TC
ISTANBUL KULTUR UNIVERSITY
INSTITUTE OF SCIENCES & ENGINEERING

INTEGRATING MOBILE MAPPING,GPS AND GIS TECHNOLOGIES

An M.Sc THESIS

By

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DEPARTMENT OF CIVIL ENGINEERING

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ISTANBULTURKEY
September 2005

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ABSTRACT

A detailed definition of Global Positioning System (GPS) as given by *Wooden* 1985] reads: “The Navstar Global Positioning System (GPS) is an all weather, space based navigation system under development by the U.S. Department of Defense (DoD) to satisfy requirements for the military forces to accurately determine their position, velocity, and in a common reference system, anywhere on or near the earth on a continuous basis”.

Despite the main military goal of GPS, it has attracted a broad spectrum of users. Moreover, it has become an essential component of various applications ranging from surveying and mapping as well as precise time determination, vessel navigations and oceanography to international air traffic management [*Parkinson et al.,* 1994].

Basically, GPS is comprised of three main segments: the space segment, the control segment and the user segment. The purpose of these segments is to provide continuous reliable positioning and timing services for GPS users. The space segment consists of 24 satellites orbiting around the earth at an altitude of about 20200 km and with a period of Approximately 12 hours as illustrated in Figure 2.1 [*Hoffmann-Wellenhof et al*., 1994].

Each satellite transmits a signal that includes the navigation messages based on periodically uploaded data from the control segment. The control segment is a set of monitor stations, ground control stations, and a master control station (that is the central control node for GPS operations) and backup master control station. The user segment consists of GPS receivers from wide varieties of manufacturers. These receivers process The received GPS signals and compute the user position.

The GPS reference coordinate system is the World Geodetic System 1984 (WGS-84) [*Decker,* 1986]. The user's coordinates are determined in this frame and can then be transformed to other systems. Timing is the heart of GPS; GPS time uses an atomic time scale. GPS time is defined as the number of seconds elapsed from Saturday midnight of the present week. The GPS time was coincident with Universal Time Coordinated (UTC is maintained by the U.S. Naval Observatory USNO) at the GPS standard epoch of January 6, 1980.

GPS time is synchronized with UTC at the microsecond level, within an integer number of seconds. The integer offset between GPS time and UTC arises because of the leap seconds periodically inserted for UTC [*Hoffmann-Wellenhof et al*., 1994].

Fundamentals of GPS signal structure, observations and error sources, as well as a brief history of the Global Positioning System, Segments of the GPS, A primer on how the GPS works, Problems with the GPS, Advancements in the GPS are presented in the following sections. These fundamentals are directly relevant to the research presented in this thesis.

Mobile mapping has been the subject of significant research and development by several Research teams over the past decade. A mobile mapping system consists mainly of a moving platform, navigation sensors, and mapping sensors. The mobile platform may be a land vehicle, a vessel, or an aircraft. Generally, the navigation sensors, such as GPS (Global Positioning System) receivers, vehicle wheel sensors, and INS (Inertial Navigation System), provide both the track of the vehicle and positional and orientational information of the mapping sensors. Objects to be surveyed are sensed directly by mapping sensors, for instance CCD (Charge Coupled Device) cameras, laser rangers, and radar sensors. Since the orientation parameters of the mapping sensors are estimated directly by the navigation sensors, complicated computations such as photogrammetric triangulation are greatly simplified or avoided. Spatial information of the objects is extracted directly from the georeferenced mapping sensor data by integrating navigation sensor data. Mobile mapping technology has evolved to a stage which allows mapping

and GIS industries to apply it in order to obtain high flexibility in data acquisition, more information with less time and effort, and high productivity. In addition, a successful Extension of this technology to helicopter - borne and airborne systems will provide a powerful tool for large scale and medium scale spatial data acquisition and database updating. This thesis provides a systematic introduction to the use of mobile mapping technology for spatial data acquisition. Issues related to the basic principle, data processing, automation, achievable accuracies and a break down of errors are given. Application considerations and application examples of the technology in highway and utility mapping are described. Finally, the perspective of the mobile mapping technology is discussed.

ACKNOWLEDGEMENTS

This thesis would not have been possible without the efforts of a large number of other people. Foremost among them Professor Turgut UZEL for his continuous guidance and support every day of my graduate studies, for his patience and his confidence in me, I have learned technology, leadership, and management from him. Dr Gursel GUZEL my supervisor. Professor Kamil EREN from GEOTECH GROUP. Professor Ali Riza GUNBAK the head of Marine Works in STFA Group for his supportive. Dr-Ing. Karsten Jacobsen The head of institute of Photogrammetry and geoinformation at University of Hannover in Germany. Professor Muhammed SAHIN from Istanbul Technical University (ITU). Thanks to all of these for their expertise, friendship and support.

I would like to express my deep appreciation to Professor Hasan KARATS (God mercifulness is upon him) for all his help, insight and encouragement.

I wish to thank my family; I would like to express my deep appreciation to my Father, Ali ALHADAD, my brothers, and sisters for being supportive in every possible way.

Last but definitely not least, I would like to express my deepest gratitude to my wife Mabrouka, for being patient and supportive, despite our busy life the past year with little Lujain.

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LIST OF ABBREVIATIONS

1-D	one-dimensional
2-D	two-dimensional
2DRMS	two Distance Root Mean Square
C/A	code Coarse/Acquisition code
DGPS	Differential Global Positioning System
IGS	International GPS Service
IPP	Ionospheric Pierce Point
ISM	Ionosphere Scintillation Monitor
GIS	Geographic Information System
GPS	Global Positioning System
NOAA	National Oceanic and Atmospheric Administration
MPC	Modulated Precision Clock
P code	Precise code
PLL	Phase Lock Loop
PRN	Pseudo-Random Noise Relative
TEC	Relative Total Electron Content
RTEC	time Rate of change of Total Electron Content
RTECI	time Rate of change of Total Electron Content Index
RTK	Real-Time Kinematic
TEC	Total Electron Content (el/m2)
TECU	Total Electron Content Unit (1016 el/m2)
SED	Storm Enhanced Density
SNR	Signal-to-Noise Ratio
SSP	Standard Positioning Service (SPS)
UT	Universal Time
UTC	Universal Time Coordinated
UV	Ultra Violet
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
GAINS	GPS-Aided-INS
WML	Wireless Markup Language
GPRS	General Packet Radio Service
HTML	Hypertext Markup Language
CHTML	Compressed HyperText Markup Language
XHTML	eXtended HTML
GSM	Global System for Mobile Communications
XML	eXtensible Markup Language
IVR	Interactive Voice Response
SMSC	Short Message Service Centre
J2ME	Java 2 Platform Micro Edition
VOIP	Voice over Internet Protocol
WAP	Wireless Application Protocol
SQL	Structured Query Language
PDAs	personal digital assistants
IOC	Initial operating capability
FOC	Full operational capability
LEO	Low Earth Orbit

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATIONS

Since the late 1950's both military and civilian agencies have actively pursued the idea of position determination and navigation using satellites.

This resulted in the development of several military systems which used specialized equipment responsive to particular mission requirements, but usually with varying degrees of accuracy. In order to integrate these independent efforts, the Department of Defense in 1973 issued a memorandum naming the Air Force as the Executive Service for the initial development of a Defense Navigation Satellite System (DNSS). This system was eventually designated the Navigation Satellite Timing and Ranging Global Positioning System, or NAVSTARGPS. The designed purpose of this system is to provide U.S. military forces and its allies a means to navigate worldwide without dependence on ground based navigation aids. The system is specifically designed to provide guidance and weapons tracking for aircraft, ships, armor and missiles (so-called "smart weapons" systems).

During the early design phase of the GPS it was determined that only 17 satellites were actually needed to provide coverage for the entire earth. However, the Pentagon decided that 24 satellites would provide enough redundancy to prevent failures or gaps in the global system. Today the GPS system is made up of 29 satellites of a version called "Block II." The first GPS satellite, a Phase 1, Block I satellite, was launched in 1978. Nine more of these developmental satellites were deployed as part of the Block I system. Then 23 Block II production satellites were launched in the 1980's and 1990's. The launch of the 24th satellite in 1994 completed the functional system we use today. The USAF NAVSTARGPS Joint Program Office, Space and Missile Systems Center in Colorado oversees overall operations of the System, and formally declared the GPS as having met the requirement for Full Operational Capability on April 27, 1995. At that time the system had cost US taxpayers $14 billion to develop and deploy.

Newer satellites are constantly being built and launched into orbit. Currently the system is comprised of 29 Block II, IIA and IIR satellites, with the newest Block IIF satellite scheduled to be launched in the near future. Of the 29 satellites currently in orbit, five are considered operational in-orbit “spares.” The newest version of satellite includes technology that will allow the GPS to function for weeks without ground control support in the event of a war. But it also includes new features specifically designed to enhance civilian use of the GPS.

In the 1980’s civilian scientists began to use GPS for non-military purposes, such as data collection. Since then GPS use in the private sector around the world has exploded. Many companies now provide products and services utilizing GPS products and services. In a study conducted by the Rand Corporation in the 1990’s, the projected civilian uses for the GPS were expected to exceed those of the military by a ratio of 8:1. It was the dramatic growth in civilian sector use of the GPS that brought a premature end to the military’s intentional dithering of the signal received by civilian GPS receivers (called “Selective Availability”) on May 2, 2000 in a decree signed by former President Clinton.

1.2 RESEARCH OBJECTIVES

1. A brief history of the Global Positioning System
2. GPS Theory
3. Segments of the GPS
4. A primer on how the GPS works
5. GPS Signals
6. GPS Survey Techniques

1.3 THESIS OUTLINE

Fundamentals of GPS signal structure, observations and error sources, as well as a brief history of the Global Positioning System, Segments of the GPS, A primer on how the GPS works, Problems with the GPS, Advancements in the GPS are presented in the following sections. These fundamentals are directly relevant to the research presented in this thesis.

