GPS ITS DEVELOPMENT AND DEPLOYMENT
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ABSTRACT
The Navstar Global Positioning System (GPS) is an all-weather, space-based navigation system under development by the US Department of Defense. The military needs and requirements are well documented, but the combined utilization, savings, and deployment by the civilian users throughout the world will surpass the benefits to be reaped by DoD.

1. DEVELOPMENT

Scientists have always reached for goals that at the time seemed unobtainable. When those goals were near, new goals were envisioned to stretch our imagination, deepen our thoughts, and yes, day dream a little - "WHAT IF?".

This simplistic view is so very true of the Physical Sciences. When the first breakthrough was made concerning matter, it only opened one door along the way, and you immediately planned the attack on the next door. The installations, at each of the laboratories around the world, have monuments to this path of discoveries. Here at CERN there are the Proton Synchrotron, the Intersecting Storage Rings, the Super Proton Synchrotron; and now, the Large Electron Positron Collider, LEP, is under construction.

In the United States, there is renewed interest in the Super Colliding Accelerator, that may have a diameter two or three times the size of LEP. As a geodesist, who has worked on an accelerator ring, I have gained a greater appreciation of the extremely high surveying accuracies required. Each new plan for the next generation of accelerators makes me stop and wonder, "will they be able to meet the surveying accuracy requirements?". GPS will play a major role in meeting those stringent demands.

Humans have never been content to accept the norm for very long, and in 1957, when the Russians launched SPUTNIK, the gestation period of GPS began. GPS has been born and has grown quite rapidly in its short life. However, we have been treated to only a very limited preview of what GPS will be. The real GPS will not occur until the full constellation of GPS satellites are in orbit, in 1988, or 1989.

The world has changed dramatically since SPUTNIK. Everyday, each of us enjoys the benefits of the "Space Age" technology, in our work, in our play, and in our normal living. The world is moving towards being a better place to live in, not only for us, but for all humans on this planet we call earth, and GPS will contribute in so many and various ways.
GPS is an all weather, space based, navigation system, under development by the United States Department of Defence (DoD), to satisfy the requirements of the military forces. Requirements include, accurately determined positions, velocity, and time in a common reference system, anywhere on or near the Earth, on a continuous basis. The Air Force Systems Command's Space Division acts as the executive agent for the DoD in managing the GPS programme. All branches of the United States military are represented, as well as the Department of Transportation, and NATO.

The Navstar GPS navigation and time-transfer system operates on two L-band frequencies, L1 (1575.4 MHz) and L2 (1227.6 MHz). The system consists of three major segments; a space segment, satellites that transmit radio signals; a control segment, ground-based equipment to monitor the satellites and update their signals; and a user segment, equipment which passively receives and converts satellite signals into positioning and navigation information.

The GPS system has already completed Phase I, concept validation. Phase II, engineering development, is nearing completion, and a constellation of six development satellites are being maintained to support testing of both the military and civilian applications. The contract for the development of the operational satellites has been awarded and, barring any additional delays such as the shuttle disaster, operational satellites are scheduled to be placed in orbit starting this year, with a planned completion of the constellation in 1988.

The full constellation will contain 18 satellites, in six orbital planes, 60 degrees apart, and each plane will have three satellites. The satellites will operate in circular 20,200 km orbits, at an inclination of 55 degrees, with 12-hour periods. Spacing is planned to ensure that at least four satellites will be in view to the user at any time on a worldwide basis.

This is a DoD programme that could serve as a model for other programmes, anywhere. It is well planned, funded, tested, and is now being put into place. The over-riding questions that have yet to be answered are - what level of accuracy, in real time, will users other than DoD, be allotted, and - will the signals be distorted?

2. GEODETIC RECEIVERS

A number of GPS geodetic receivers are already being used to gather data, while others are undergoing tests in preparation for their employment. At the present time these include:

- MACROMETER V-1000, the first GPS geodetic receiver developed for precise surveying by Macrometrics Inc. The Aero Service Division of Western Geophysical Company of America, Houston, Texas, acquired the Macrometrics Company, in March 1984.
- TEXAS INSTRUMENT TI 4100, developed by Texas Instruments, with funding from U.S. Government Agencies. This was the first dual frequency geodetic receiver to be produced utilizing both the P- and the S-code.

- GPS LAND SURVEYOR, MODEL 2002, developed by ISTAC Inc., Pasadena, California. It is an outgrowth of the SERIES technology, originally conceived and developed by MacDoran and his co-workers at the Jet Propulsion Laboratory, Pasadena, California.

- TRIMBLE 4000S, a second generation GPS instrument developed by Trimble Navigation, Ltd., Sunnyvale, California. The first GPS instrument developed by Trimble was the 4000A, a navigation instrument, developed primarily for the shipping industry.

