of the total cost of mapping and engineering projects. When GPS techniques are employed, this cost can be reduced to 10%, but it becomes imperative to have known control points that are at least one magnitude better in accuracy than the new control points to be established.

(e) EASE

GPS can combine ease, economy, and speed with high precision (better than 1:100,000 or order C) control points. The existing National Geodetic Reference System (order C/First Order) available in every country is not adequate for GPS work at the accuracy level of 1:100,000 or better. For the existing NGRS to remain adequate, GPS surveys would only establish up to 1:50,000 accuracy.

(f) AVAILABILITY

The existing geodetic networks in the countries in Africa, Asia, South America, and Eastern Europe do not provide 1:100,000 relative accuracy in all areas. Existing networks are too sparse, inaccessible, and inadequate. Many of these monuments are destroyed or are located under obstructions. From past experiences, time required to recover these type of monuments in these countries can comprise up to one fourth of total project time required to establish a medium-sized GPS control network project.

(g) NEW APPLICATIONS

Local users have requirements and specific interests in a higher accuracy reference system (dam movement studies, tectonic studies, etc.).

(h) CONSISTENCY AND HOMOGENEITY

To operate and utilize GPS technology, we need evenly-spaced high precision GPS control stations in every country. Establishing a continentwide GPS survey can bring consistency to mapping and GIS efforts throughout the continents.

(i) COMPATIBILITY

GPS surveys provide data in a variety of formats for use in any platform and software package. The need and value of a geodetic reference system is realized for all spatial data handling.

GPS will become a most efficient tool for capturing attribute data for large-scale GIS and AM/FM projects.

Some Example Applications of Continent-Wide High Precision Networks are:

1.1 (C-HAGNET) and the International Civil Aviation Organization (ICAO)

According to a report by GPS World, during the past five years, 39 accidents involving scheduled passenger flights worldwide were due to controlled flight into terrain (CFIT), resulting in the deaths of more than 1800 persons. Had GPS receivers been on board and operational, the US Global Positioning System could have provided the necessary information and air crew situational awareness to avoid many of these tragedies.

The GPS en route navigation and non-precision approach service is available for both US and international users. On October 17, 1994, Federal Aviation Administrator David R. Hinson presented a letter to the ICAO, offering the use of GPS to ICAO member states for at least 10 years with no direct user charge. ICAO accepted it. To fully utilize GPS or GNSS for navigational purposes a continent-wide GPS network including all international airports is very important.

1.2 C-HAGNETS and the World Environmental Problems

About the world environmental problems Vice President Al Gore in his book "Earth in the Balance" vividly captures the impact of rapid population growth, and sudden acceleration in scientific and technological revolution on our environment. Some of his thoughts and evidences are cited in here to reveal the seriousness of global environmental problems.

"This century has witnessed dramatic changes in two key factors that define the physical reality of our relationship to the earth: a sudden and startling surge in human population, with the addition of one China's worth of people every ten years, and a sudden acceleration of the scientific and technological revolution, which has allowed an almost unimaginable magnification of our power to affect the world around us by burning, cutting, digging, moving, and transforming the physical matter that makes up the earth".

"The surge in population is both a cause of the changed relationship and one of the clearest illustrations of how startling the change has been, especially when viewed in a historical context. From the emergence of modern human 200,000 years ago until Julius Caesar's time, fewer than 250 million people walked on the face of the earth. When Christopher Columbus set sail for the New World 1,500 years later, there were approximately 500 million people on earth. By the time Thomas Jefferson wrote the Declaration of Independence in 1776, the number had doubled again, to 1 billion. By midway through this century, at the end of World War II, the number had risen to just above 2 billion people".

"In other words, from the beginning of humanity's appearance on earth to 1945, it took more than ten thousand generations to reach a world population of 2 billion people. Now, in the course of one human lifetime - mine - the world population will increase from 2 billion to more than 9 billion, and it is already more than halfway there".

"Like the population explosion, the scientific and technological revolution began to pick up speed slowly during the eighteenth century. And this ongoing revolution has also suddenly accelerated exponentially. For example, it is now an axiom in many fields of science that more new and important discoveries have taken place in the last ten years than in the entire previous history of science. While no single discovery has had the kind of effect on our relationship to the earth that nuclear weapons have had the kind of effect on our relationship to warfare, it is nevertheless true that taken together, they have completely transformed our cumulative ability to exploit the earth for sustenance making the consequences of unrestrained exploitation every bit as unthinkable as the consequences of unrestrained nuclear war".