CHAPTER 2

2.1 GPS THEORY OVERVIEW

"GPS provides users with accurate information about their position and velocity as well as the time, anywhere in the world and in all weather conditions".
["Global Positioning System." Microsoft Encarta Encyclopedia. 2002 ed].

A detailed definition of Global Positioning System (GPS) as given by *Wooden* [1985] reads: "The Navstar Global Positioning System (GPS) is an all weather, space based navigation system under development by the U.S. Department of Defense (DoD) to satisfy the requirements for the military forces to accurately determine their position, velocity, and time in a common reference system, anywhere on or near the earth on a continuous basis".

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GPS time is synchronized with UTC at the microsecond level, within an integer number of seconds. The integer offset between GPS time and UTC arises because of the leap seconds periodically inserted for UTC [*Hoffmann-Wellenhof et al.*, 1994].

2.2 The Segments of GPS System

"The Global Positioning System (GPS) is a Constellation of Earth-Orbiting Satellites Maintained by the United States Government for the Purpose of Defining Geographic Positions On and Above the Surface of the Earth. It consists of Three Segments, the three major components that make up the GPS system: Space Segment, Control Segment, and User Segment."[NIMA, NATIONAL IMAGERY AND MAPPING AGENCY]

2.2.1 Control Segment

"This segment consists of 5 Monitor Stations on islands near the equator (Hawaii, Ascension, Diego Garcia, and Kwajelin) and one Master Control Station located at Falcon AFB, Colorado. All of these stations track the GPS signals, and send them back to the Master Control Station at Falcon. The four stations track and monitor the where-about of each GPS satellite each day. Then land-based and space-based communications are used to connect the monitoring stations with MCS."[NIMA, Geodesy workshop, Fred henistredg, 1999]

The Master Control Station or MCS (also known as the Consolidated Satellite Operations Center) is located at the US Air Force Space Command Center at Schriever Air Force Base (formerly Falcon AFB) in Colorado Springs, Colorado. It's responsible for satellite control and overall system operations. The Control segment is made up of a Master Control Station (MCS), four monitor stations, and three ground antennas (plus a reserve antenna at Cape Canaveral used primarily for pre-launch satellite testing) used to uplink data to the satellites. Monitor Stations continuously receive GPS satellite transmissions, and relay this information in real time to the Master Control Station in Colorado. The user segment also receives these same transmissions.

Monitor stations (MS) are located at Schriever Air Force Base, Hawaii, Kwajalein Atoll, and Diego Garcia, and Ascension islands. These stations are unmanned remote sensors that passively collect raw satellite signal data and re-transmit it in real time to the MCS for evaluation. Monitor stations basically function as very precise radio receivers, tracking each satellite as it comes into view. Ground antennas are remotely controlled by the MCS. They are also located at Ascension, Diego Garcia, Kwajalein Atoll, as well as Cape Canaveral, Florida. Ground antennas transmit data commands received from the Master Control Station to GPS satellites within their sky view. They also collect telemetry data (the transmission of data from space vehicles to receiving stations on the ground) from the satellites.

The MCS uplinks data to GPS satellites which includes:

-Clock-correction factors for each satellite; necessary to insure that all satellites are operating at the same precise time (known as “GPS Time”).

-Atmospheric data (to help correct most of the distortion caused by the GPS satellite signals passing through the ionosphere layer of the atmosphere).

-Almanac, which is a log of all GPS satellite positions and health, and allows a GPS receiver to identify which satellites are in its hemisphere, and at what times. An almanac is like a schedule telling a GPS receiver when and where satellites will be overhead. Transmitted continuously by all satellites, the almanac allows GPS receivers to choose the best satellite signals to use to determine position. The almanac is automatically downloaded from satellites whenever a receiver is collecting a GPS signal. An almanac can also be downloaded from a computer, a base station or other archived almanac.

-Ephemeris data is unique to each satellite, and provides highly accurate satellite position (orbit) information for that GPS satellite alone. It does not include information about the GPS constellation as a whole. Ephemeris information is also transmitted as a part of each satellite’s time signal.

By using the information from the GPS satellite constellation almanac in conjunction with the ephemeris data from each satellite, the position of a GPS satellite can be very precisely determined for a given time.

“The MCS, at Falcon AFB, is responsible for the overall command and control, which includes maintaining the exact orbits of each satellite and determining any timing errors that may be present in the highly accurate atomic clocks. The errors are corrected by Falcon with updated orbits and clock corrections relayed once a day to each satellite via four ground antennas. In the future, more monitor stations will be added to further refine the system. Military customers get better than required accuracy as a result. It is important to note that even though the Air Force operates the constellation of satellites on a day-to-day basis, the overall GPS program is jointly managed. The unit that develops the hardware (both military receivers and the actual satellites) is the GPS Joint Program Office (JPO) at Los Angeles AFB. There are, among others, Army, Navy, DoT, and even DMA Deputy Program Managers. .”[NIMA, Geodesy workshop, Fred henistredg, 1999]

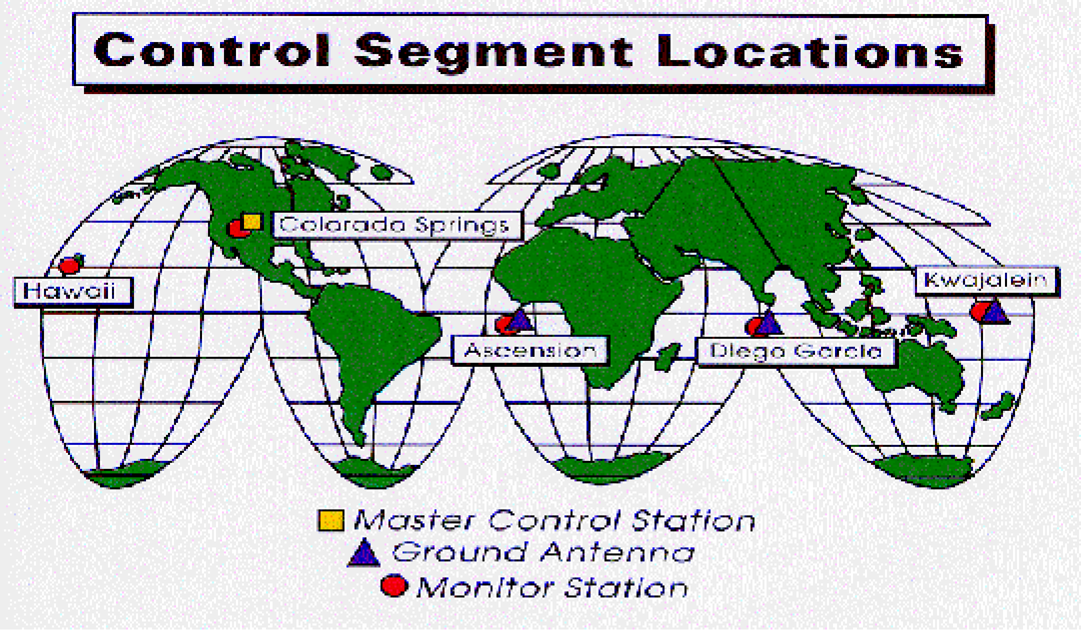


Figure 2.1- Monitor and control stations [NIMA]

2.2.2 Space Segment

The space segment is an earth-orbiting constellation of 24 or more active and five spare GPS satellites circling the earth in six orbital planes. Each satellite is oriented at an angle of 55 degrees to the equator. The nominal circular orbit is 20,200-kilometer (10,900 nautical miles) altitude. Each satellite completes one earth orbit every twelve hours (two orbits every 24 hours)." Actually, a satellite will pass over the same location every 23 hours and 56 minutes. This also means that the SVs are not geostationary - they are constantly moving overhead, rising and falling from the perspective of someone on the ground. The orbit is fairly high, making it is a little harder to attack the SVs than if they were in a Low Earth Orbit (LEO). The higher altitude gives broader ground coverage than satellites in a LEO, and allows each SV to pass over an Upload Station twice in every 24 hour period." .[NIMA, NATIONAL IMAGERY AND MAPPING AGENCY]

That's an orbital speed of about 1.8 miles per second, so that each satellite travels from visible horizon to horizon in about 2 hours.

Each satellite has a design life of approximately 10 years, weighs about 2,000 pounds, and is about 17 feet across with its solar panels extended. Older satellites (designated Block II/IIA) still functioning are equipped with 2 cesium and 2 rubidium atomic clocks. Newer satellites (designated Block IIR) are equipped with rubidium atomic clocks. All satellites also contain 3 nickel-cadmium batteries for backup power when a satellite is in earth eclipse (out of view of the sun).

Each satellite transmits as part of its signal to ground stations and all users the following information:

-Coded ranging signals (radio transmission time signals that allow receivers to triangulate their positions).

-Ephemeris position information (a message transmitted every 30 seconds containing precise information on the location of the satellite in space).

-Atmospheric data (necessary to help correct signal interference from the satellites to the receiver).

-Clock correction information defining the precise time of satellite signal transmission (in GPS Time), and a correction parameter to convert GPS Time to UTC.

-An almanac containing information on the GPS constellation, which includes location and health of the satellites. Whenever a GPS receiver is operating outdoors it automatically downloads an almanac from the satellites. This almanac is stored in the receiver’s memory until the next time it is turned. The stored almanac allows a receiver to more quickly acquire GPS satellite signal because it already knows the general location, and other information, about the satellites in the constellation. However, if a GPS receiver is left turned off for several months, or is moved more than 300 miles while turned off (or turned on but not picking up satellites), the stored almanac may not be of any use to the receiver when it is finally turned back on. A new almanac will be needed to be downloaded to the receiver for it to be able to quickly acquire satellite signals again.