- WM 101, a joint venture between the Wild Co., Heerbrugg, Switzerland, and Magnavox, Torrance, California. The instrument is presently undergoing testing, prior to being put into service.

- TR5S, developed by Sercel, France. These units have already collected data, but no additional information is available.

There will undoubtedly be numerous new geodetic receivers available in the near future. Many of these receivers will be second generation receivers. They will shrink in size and decrease in price as production increases to meet the demand of the multitude of users.

3. DEPLOYMENT

No one can dispute the needs, requirements, and planned use DoD has for GPS. The accomplishments will be too numerous to tabulate. However, the combined utilization, savings, and deployment by the civilian users, throughout the world, will surpass the benefits to be reaped by DoD, perhaps not in the near term, but within a very short span after the system is fully operational.

Even in the development phase, GPS is being utilized to monitor seismic actions, both horizontal and vertical. It eliminates the time delay factor, and because the satellites are in space, ground truths can be located in regions completely outside the areas under study.

One of the major problems the scientist working at sea has always been confronted with, is accurate location while underway. Geophysical profiling is now, with the aid of computers, three-dimensional. When the profiles show a promising structure, the scientists can be confident that the coordinates are accurate, thereby ensuring that the drilling crew will be able to pierce the structure. Utilizing the GPS translocation mode, ships can now be assured of one metre accuracies, within a range of about 300 kilometres from the GPS receiver over a known location.
The most excitement GPS has generated, has been in the geodesy community. Using methods that will be discussed later by other speakers, geodesists have been able to achieve extremely high accuracies between two points. These are greater than the normal accuracies obtainable with traditional surveying equipment and approach, or sometimes exceed, the accuracies of special surveys at installations such as CERN.

When the electronic distance measuring equipment became available to the surveying and geodetic communities, it broke the bond the steel tape had had on them. Formerly, distances could only be measured if a clear line of sight was available and the angles had to be determined in order to permit the computations to be made. All that has changed. No line of sight is required, no angles are needed, only a window to the sky, a piece of space-age technology, an innovative computer program, and the radio signals from a military programme satellite.

3.1 Mapping

With the advent of satellites, mapping of the earth's surface and resources, has become a new science, a science that was only dreamed of 30 years ago. Remote sensing has been responsible for many new discoveries and has allowed new maps of the world to be produced, at least in regions where aerial photography is allowed. But the science of remote sensing has not reached the level of accuracy, or scale, required for both developed, and the developing nations. With GPS, employed in the translocation mode, and the other antenna mounted in an airplane, positions can be computed for the airplane, either in flight, or post-processed, to an accuracy of less than one metre within a range of 300 kilometres. With very little additional equipment, other than an aerial camera, the pictures taken can be used to produce maps to a scale of 1/40,000, with little or no ground control. Mapping on this scale is more than adequate for all developing nations who need to plan and establish the basic road systems, access the natural visible resources, manage the water resources, and institute major land reforms.

Most of the developing nations do not enjoy an adequate network of coordinated control, the existing system being established by methods now labelled as inadequate. The GPS instruments allow control to be established faster and less expensively than with other means. They can also be used to up-grade the existing facilities and to tie in separated areas to provide a single coordinated framework.

3.2 Air navigation

If the Precise Positioning Service (PPS) would be available to the civilian users, an accuracy of 15 metres in x, y, and z would be available for positioning aircraft in flight. That accuracy represents a distance that is less than the wing span of almost every aircraft in existence.

The present method for flight plans for commercial aircraft, is to assign a flight altitude in a designated corridor, with check points along the way. The aircraft is
tracked by ground control systems that relay this information to air traffic controllers, assigned to monitor that particular flight. None of the in-flight and the ground tracking instrumentation can provide the pilot with real time locations as accurately as the PPS GPS system. Barrin the problems all systems experience, a pilot, flying an airplane equipped with GPS, could take off in zero visibility, navigate to the destination, and land in near zero visibility without any outside assistance. When the coordinates, $x$, $y$, and $z$ are established by GPS at the end of every runway, and PPS GPS is available, each of them becomes an emergency landing site.

The accuracy of the Standard Positioning Service (SPS), to be available to the worldwide community of civil users, will be 100 metres, in $x$, $y$, and $z$ with a 95% confidence level. This is still as much accuracy as a pilot, travelling at 600 knots/hour, can use in flight, and it is only the $z$ that is so useful to them in landing with reduced visibility.

One can speculate on the adverse side of GPS in aviation. Will inexperienced pilots, not proficient in flying by instrument, substitute the advantages of GPS for experience and attempt to fly in adverse weather conditions or after dark? Even cautious pilots become lost, perhaps due to weather fronts moving into the flight path, and fail to reach their destination even during daylight hours. GPS can add a measure of safety.