"Now that our relationship to the earth has changed so utterly, we have to see that change and understand its implications. Our challenge is to recognize that the startling images of environmental destruction now occurring all over the world have much more in common than their ability to shock and waken us. They are symptoms of an underlying problem broader in scope and more serious than any we have ever faced. Global warming, ozone depletion, the loss of living species, deforestation - they all have a common cause: the new relationship between human civilization and the earth's natural balance".

Vice President Gore further mentions the solution to keep earth in the balance by reinventing and healing the relationship between civilization and the earth. According to him this can only be accomplished by undertaking a careful **reassessment of all the factors** that led to the relatively recent dramatic change in the relationship.

The following institutes list the factors of global concern as follows:

Dr. Nay Htun, Deputy Executive Director of **the United Nations Environment Programme**, at the Aspen Global Change Institute, listed six issues of global concern which are: (1) biodiversity, (2) consumption and production, (3) demographics, (4) desertification, (5) fresh water, and (6) poverty (Estes and Mooneyhan, 1994).

The World Resources Institute (WRI) identified the following issues for which policy makers require more or better global scale information: (a) climate change, (b) land degradation, (c) land use, (d) vegetation changes, (e) water quality and quantity, (f) air quality, (g) human health, (h) population, (i) ecosystems health, (j) forest health, (k) faunal populations, and (l) energy use (Estes and Mooneyhan, 1994).

The United States Global Change Research Program (USGCRP) has identified seven priority areas where research is needed. In priority order, these areas are: (i) climate/hydrology, (ii) biogeochemical cycles, (iii) ecosystem dynamics, (iv) earth history, (v) human dimensions of global change, (vi) solid earth process, and (vii) solar terrestrial interaction (Estes, and Mooneyhan, 1994).

All the above mentioned research areas or factors of global concern need some sort of maps or geographical information systems (GIS) as a primary source of data for such studies in a common reference system. But the fact is that many developing countries do not have maps. Only 33.3 percent of the world land surface area is covered at a scale larger than 1:50,000 (UN report).

The uses and applications of geographical information system (GIS) are expanding very rapidly; however, one of the biggest hurdle facing GIS today is the efficient and economical collection of graphical and attribute data into a common reference system. A large number of GIS base maps are produced by digitizing existing passé hard copy maps. These base maps rarely meet accuracy standards for many GIS applications and this is particularly evident for larger scale base maps. GPS can help provide economic, authentic, and practical solutions for common reference system, and graphical/ attribute data collection for update or creation of GIS basemaps (Acharya et al. 1994).

In the field of GIS base mapping, the enormous problem facing nations today are their inconsistent and inadequate number of geodetic control points available for all large and medium scale GIS base mapping projects. Geodetic control points serve as "backbone" for all GIS base maps produced by conventional, photogrammetric, or remote sensing methods. Geodetic control points are required for all mapping and engineering projects.

To fulfill the objectives and purposes of the United Nations, and global environmental problems, a global (covering entire continent), and a regional (covering each nation in the continent) geographic information systems are essential tools. As mentioned earlier this kind of information system can not be optimally designed at this time because of unavailability of common continental reference systems, mainly in **Africa, Asia, and South America**.

The continent-wide high accuracy GPS networks (C-HAGNETS) will serve as a backbone for all mapping and GIS activities performed within the Continent. The optimal and timely yield from such a network would only be possible if different agencies such as **The World Bank, USAID**, different organization of the UN, and different development agencies from the countries in the continents use this network for different applications: densification of lower order networks in the immediate future, establishment of regional and local level GISs and research by universities.

Table 2: EXAMPLE CONTINENT-WIDE HIGH ACCURACY GPS NETWORK BY CONTINENTS

Continent	Total area (in sq km)	Station spacing (radius in km)	Estimated number of points required	Remarks
Africa	30,321,130	75 - 125	970	
Asia	44,362,815	75 - 125	1412	
South America	17,806,250	75 - 125	567	
Total	92,490,195		2949	

2 CONTINENT-WIDE GEODETIC DATABASE

The C-HAGNETS will also provide the infrastructure for any kind of Worldwide GISs. A GPS database of this nature will play an important role in preparing or updating Worldwide GIS basemaps (raster images) using the currently available high resolution satellite images (one meter B/W and 4 meter color).