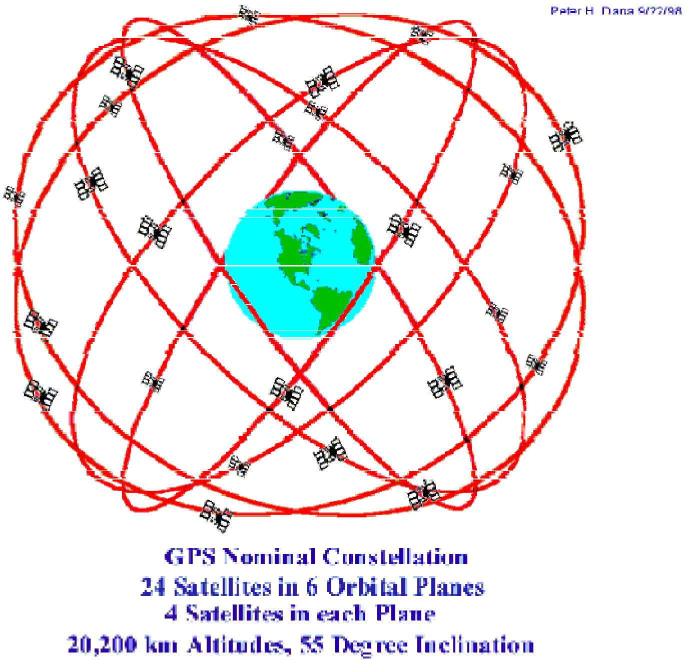


Figure 2.2- GPS Nominal Constellation

2.2.3 User Segment

“The User Segment consists of GPS Receivers that convert satellite signals into position, velocity, and time. Four satellites are needed for computation (longitude, Latitude, Altitude, & clock offset).”[Introduction to: Global Positioning System, Michael Feramez, 2003].

The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and Time. GPS receivers are used for navigation, positioning, time dissemination, and other research.

•Navigation in three dimensions is the primary function of GPS. Navigation receivers are made for aircraft, ships, ground vehicles, and for hand carrying by individuals.

Precise positioning is possible using GPS receivers at reference locations providing corrections and relative positioning data for remote receivers. Surveying, geodetic control, and plate tectonic studies are examples. •Time and frequency dissemination, based on the precise clocks on board the SVs and controlled by the monitor stations, is another use for GPS. Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers. •Research projects have used GPS signals to measure atmospheric parameters.

GPS receivers normally track more than one signal at a time using multiple channels or multiple signals on a time sharing single channel.

“Most common use of GPS is for navigation, examples including helicopter search and rescue, munitions guidance such as the NAVY’S Stand off Attack Missile (SLAM), Military., Search and rescue., Disaster relief., Surveying ,Marine, aeronautical and terrestrial navigation., Remote controlled vehicle and robot guidance., Satellite positioning and tracking ,Shipping., Geographic Information Systems (GIS).,Recreation.” [NIMA Geodesy workshop, Fred henistredg, 1999,].

2.3 Basic Functions of the GPS

The four primary functions of the GPS fall into four categories:

1) Position and waypoint coordinates. Using the GPS a receiver can provide position or waypoint information for its current location or for any remote location on the earth, and display that information in a variety of coordinates.

2) The distance and direction between a receiver's position and a stored waypoint, or between two remote waypoints.

3) Velocity reports: Distance to and between waypoints; tracking to a waypoint; heading (direction of travel); speed; estimated time of arrival.

4) Accurate time measurement: GPS has become the universal timepiece, allowing any two receivers (as well as any two clocks or watches) to be precisely synchronized to each other anywhere in the world.

2.4 GPS Satellite Theory and Signals

•The SVs transmit two microwave carrier signals. The L1 frequency (1575.42 MHz) carries the navigation message and the SPS code signals. The L2 frequency (1227.60 MHz) is used to measure the ionospheric delay by PPS equipped receivers.

•Three binary codes shift the L1 and/or L2 carrier phase.

•The C/A Code (Coarse Acquisition) modulates the L1 carrier phase. The C/A code is a repeating 1 MHz Pseudo Random Noise (PRN) Code. This noise-like code modulates the L1 carrier signal, "spreading" the spectrum over a 1 MHz bandwidth. The C/A code repeats every 1023 bits (one millisecond). There is a different C/A code PRN for each SV. GPS satellites are often identified by their PRN number, the unique identifier for each pseudo-random-NOISE code. The C/A code that modulates the L1 carrier is the basis for the civil SPS.

•The P-Code (Precise) modulates both the L1 and L2 carrier phases. The P-Code is a very long (seven days) 10 MHz PRN code. In the Anti-Spoofing (AS) mode of operation, the P-Code is encrypted into the Y-Code. The encrypted Y-Code requires a classified AS Module for each receiver channel and is for use only by authorized users with cryptographic keys. The P (Y)-Code is the basis for the PPS.

•The Navigation Message also modulates the L1-C/A code signal. The Navigation Message is a 50 Hz signal consisting of data bits that describe the GPS satellite orbits, clock corrections, and other system parameters. [K.EREN, 2003

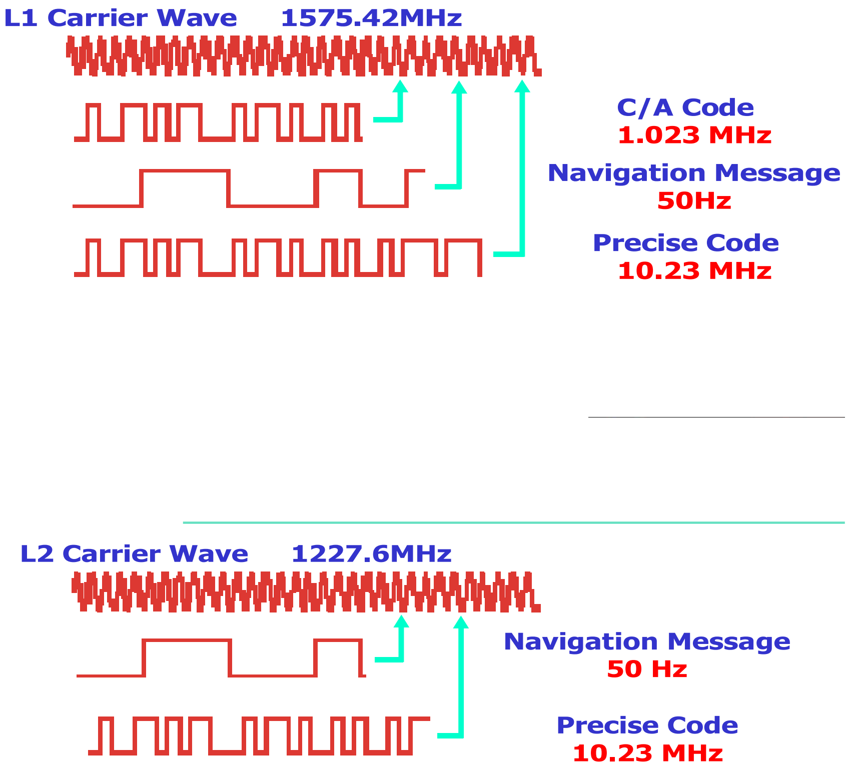


Figure 2.3- GPS Signal Structure[NIMA

2.4.1 Position, and Time from GPS

Since GPS is based on knowing your distance to satellites in orbit, a method must be devised to figure out how far we are from the satellites. The GPS system works by timing how long it takes a radio signal to reach us from a satellite and then calculating the distance from that time. We calculate this by measuring distance or the velocity times travel time. Radio waves travel at the speed of light: 186,000 miles per second.

If we can then compute the exactly when the signal started at the satellite and ended at the receiver then we have our required distance. We then multiply the time by the velocity to derive the distance.

The time is differential is computed by synchronizing the satellites and receivers so they are generating the ***same code*** at exactly the ***same time***

Figure (2.4) is a diagram that shows how radio signals work in general. Each SV generates a plain sine wave called the Carrier 1575.42 MHz and 1227.6 MHz. This carrier is modulated (altered) by adding **three** signals to it. (The C/A code, P-Code and the Navigation message). In this case, it is that particular SV's Pseudo-Random Noise (PRN) Code this is essentially the P-Code and the C/A code for each SV. The PRN code looks like a square wave because it's just 1's and 0's; digital information that is Phase Modulated (PM).

Then what the SV actually broadcasts is that modulated signal. Your receiver picks this up, subtracts the carrier (it can generate a copy of the carrier on its own), and is left with a copy of the original signal. All radios works this way. The significance for GPS is that the signal that is produced in the receiver is delayed by a small amount of time. For GPS, the information in the signal is not the only important part - as we've seen, it's the time delay that we really care about. In fact, GPS receivers already have to have a copy of the signal (most of it anyway) just to pick it up in the first place. Remember, all the SVs are talking on the same frequency, so we can't pick them out of the chatter without knowing what to expect ahead of time.

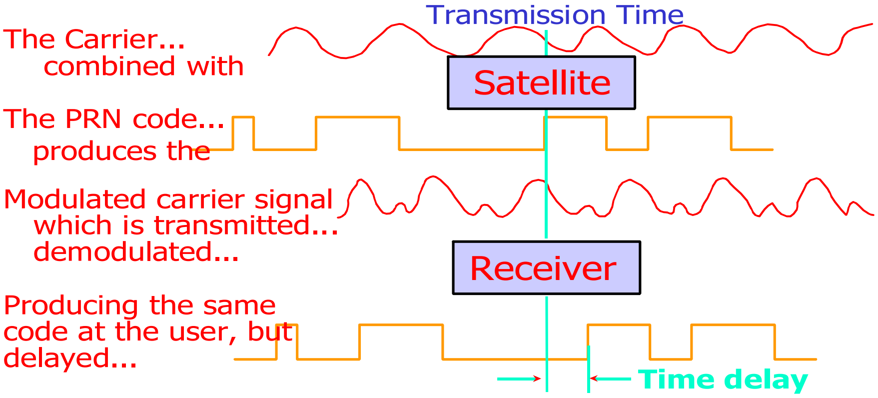


Figure 2.4 - Radio signals [NIMA]

2.4.1.1 Receiver Position is based on Time

The Global Positioning System allows a GPS receiver to determine its position by using a simple formula: **Velocity x Time = Distance**

GPS satellites continuously transmit digital radio pulses at precise, known times. So by measuring the exact instant when the pulses arrive, the receiving GPS equipment can determine the distance to each satellite. But there's a problem. The clocks on board the satellites are all extremely accurate, while the clock in the GPS receiver is not. So a GPS receiver calculates what are called pseudo-ranges ("false" ranges), which are approximate calculated distances (as a measurement of time) to every satellite the receiver has acquired.