We are so prone to think only of the flying conditions of our respective countries where we have excellent facilities. Why should less fortunate people, living in distant lands without adequate air traffic control or improved airports, be subject to more hazardous flights when flying is often their only link to the outside? With GPS they will be able to take a quantum leap forward in air navigation and safety, even with the SPS, 100 metre accuracy.

3.3 Sea navigation

Shipping has used Transit satellite generated positions for many years. Transit has a 90 minute interval between fixes, therefore is not an adequate system for navigating in close quarters. When GPS is available world wide, it may spell the end of "freedom of the seas". No ship has the right to endanger the coastline of another nation, by polluting its shores with an oil spill. GPS will allow the nations of the world to assign dangerous cargo vessels to certain shipping lanes that will not cross, except at designated points. Very few ships collide when going in the same direction; the majority of collisions occur in passing or crossing situations. GPS can not alleviate the crossing situation, but can eliminate the chance of a passing collision, if shipping lanes are established, and GPS is a requirement.

3.4 Multipurpose cadastre

There is a very critical requirement for a land information system in the United States. The system is needed to improve land-conveyance and to provide for equitable
taxation, information for resource management and environmental planning. We need a MULTIPURPOSE CADASTRE. We have needed it for more years than we care to admit.

The concept of the multipurpose cadastre, is a framework that supports continuous, readily available and comprehensive land-related information at the individual parcel level. The first component is a reference framework, consisting of a geodetic network. The geodetic control must be an integrated network of points on the ground, over the entire area of the parcels that are related to each other. For a true cadastre, the continental United States must have a single, densely spaced, related geodetic network. Most of the populated European countries have a densely spaced control network, that supports their cadastre. These nations have utilized, and benefited from the use of their multipurpose cadastre system for many, many years.

GPS presents to the United States, the first chance to have a truly continental integrated network of control, at an acceptable price, and within a reasonable time frame, a requirement for our cadastre. The continental network will be a part of the world network, to respond to the intercontinental needs.

3.5 Commercial application

One United States automobile manufacturer is planning to offer GPS in its 1989 models. A GPS receiver will be connected to a computer and digitized map system and will display on a small screen a continuous, detailed, map of the location of the automobile. This will be a very useful tool for travellers to a new location, and to those individuals who have difficulty finding their way. The system will allow a delivery firm to prepare a route map for the driver, increasing the efficiency of the driver and vehicle, and eliminating the, "I got lost", excuse. (How many more distractions can the human driver master?)

3.6 Rescue

GPS will become a very important element for air and sea rescue. When the search aircraft or vessel knows its exact location within a few metres, there is no doubt that the suspected area has been covered. If the aircraft, vessel, or person knows the exact location, and can relay this information, finding them becomes almost as easy as following the vehicle on the screen in the car.

3.7 Boundary locations

There are some countries that continue to have boundary disputes with their neighbours. Surprisingly enough, many of the disputes are not over the physical location, they are over the coordinates of the common turning points of the boundaries, such as the mountain peak. GPS may eliminate many of these problems by placing each country on an identical coordinate system, thereby establishing common coordinates for boundary points.
3.8 Day dreaming

If we are allowed to day dream, there are some excellent humanitarian projects where GPS could play a major role. What if we were able to build a GPS unit including a digitized map of Geneva on a small micro disk and small enough to fit into a back-pack. This could acquire the satellite signals, compute the position, and feed this information to the computer which would search the digitized map and then, verbally inform the person of his exact location.

I do not believe this is a "what if", but rather a "when" idea. When will it be available to all those people who need it now? Such a device would give them the freedom to move about with ease, with confidence, and with the assurance that they could go it alone and not be dependent upon others for guidance.

4. SUMMARY

The original GPS scientists may never hear the many thanks that surely will be voiced on behalf of their invention. They may never receive the recognition rightfully due to them, but they can take a great deal of pride in knowing that their efforts have benefited and will continue to benefit mankind, all over the earth, in so many ways, for so many years to come.

THE USE OF GPS IS ONLY LIMITED TO OUR IMAGINATION AND INGENUITY.

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REFERENCES

R.W. King, E.G. Masters, C. Rizos, A. Stoltz, J. Collins; Surveying with GPS; Monograph No. 9, School of Surveying, The University of New South Wales, Kensington NSW, Australia 2033.

Need for a Multipurpose Cadastre; Panel on a Multipurpose Cadastre, Committee on Geodesy, Assembly of Mathematical and Physical Sciences, National Research Council; National Academy Press, Washington, D.C. 1980.