3 GLOBAL AND REGIONAL GIS/BASE MAPPING DESIGN

After the C-HAGNET has been established, the second step would be to design a global and regional GIS for the nations. The monuments will be established in such a way that they can be used in conjunction with the future high resolution satellite images available from the private sector, and thus almost a real time digital orthophoto can be produced for each continent. These tasks are beyond the scope of this proposal, and will not be discussed in here.

4 PROCEDURES FOR ESTABLISHING THE C-HAGNETS

The entire process is divided into three different phases. Each phase can be treated as a separate process; since they do not have direct relationship between each other.

4.1 Map Reconnaissance

Search for suitable locations on maps for high precision GPS control points based on distances and visibility to satellite/aerial images should be made using different scale topographic maps (as available): 1:250,000, 1:100,000, and 1:24,000. The map reconnaissance survey may provide documents required for field reconnaissance and monumentation of high precision GPS control points. The existing geodetic control points available in the vicinity should be researched and considered first, before selecting a new location of a control point. At least 50% of the total stations selected should be existing monuments so that the datum transformation can be performed properly.

4.2 Field Reconnaissance

Final selection of site locations by field visit should be made in this phase of the process. The following information about the control points should be gathered: satellite visibility diagram, station descriptions, witness marks, and location diagrams.

4.3 Monumentations

Although, the existing geodetic control points should be incorporated in the high precision GPS network, the experience shows that most of the existing monuments may not be suitable for GPS surveying. At least fifty percent of 2949 high precision GPS control points may be established in new locations. The cost of establishing these new monuments will vary according to the geographic locations and design of these monuments.

4.4 Observations

Dual frequency, P code GPS receivers should be used in obtaining data on the C-HAGNET stations. About 20 receivers should be used to simultaneously observe satellites for the entire network. The total number of sessions required should be approximately 450 (with 20 receivers).

4.5 Post Processing

Although post-processing of GPS data is performed on a daily basis, the final processing of data should take place in an office using a high speed computer. The post processing should include combined adjustment of continental control points.

5. SUMMARY OF TIME ESTIMATES

The time required for the project can be as tabulated below if the project started by the end of 2000.

Table 3: Tentative Project Delivery Schedule

Continent	No. of Control Points	Start Time	Completion	Control Points Delivery
Africa	970	August 2001	August 2002	August 2003
Asia	1412	August 2002	August 2003	August 2004
South America	567	August 2003	August 2004	August 2005

6. BENEFITS FROM HAVING THE C-HAGNET

The major benefits from the C-HAGNET to the Nations of the World are:

1. Uniformity in GIS/Mapping within a continent
2. Towards 100% large scale map coverage in all the continents
3. Boundary dispute between nations can be solved scientifically
4. Large Scale Digital Elevation Models (DEMs) for entire continent
5. Same elevation and coordinate system within a continent
6. Landlocked countries will have equal access to elevation system
7. Optimal utilization of renewable and sustainable resources to improve the quality of life
8. The project will enhance the charter of the United Nations: It will bring togetherness between nations
9. Efficient geodetic, geophysical, and environmental studies within continents
10. Continental, Regional and Local Level GIS for overall development of nations
11. The United Nations will have better information system about the planet earth.

The densification of high precision GPS network to 100 km baselines would provide tremendous savings when compared to the cost of future establishment/densification of order B and or first order, thus making the GPS technology affordable to all development works.

Once a high precision GPS control network of order A has been established, the densification and many other every day surveying/GIS activities can be performed optimally using GPS technology, thus providing efficiency and more job opportunities to the local engineering and surveying communities.

With the 100 km baseline GPS control network intact, all other GPS works to first order and lower, and attribute data collection can be performed using the single frequency receivers or code phase receivers which are affordable even to a small surveying/engineering firm.

7. CONCLUSIONS

In this paper we proposed high accuracy GPS networks for those continents that are lacking a geodetic frame work which is a backbone for building the 21st century geoinfomation. We discussed the advantages of C-HAGNET as well as the disadvantages due to not having it. We believe this task should be performed under the auspice of world organization such as the United Nations. The schedules for project delivery and other factors shown in various tables are simply to illustrate the contemplation of such a project.

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