Eventually, in order for the GPS receiver to determine a precise position it will have to get its own clock synchronized with the satellite clocks. A clock error in the GPS receiver of as little as a few nanoseconds (billionths of a second) can translate into a position error on the ground of as much as 300 meters. (More about this later.)

For example, if a GPS satellite transmits its signal at precisely T+ 0 nanoseconds, travels at 186,000 miles per second (light speed) to the earth, and arrives at the receiver at precisely T+ 645,160 nanoseconds later, then the signal traveled 12,000 miles (12,000 miles at 186,000 miles per second = 64.516 milliseconds, or 645,160 nanoseconds). The receiver does this for every satellite signal it acquires, tracking each satellite's code by its unique pseudo random noise (PRN) number. This example was presented without introducing any errors into the signal or its path to the GPS receiver. More about that later. [Charlie Leonard 1999.]

2.4.1.2 How the Current Locations of GPS Satellites are Determined

GPS satellites are orbiting the Earth at an altitude of 11,000 miles. The DOD can predict the paths of the satellites vs. time with great accuracy. Furthermore, the satellites can be periodically adjusted by huge land-based radar systems. Therefore, the orbits, and thus the locations of the satellites, are known in advance. Today's GPS receivers store this orbit information for all of the GPS satellites in what is known as an **almanac**. Think of the almanac as a "bus schedule" advising you of where each satellite will be at a particular time. Each GPS satellite continually broadcasts the almanac. Your GPS receiver will automatically collect this information and store it for future reference.

The Department of Defense constantly monitors the orbit of the satellites looking for deviations from predicted values. Any deviations (caused by natural atmospheric phenomenon such as gravity), are known as **ephemeris** errors. When ephemeris errors are determined to exist for a satellite, the errors are sent back up to that satellite, which in turn broadcasts the errors as part of the standard message, supplying this information to the GPS receivers. By using the information from the almanac in conjunction with the ephemeris error data, the position of a GPS satellite can be very precisely determined for a given time.

2.4.1.3 How A GPS Receiver Determines Its Position

Each satellite transmits what's called a Navigation Message, which is downloaded by GPS receivers. The NAV Message the following information: GPS constellation status (all the satellites) satellite ephemeris and health data (individual satellites), GPS Time and UTC time transfer parameters, and ionosphere interference correction parameters. The GPS currently uses two frequencies to accomplish data transmission, L1 and L2. The NAV Message and coarse acquisition information are provided on the L1 frequency.

Another frequency (L3) is planned for the next generation of satellites to enhance position and navigation precision of GPS receivers.

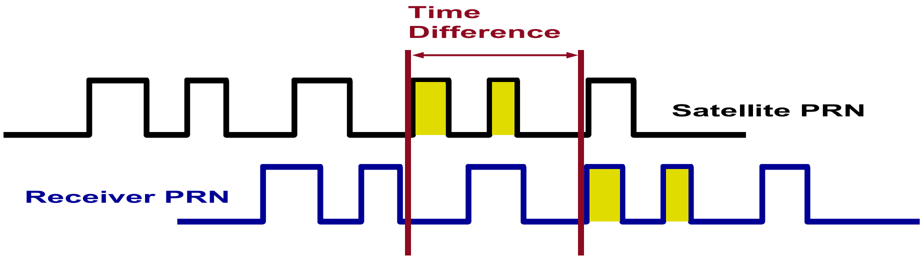


Figure 2.5- The pseudo random noise (PRN) code [Charlie Leonard 1999.]

The pseudo random noise (PRN) code is a fundamental part of the GPS. It's a very complicated digital code unique to each satellite. It's a complex sequence of "on" and "off" digital pulses (see the diagram). The signal looks like random electrical noise (similar to the "snow" you might see on a TV), but is actually a very precise code. Hence the name "pseudo-random noise."

When a GPS receiver acquires a GPS signal it examines the satellite's incoming PRN and begins generating a matching digital signal to mimic the satellite's signal. The receiver matches each satellite's PRN code with an identical copy of the code contained in the receiver's database. Its next task is to try and determine how long ago the signal was generated by the satellite. But there's a problem. As explained earlier, each satellite is equipped with atomic clocks; clocks which are constantly monitored for accuracy by the Master Control Station. The GPS receiver on the other hand is equipped only with a single digital clock comparable to a cheap wrist watch. The only way for the receiver to calculate an accurate position is if it can accurately measure the precise travel time of the satellite radio signal. A discrepancy of just a few nanoseconds between satellite and receiver will translate into a large position error on the ground.

So the GPS receiver uses a clever technique to calculate the precise time it took for the GPS signal to reach it. By shifting its own generated copy of the satellite's PRN code in a matching process, and by comparing this shift with its own internal clock, the receiver can calculate how long it took the signal to travel from the satellite to itself. By comparing the time difference between the two, and multiplying that time by the 186,000 miles per second travel speed of the signal, the receiver can roughly determine the distance separating it from the satellite. This process is repeated with every satellite signal the receiver locks on to.

The distance between satellite and receiver derived from this method of computing distance is called a pseudo-range ("false range") because the receiver's clock is not synchronized with the satellites clocks. Pseudo-range is subject to several error sources, such as delays caused by the atmosphere, and multipath interference. More about that later.

Here's a simplified example of how a GPS receiver synchronizes itself to GPS Time for precise positioning. Imagine that the GPS satellite PRN signal is a song being broadcast by a radio station. The GPS receiver is a record player which is playing the same song, but it's not synchronized to the broadcast song. Both songs are playing, but at different places in the song and at different speeds. By speeding up or slowing down the turntable, the two songs can be precisely matched. They become synchronized. Similarly, the GPS receiver synchronizes its digital signal to match that of each satellite's signal.

Once the receiver has its internally generated PRN code in synch with the satellite's code it can determine a pseudo-range distance to the satellite. It does this for every satellite signal it receives. As will be explained later, under ideal conditions four satellites are used to calculate a precise position.

Since GPS Time is one of the most important components of the System, it's important to understand what GPS Time actually is. GPS Time is measured in weeks and seconds from 24:00:00, January 5, 1980 and is adjusted to within one microsecond of Universal Coordinated Time (UTC). Universal Coordinated Time is the international standard for time, and is tied to the earth's rotation. Because of this it must be periodically adjusted to compensate for the slowing of the earth's rotation – these adjustments are called leap seconds. But because GPS Time has no leap seconds, it is not adjusted, which puts it ahead of UTC time by several seconds. Universal Coordinated Time is computed from GPS Time using the UTC correction parameters sent by the Master Control Station to the satellite constellation as part of the navigation message. At the transition between 23:59:59 UTC on June 30, 1997 and 00:00:00 UTC on July 1, 1997, UTC time was retarded one additional second, putting GPS Time ahead of UTC time by thirteen seconds. A GPS receiver will use the GPS Time to UTC time correction parameter to provide the user with UTC time on the receiver's display.

It's important to note that setting an incorrect time zone in a GPS receiver has no effect on the receiver's ability to provide an accurate position. An incorrect time zone merely provides different time on a receiver's display, not inaccurate time.

2.4.1.4 Time from GPS

Universal Time Coordinated (UTC) is the same as Greenwich Mean Time (GMT), which runs through Greenwich, England - hence its name. It's also known as "Zulu" time (a term used mostly by pilots and the military). Greenwich, England is where east meets west for both time zones and latitude and longitude coordinates. The world is broken down into 24 time zones of one hour each. Universal Time Coordinated is the "official" time standard recognized by most of the world, and it forms the basis for GMT and Zulu time.

Midnight in Greenwich, England is 0000 hours UTC and Zulu (and 0000 hours + 13 seconds in GPS Time!). Each time zone east of Greenwich adds one hour, and each time zone west of Greenwich subtracts an hour. Most of the United States practices Daylight Saving Time (DST) during spring and summer, which adds one hour to each U.S. time zone. The rest of the year is referred to as Standard Time. When it's midnight in Greenwich, it's five hours (or five time zones) behind on the eastern seaboard of the U.S. during Standard Time (7:00 PM), or four hours (or four time zones) behind Greenwich during Daylight Saving Time (8:00 PM).

Universal Time Coordinated is not military time. Military time is simply using a 24 hour clock to represent local time. For example, 1800 hours in military time is 6:00 p.m. *local time*. But 1800 hours Zulu time (or UTC time, or Greenwich Time) is 6:00 p.m. in Greenwich, England.

Presented another way, 1800 hours in military time in Boise, Idaho (6:00 p.m. local) is 2400 hours in UTC time during Mountain Daylight Saving Time, or 0100 hours during Mountain Standard Time (Boise lies in the seventh time zone behind Greenwich). But if it's 9:00 AM (0900 military time) in Boise, and you tell someone that you will meet them at a pub at 1600 Zulu (assuming Standard Time), then you had better hurry because 0900 Mountain Standard Time *is* 1600 Zulu Time!

Some points to remember about time:

UTC, GMT and Zulu time are all the same, and refer to local official time set in Greenwich, England. All other time zones must add or subtract hours to convert UTC, GMT and Zulu to local time.

Military time is nothing more than local time converted to a 24 hour clock (2:00 p.m. is 1400 hours, and so on).

UTC time is the "official" time for the entire world, and is kept by a number of observatories around the world (the U.S. Naval Observatory is one – http://tycho.usno.navy.mil).

The Global Positioning System operates on GPS Time, which is UTC time plus approximately 13 seconds (periodic adjustments in leap seconds may vary the number of seconds).

The following chart shows different time offsets for various cities. All times shown assume Standard Time, but the last column provides Daylight Saving Time (DST) conversion for that city. Remember, Daylight Saving Time occurs only in spring and summer, and most of the world does not subscribe to it.

Place	Local Time	Military (local)	UTC, GMT, Zulu	Time Zone	Local DST Offset
Greenwich, UK	12:00p.m	1200 hours	0000 hours	0 offset	0
Tallahassee, FL	7:00 p.m	1900 hours	0000 hours	- 5 hours	-4 hours (8:00 p.m.)
Tallahassee, FL	11:00 a.m	1100 hours	1600 hours	-5 hours	-4 hours (12:00 p.m.)
Joshua Tree, CA	2:00 a.m	0200 hours	1000 hours	-8 hours	-7 hours (03:00 a.m.)
Joshua Tree, CA	10:30 p.m.	2230 hours	0630 hours*	-8 hours	-7 hours (03:00 a.m.)
Paris, FR**	4:00 p.m.	1600 hours	1500 hours	+1 hour	

Table 2.1- different time offsets for various cities [Charlie Leonard 1999.]

* 0630 (or 6:30 a.m.) the next day.

** Paris lies east of Greenwich by one hour, so time is added rather than subtracted. But DST is not affected.

Note: all GPS receivers perform position calculations using GPS Time. But the time shown on a receiver's screen is UTC time (currently 13 seconds behind GPS Time). According to the Garmin Company, their receiver clocks usually vary from ½ to 1 second from true UTC time if a current almanac is loaded in the receiver.

2.5 GPS SURVEY TECHNIQUES

2.5.1 Pseudo Range Navigation

- The position of the receiver is where the pseudo-ranges from a set of SVs intersect.
- Position is determined from multiple pseudo-range measurements at a single measurement epoch. The pseudo range measurements are used together with SV position estimates based on the precise orbital elements (the ephemeris data) sent by each SV. This orbital data allows the receiver to compute the SV positions in three dimensions at the instant that they sent their respective signals.
- Four satellites (normal navigation) can be used to determine three position dimensions and time. Position dimensions are computed by the receiver in Earth-Centered, Earth-Fixed X, Y, Z (ECEF XYZ) coordinates.
- Time is used to correct the offset in the receiver clock, allowing the use of an inexpensive receiver clock.
- SV Position in XYZ is computed from four SV pseudo-ranges and the clock correction and ephemeris data.
- Receiver position is computed from the SV positions, the measured pseudo-ranges (corrected for SV clock offsets, ionospheric delays, and relativistic effects), and a receiver position estimate (usually the last computed receiver position).
- Three satellites could be used determine three position dimensions with a perfect receiver clock. In practice this is rarely possible and three SVs are used to compute a two-dimensional, horizontal fix (in latitude and longitude) given an assumed height. This is often possible at sea or in altimeter equipped aircraft.
- Five or more satellites can provide position, time and redundancy. More SVs can provide extra position fix certainty and can allow detection of out-of-tolerance signals under certain circumstances. [K.EREN,2003]

2.5.2 Carrier Phase Tracking (Surveying)

- Carrier-phase tracking of GPS signals has resulted in a revolution in land surveying. A line of sight along the ground is no longer necessary for precise positioning. Positions can be measured up to 30 km from reference point without intermediate points. This use of GPS requires specially equipped carrier tracking receivers.
- The L1 and/or L2 carrier signals are used in carrier phase surveying. L1 carrier cycles have a wavelength of 19 centimeters. If tracked and measured these carrier signals can provide ranging measurements with relative accuracies of millimeters under special circumstances.
- Tracking carrier phase signals provides no time of transmission information. The carrier signals, while modulated with time tagged binary codes; carry no time-tags that distinguish one cycle from another. The measurements used in carrier phase tracking are differences in carrier phase cycles and fractions of cycles over time. At least two receivers track carrier signals at the same time. Ionospheric delay differences at the two receivers must be small enough to insure that carrier phase cycles are properly accounted for. This usually requires that the two receivers be within about 30 km of each other.
- Carrier phase is tracked at both receivers and the changes in tracked phase are recorded over time in both receivers.
- All carrier-phase tracking is differential, requiring both a reference and remote receiver tracking carrier phases at the same time.
- Unless the reference and remote receivers use L1-L2 differences to measure the ionospheric delay, they must be close enough to insure that the ionospheric delay difference is less than a carrier wavelength.
- Using L1-L2 ionospheric measurements and long measurement averaging periods, relative positions of fixed sites can be determined over baselines of hundreds of kilometers.

- Phase difference changes in the two receivers are reduced using software to differences in three position dimensions between the reference station and the remote receiver. High accuracy range difference measurements with sub-centimeter accuracy are possible. Problems result from the difficulty of tracking carrier signals in noise or while the receiver moves.
- Two receivers and one SV over time result in single differences.
- Two receivers and two SVs over time provide double differences.
- Post processed static carrier-phase surveying can provide 1-5 cm relative positioning within 30 km of the reference receiver with measurement time of 15 minutes for short baselines (10 km) and one hour for long baselines (30 km).
- Rapid static or fast static surveying can provide 4-10 cm accuracies with 1 kilometer baselines and 15 minutes of recording time.
- Real-Time-Kinematic (RTK) surveying techniques can provide centimeter measurements in real time over 10 km baselines tracking five or more satellites and real-time radio links between the reference and remote receivers. [K.EREN,2003]

2.5.3 Differential GPS (DGPS) Techniques (General principals)

- The idea behind all differential positioning is to correct bias errors at one location with measured bias errors at a known position. A reference receiver, or base station, computes corrections for each satellite signal.
- Because individual pseudo-ranges must be corrected prior to the formation of a navigation solution, DGPS implementations require software in the reference receiver that can track all SVs in view and form individual pseudo-range corrections for each SV. These corrections are passed to the remote, or rover, receiver which must be capable of applying these individual pseudo-range corrections to each SV used in the navigation solution. Applying a simple position correction from the reference receiver to the remote receiver has limited effect at useful ranges because both receivers would have to be using the same set of SVs in their navigation solutions and have identical GDOP terms (not possible at different locations) to be identically affected by bias errors. . [K.EREN,2003]

2.5.3.1 Differential Code GPS (Navigation)

- Differential corrections may be used in real-time or later, with post-processing techniques.
- Real-time corrections can be transmitted by radio link. The U. S. Coast Guard maintains a network of differential monitors and transmits DGPS corrections over radio beacons covering much of the U. S. coastline. DGPS corrections are often transmitted in a standard format specified by the Radio Technical Commission Marine (RTCM).
- Corrections can be recorded for post processing. Many public and private agencies record DGPS corrections for distribution by electronic means.
- Private DGPS services use leased FM sub-carrier broadcasts, satellite links, or private radio-beacons for real-time applications.
- To remove Selective Availability (and other bias errors), differential corrections should be computed at the reference station and applied at the remote receiver at an update rate that is less than the correlation time of SA. Suggested DGPS update rates are usually less than twenty seconds.
- DGPS removes common-mode errors, those errors common to both the reference and remote receivers (not multipath or receiver noise). Errors are more often common when receivers are close together (less than 100 km). Differential position accuracies of 1-10 meters are possible with DGPS based on C/A code SPS signals. . [K.EREN,2003]

2.5.3.2 Differential Carrier GPS (Survey)

- All carrier-phase tracking is differential, requiring both a reference and remote receiver tracking carrier phases at the same time.
- In order to correctly estimate the number of carrier wavelengths at the reference and remote receivers, they must be close enough to insure that the ionospheric delay difference is less than a carrier wavelength. This usually means that carrier-phase GPS measurements must be taken with a remote and reference station within about 30 kilometers of each other.

- Special software is required to process carrier-phase differential measurements. Newer techniques such as Real-Time-Kinematic (RTK) processing allow for centimeter relative positioning with a moving remote receiver. . [K.EREN,2003]

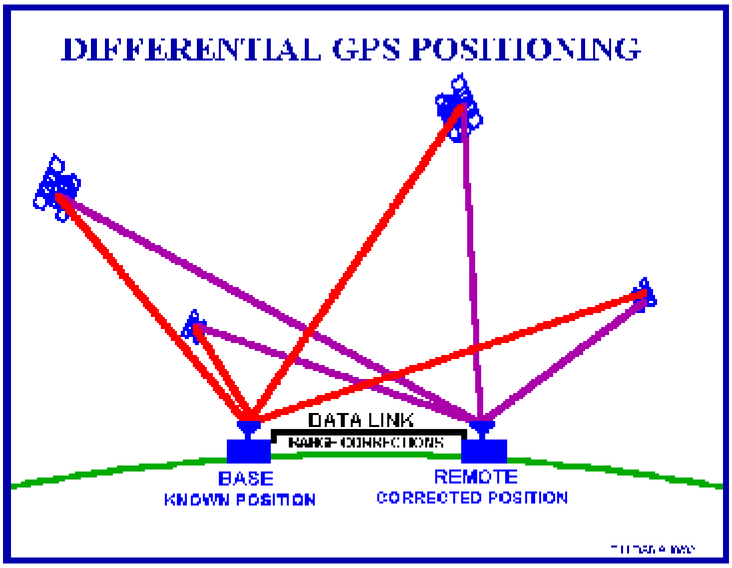


Figure 2.6- Differential GPS Positioning

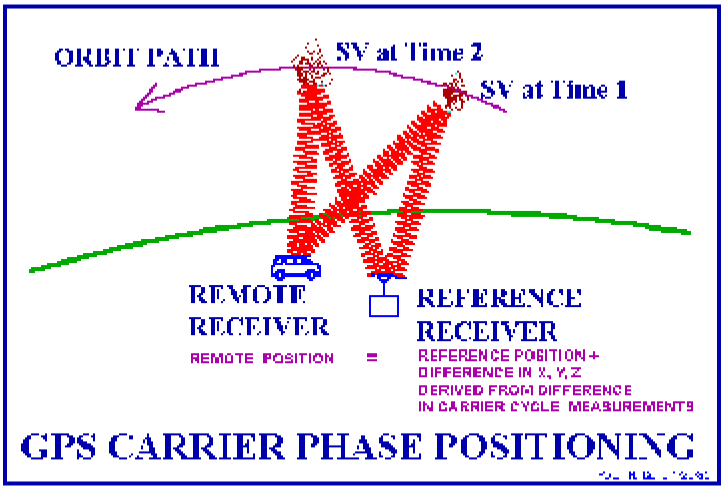


Figure 2.7- GPS Carrier Phase Positioning [George T.French]

2.6 Trilateration, How GPS Determines a Location

For simplicity sake, we calculate our position by understanding where a satellite is in orbit and then further computing how far we are from those satellites.

2.6.1 Signals from One Satellite

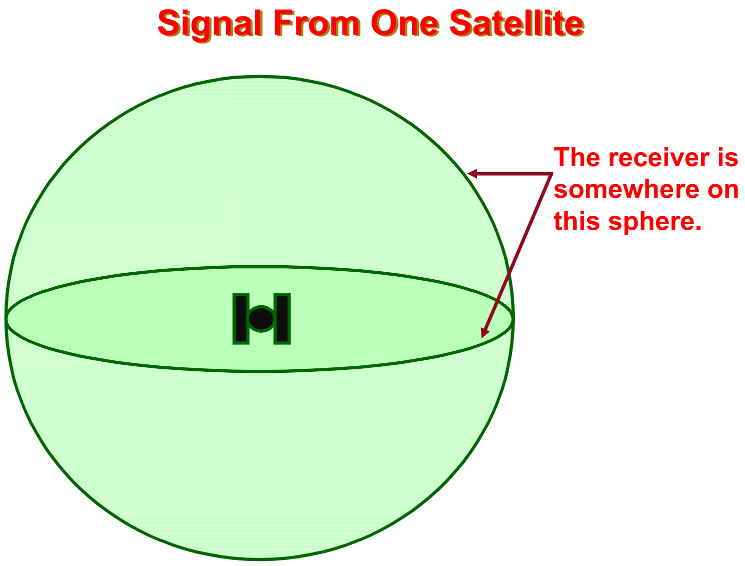


Figure 2.8 Signals From One Satellite [Charlie Leonard 1999.]

GPS receiver to accurately calculate the distance between it and each satellite provided that several factors are met.

Those factors are:

Good satellite signal lock by the GPS receiver (already covered)

A minimum of four satellite signals (discussed next)

Good satellite geometry (discussed later)

When a GPS receiver is turned on it immediately begins searching the sky for satellite signals. If the receiver already has a current almanac (such as one acquired on a previous outing), it speeds up the process of locating the first satellite signal. Eventually it locates and acquires its first signal. Reading this signal the receiver collects the Navigation Message. If the receiver does not have a current almanac, or was moved more than 300 miles while turned off, it must collect a new almanac, which will take about 12-13 minutes after the first satellite signal is acquired. Why the need for a new almanac if the receiver is moved more than 300 miles while turned off? Beyond 300 miles from its last used location the receiver is presumed to be using different GPS satellites, and therefore should download a new almanac to reflect the new PRN codes. If the receiver is turned on and collecting satellite signals while moving over 300 miles, its almanac is automatically updated.

In the above graphic, the GPS receiver calculates a rough location somewhere on this three dimensional sphere, which is actually thousands of miles in diameter. All the receiver can really do at this point is collecting system data and search for more satellites. **[Charlie Leonard 1999.]**

2.6.2 Signals from Two Satellites

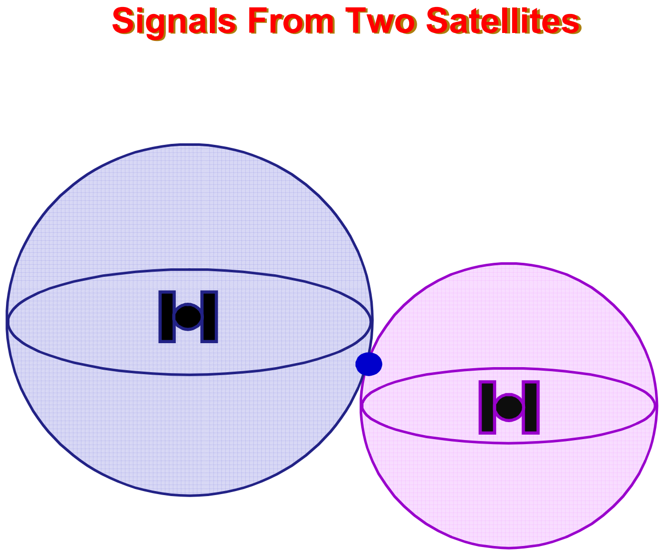


Figure 2.9 Signals From Two Satellite [Charlie Leonard 1999.]

In a perfect world, where both satellite and receiver clocks were perfectly synchronized with each other, an accurate position could be determined from just two satellites. However, most receivers are incapable of calculating an accurate position using just two satellites. The dot in the example represents the approximate location of where the receiver thinks it is based on the information provided by two satellites. At least now the receiver knows that it is somewhere at the intersection of those two satellite signals. But that's the only improvement in its position calculations.

The satellite signal spheres should intersect at precisely the receiver's location, but don't because the clock in the GPS receiver isn't yet synchronized with GPS Time. So the receiver estimates a "pseudo-range" to each satellite.

2.6.3 Three Satellites (2D Positioning)

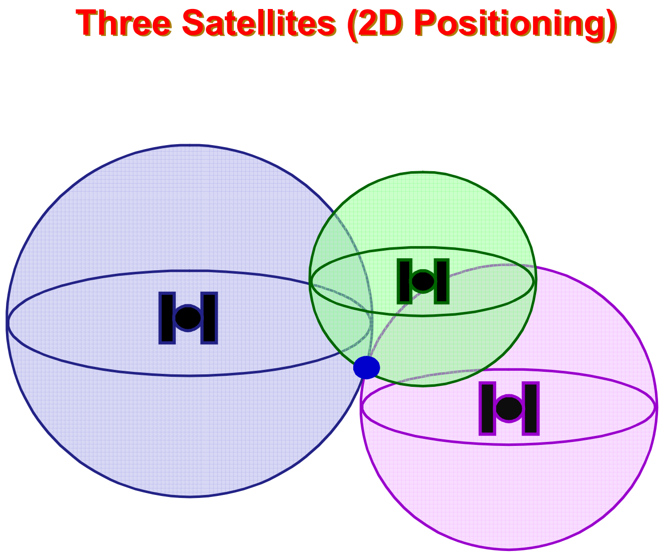


Figure 2.10- 2D Positioning [Charlie Leonard 1999.]

Three satellites can provide only a two-dimensional (2D) position. Without manually entering the receiver's exact elevation (most GPS receivers don't allow elevation to be entered manually), the rendered 2D position may be off by several kilometers on the ground. If the exact elevation of the GPS receiver is known, entering that elevation into a receiver with this capability replaces the need for a fourth satellite signal to allow a receiver to triangulate a precise position. The receiver essentially uses elevation in lieu of a fourth satellite, and makes the appropriate adjustments to trilaterate a reasonably good 3D position.

But without manual elevation correction most GPS receivers must rely on a fourth satellite to provide the final clock correction information necessary to calculate a 3D position. Until a fourth satellite signal is acquired the receiver will not be able to determine x and y horizontal, and z vertical positioning (a true 3D position). This is because the fourth satellite signal is used by the receiver not to provide more position data, but, rather, the final time correction factor in its ranging calculations.

As a rule, 2D positions should always be avoided whenever possible. Use 2D positioning only when a 3D position is not possible, but be aware of the horizontal error inherent in any 2D position. The inability of a GPS receiver to triangulate a 3D position may be due to a variety of factors, including user error, poor satellite geometry, and harsh landscape conditions (tall buildings, canyons, and dense tree cover among others). As will be shown later in the course, all GPS receivers provide some means for informing the user which mode they are operating in. It's up to the user to be aware of the errors associated with 2D positioning.

2.6.4 Triangulating Correct Position

Unfortunately, accessing only two or three satellite signals, the clock in the GPS receiver cannot yet be synchronized precisely with GPS Time. The pseudo-range spheres (the diagram here shows only two satellites for simplification), as interpreted by the GPS receiver, will either be just a little too large (if the receiver's clock is running faster than GPS Time) or too small (if the receiver's clock is slower than GPS Time). The spheres will not intersect with each other. In this example, the "do not" could be the false pseudo-range position if the GPS receiver's clock is running faster than GPS Time, or the dot is the position if the receiver's clock is slower than GPS Time. For the purpose of this example, we'll pretend that the receiver's clock is running a little fast, so the dot is the true location.

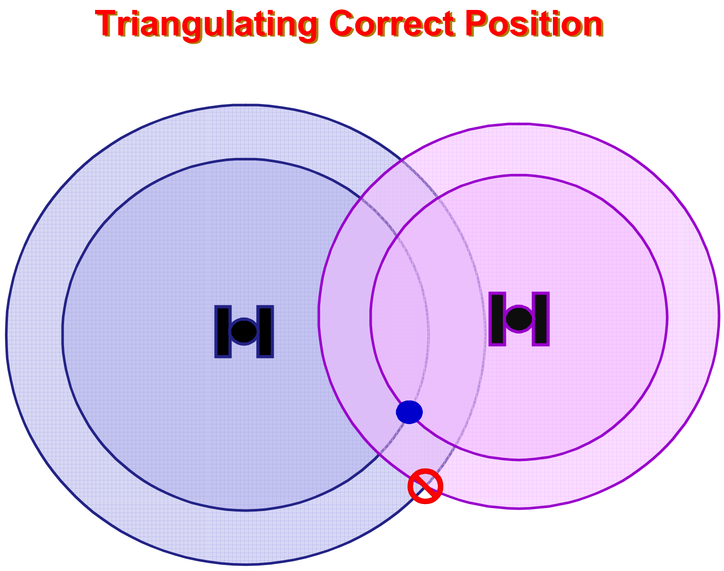


Figure 2.11- Triangulating Correct Position [Charlie Leonard 1999.]

2.6.5 Three Dimensional (3D) Positioning

For a GPS receiver to achieve *three-dimensional* (3D) positioning it needs to acquire four or more satellite signals. A 3D position is comprised of X and Y (horizontal), Z (vertical) positions, and precise time (not varying more than a few hundred nanoseconds). The receiver's processor uses the fourth satellite pseudo-range as a timing cross check to estimate the discrepancy in its own ranging measurements and calculate the amount of time offset needed to bring its own clock in line with GPS Time (recall the radio station and record player simultaneously playing the same song). Since any offset from GPS Time will affect all its measurements, the receiver uses a few simple algebraic calculations to come up with a single correction factor that it can add or subtract from all its timing measurements that will cause all the satellite spheres to intersect at a single point (x, y, and z).

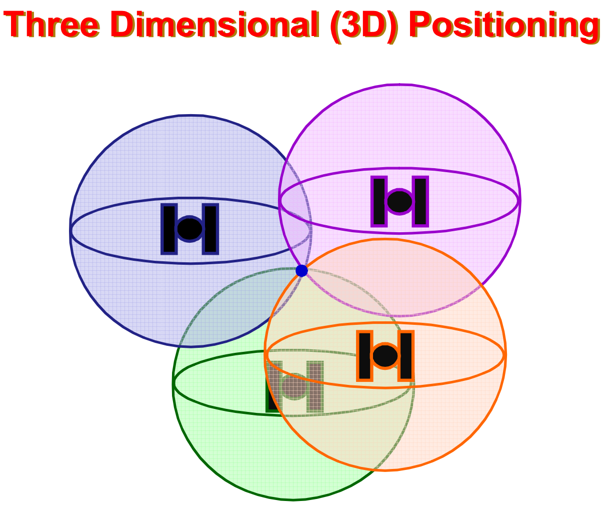


Figure 2.12- 3D Positioning [Charlie Leonard 1999.]

That time correction synchronizes the receiver's clock with GPS Time. Now the receiver essentially has atomic clock accuracy with the time correction factor needed to achieve precise 3D positioning. The pseudo-ranges calculated by the GPS receiver will correspond to the four pseudo-range spheres surrounding the satellites, causing the four spheres to intersect at precisely the receiver’s location (the dot in the diagram).

2.7 The GPS Error Budget

The GPS system has been designed to be as nearly accurate as possible. However, there are still errors. Added together, these errors can cause a deviation of **+/- 50 -100** meters from the actual GPS receiver position. There is a host of errors that are inherent with a GPS system. The accuracy of a GPS is influenced by this budget. Collectively these factors combine to induce the 100m plan position error, at 2 deviations root mean square (2drms) at 98% probability experienced by Standard Positioning System (SPS) users, and 17.8m at 2 deviations root mean square (2drms) at 98% probability experienced by the Precise Positioning System (PPS) users. The sum of all the errors or biases is referred to as bias range or “pseudo range.”

Principal contributors to the final range error that also contribute to the overall GPS error are ephemeris error, satellite clock error, electronic inaccuracies, tropospheric and ionospheric refraction, atmospheric absorption, receiver noise and multipath effects. In addition to these errors, GPS also contains other interruptions to the service that can be introduced by the U.S. DoD are Selective Availability and Anti-Spoofing.

2.7.1 Sources of GPS Error

- GPS errors are a combination of noise, bias, and blunders.
- Noise errors are the combined effect of PRN code noise (around 1 meter) and noise within the receiver noise (around 1 meter).
- Bias errors result from Selective Availability and other factors: SV clock errors, Ephemeris data errors, unordered ionosphere delays, Multipath.
- Blunders can result in errors of hundred of kilometers from: Control segment mistakes, User mistakes, Receiver errors.

2.7.1.1 Selective Availability (S / A)

Selective Availability (S/A) was the intentional degradation (referred to as “dithering”) of the Standard Positioning Service (SPS) signals by a time varying bias. Selective Availability is controlled by the DOD to limit accuracy for non-U. S. military and government users. The potential accuracy of the coarse acquisition (C/A) code at around 30 meters was reduced by Selective Availability up to 100 meters. In May, 2000, bowing to pressure from business and the White House, the Pentagon set Selective Availability to zero. The Pentagon did not turn S/A off, but rather merely reduced the amount of signal dithering to zero meters, effectively eliminating intentional position errors.

During the recent Afghanistan conflict there has been no sign that U.S. Space Command has reactivated Selective Availability, and it does not appear likely that this will happen. However, the Pentagon retains the ability to reactivate S/A without notice to non government GPS users. So it's important to understand what Selective Availability is, and to be aware that it could be reactivated by the U.S. military at any time without prior notification. On other hand Ephemeris errors should not be confused with Selective Availability (SA), which is the intentional alteration of the time and Ephemeris signal by the Department of Defense. SA can introduce 0-70 meters of positional error. Fortunately, positional errors caused by SA can be removed by differential correction.

Anti-Spoofing (A-S) is done not to prevent others from reading the P-code, but to prevent them from broadcasting a fake P-code. Ever since Feb 94, A-S has been on continuously. At the SV, the P-codes are encrypted with a W-code, and broadcast as Y-codes. Numerous DoD directives say that U.S. military forces will not operate on the battlefield with receivers that are not capable of reading and un-encrypting the Y-code. To do this, the receiver needs a special circuit that is only available in military UE sets, and a current crypto key. There are several types of keys, but they all allow the military UE set to read the encrypted codes, and remove the effects of SA. Every once in awhile, A-S is turned off for short periods for testing and other classified purposes. [Fred Henstridge, Bob Nelson 1999]

2.7.1.2 Satellite clock errors: Caused by slight discrepancies in each satellite's four atomic clocks. Errors are monitored and corrected by the Master Control Station.

2.7.1.3 Orbit errors: Satellite orbit (referred to as "satellite ephemeris") pertains to the altitude, position and speed of the satellite. Satellite orbits vary due to gravitational pull and solar pressure fluctuations. Orbit errors are also monitored and corrected by the Master Control Station.

2.7.1.4 Ionospheric interference: The ionosphere is the layer of the atmosphere from 50 to 500 km altitude that consists primarily of ionized air. Ionospheric interference causes the GPS satellite radio signals to be refracted as they pass through the earth's atmosphere – causing the signals to slow down or speed up. This results in inaccurate position measurements by GPS receivers on the ground. Even though the satellite signals contain correction information for ionospheric interference, it can only remove about half of the possible 70 nanoseconds of delay, leaving potentially up to a ten meter horizontal error on the ground. GPS receivers also attempt to "average" the amount of signal speed reduction caused by the atmosphere when they calculate a position fix. But this works only to a point. Fortunately, error caused by atmospheric conditions is usually less than 10 meters. This source of error has been further reduced with the aid of the Wide Area Augmentation System (WAAS), a space and ground based augmentation to the GPS (to be covered later).

2.7.1.5 Tropospheric interference: The troposphere is the lower layer of the earth's atmosphere (below 13 km) that experiences the changes in temperature, pressure, and humidity associated with weather changes. GPS errors are largely due to water vapor in this layer of the atmosphere. Tropospheric interference is fairly insignificant to GPS.

2.7.1.6 Receiver noise: is simply the electromagnetic field that the receiver's internal electronics generate when it's turned on. Electromagnetic fields tend to distort radio waves. This affects the travel time of the GPS signals before they can be processed by the receiver. Remote antennas can help to alleviate this noise. This error cannot be corrected by the GPS receiver.

2.7.1.7 Multipath interference (Radio Wave Propagation): is caused by reflected radio signals from surfaces near the GPS receiver that can either interfere with or be mistaken for the true signal that follows an uninterrupted path from a satellite. An example of multipath is the ghosting image that appears on a TV equipped with rabbit ear antennas. Multipath is difficult to detect and sometimes impossible for the user to avoid, or for the receiver to correct. Common sources of multipath include car bodies, buildings, power lines and water. When using GPS in a vehicle, placing an external antenna on the roof of the vehicle will eliminate most signal interference caused by the vehicle. Using a GPS receiver placed on the dashboard will always have some multipath interference. [Charlie Leonard 1999.]

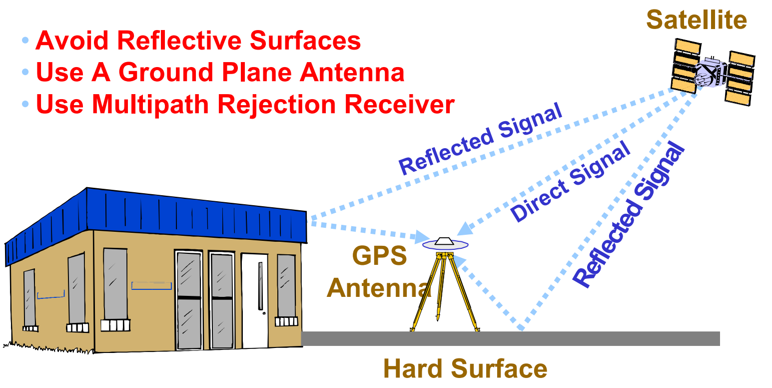


Figure 2.13- GPS Multipath Errors [Fred T. Henstridge 1999]

Multi-Path is simply the reception of a reflected satellite signal. With multi-path reception, the receiver collects both the direct signal from the satellite and a fractionally delayed signal that has bounced off of some nearby reflective surface then reached the receiver. This is the same kind of thing seen in television "ghosts”.

The problem is that the path of the signal that has reflected off some surface is longer than the direct line to the satellite. This can "confuse" some lower-end receivers resulting in an incorrect range measurement and, consequently, an incorrect position.

There are several ways to deal with this problem. Most receivers have some way of "seeing" and comparing the correct and incorrect incoming signal. Since the reflected multi-path signal has traveled a longer path, it will arrive a fraction of a second later, and a fraction weaker than the direct signal. By recognizing that there are two signals, one right after another, and that one is slightly weaker than the other, the receiver can reject the later, weaker signal, minimizing the problem. This ability is referred to as the receiver's multi-path rejection capability.

Mapping and survey quality receivers also use semi-directional, ground-plane antennas to reduce the amount of multi-path that the receiver will have to deal with. Semi-directional antennas are designed to reject any signal below a tangent to the surface of the Earth, meaning that they are preferentially directional upward. This is usually seen as a large (up to 20 to 30 centimeters across) flat metal plate (usually aluminum) with the actual, much smaller, receiver antenna attached on top. The metal plate interferes with any signals that may be reflected off of low reflective surfaces below them, such as bodies of water. [Fred T. Henstridge, Bob Nelson, 1999]

2.7.1.8 Control Segment blunders: due to computer glitches or human error can cause position errors from several meters to hundreds of kilometers. Checks and balances by the Air Force Space Command virtually eliminates any blunders in the Control and Space segments of the GPS.

2.7.1.9 User mistakes: account for most GPS errors. Incorrect datum and typographic errors when inputting coordinates into a GPS receiver can result in errors up to many kilometers. Unknowingly relying on a 2D position instead of a 3D position can also result in substantial errors on the ground. A GPS receiver has no way to identify and correcting user mistakes.

Even the ***human body*** can cause signal interference. Holding a GPS receiver close to the body can block some satellite signals and hinder accurate positioning. If a GPS receiver must be hand held without benefit of an external antenna, facing to the south can help to alleviate signal blockage caused by the body because the majority of GPS satellites are oriented more in the earth's southern hemisphere.

Errors in GPS are cumulative, and are compounded by position dilution of precision (PDOP) (covered later). It is the user’s responsibility to insure the accuracy of the data being collected with the GPS.

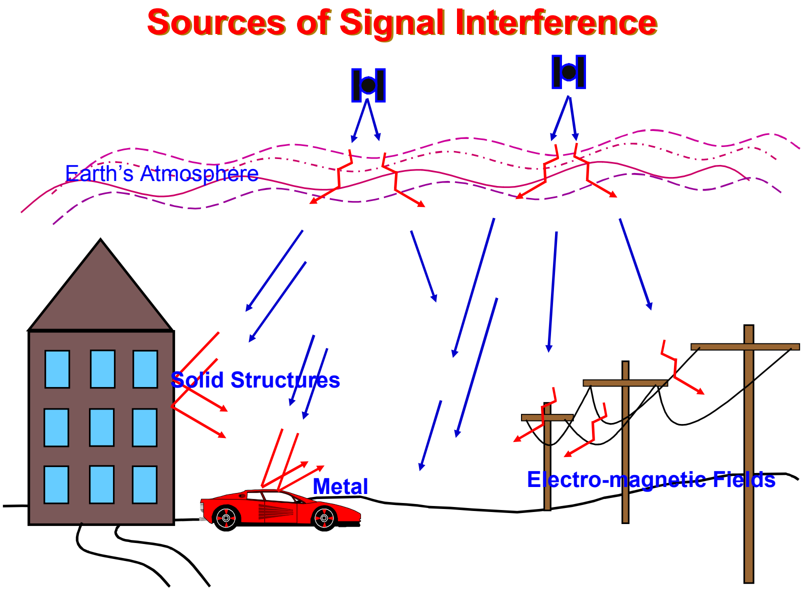


Figure 2.14- Sources of Signal Interference [Charlie Leonard 1999.]

GPS Error Budget

Standard Positioning Service (SPS): Civilian Users

Source	Amount of Error
➢ Satellite clocks:	1.5 to 3.6 meters
➢ Orbital errors:	< 1 meter
➢ Ionosphere:	5.0 to 7.0 meters
➢ Troposphere:	0.5 to 0.7 meters
➢ Receiver noise:	0.3 to 1.5 meters
➢ Multipath:	0.6 to 1.2 meters
➢ Selective Availability	(30 Average) 0 to 70 meters
➢ User error:	Up to a kilometer or more

Errors are cumulative and increased by PDOP

TOTALL ERROR W/SA ON: ~ 100 M

TOTALL ERROR W/SA OFF: ~ 28 M

Table2.2- GPS Error Budget [Charlie Leonard 1999.]

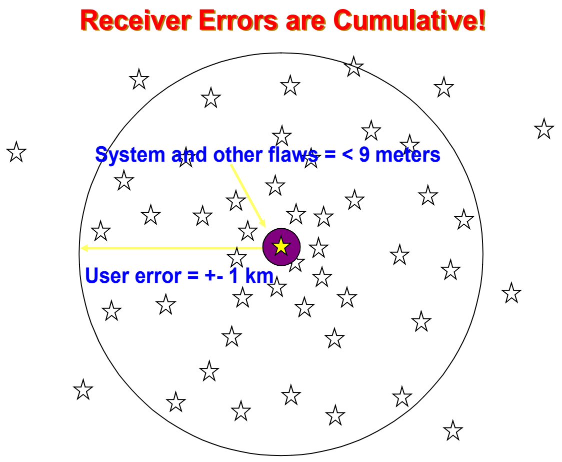


Figure 2.15 Receiver Errors

As shown in the previous diagram, the Global Positioning System can contribute system errors of up to about nine meters on the ground. However, user errors can dramatically increase that to a kilometer or more. Among the most common user errors include using a 2D position instead of a 3D position, mismatched datums between a GPS receiver and a user's map, and high position dilution of precision (PDOP).

In the case of two dimensional positioning, the error occurs because the GPS receiver isn't acquiring enough satellite signals (usually four or more) to provide a precise position. The difference can be as much as several kilometers from a user's true location. Position dilution of precision (PDOP) will be covered later in this lesson. The importance of not using mismatched datums will be covered in the mapping section of the course.

In the above example, the dark stars represent the potential positions a GPS receiver can triangulate for a user depending on the amount error incorporated into that receiver's triangulation calculations. The large circle is a gross example of poor user control over the GPS receiver, and the smaller circle is the uncontrollable circle of error possible through system errors. The centered star represents the hypothetical true location of the user. **[Charlie** Leonard 1999.]

2.8 GPS Dilution of Precision and Its Affects on GPS Accuracy

Satellite position geometry can affect the quality of GPS signals and accuracy of receiver trilateration. Dilution of Precision (DOP) reflects each satellite's position relative to the other satellites being accessed by a receiver.

There are five different kinds of **DOP:**

GDOP: Geometric Dilution of Precision (refers to GPS satellite orbit anomalies)

VDOP: Vertical Dilution of Precision (imperfect height measurements on the ground)

HDOP: Horizontal Dilution of Precision (imperfect horizontal measurements on the ground)

TDOP: Time Dilution of Precision (refers to slight anomalies in time measurements)

PDOP: Position Dilution of Precision (three-dimensional position errors)

Position Dilution of Precision (PDOP) is the DOP value used most commonly in GPS to determine the overall quality of a receiver's position, and the quality of the data collected by the receiver. PDOP is specifically the calculated likelihood of position error based on the present position of the satellites being tracked, including horizontal and vertical errors. In other words, it's HDOP and VDOP combined. [Fred T. Henstridge, Bob Nelson, 1999]

2.8.1 Ideal Satellite Geometry

Satellite geometry refers to the positions of satellites relative to each other in space. Dilution of Precision (DOP) is an indicator of the quality of a GPS receiver's triangulated position relative to the quality of the geometric positions of the satellites whose signals the receiver is using. GPS receivers get satellite position information from the ephemeris message sent as part of the data stream from each satellite.

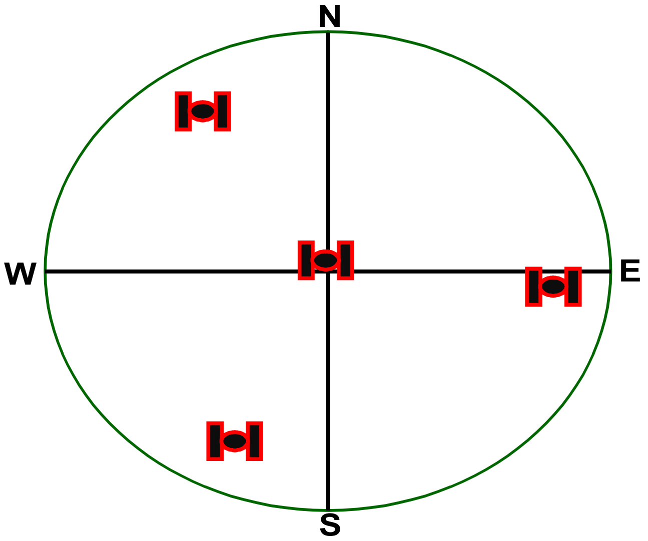


Figure 2.16 - Ideal Satellite Geometry

Dilution of precision uses numerical values to represent the quality of satellite geometry, from 1 to over 100. The lower the number, the better the accuracy of position fixes. Some high-end GPS receivers (such as Trimble data loggers) have a default PDOP setting of around 8, and the value can be changed to meet the needs of the user. Garmin receivers do not allow PDOP manipulation by the user, nor do they provide a PDOP value. Instead they use estimated position error (EPE) value in feet or meters, which provides an estimate of the amount of horizontal error caused by poor satellite geometry.

The outer ring of the circle in the above diagram represents the earth's horizon. The center of the cross hair represents the sky directly above the GPS receiver. The satellite configuration shown is considered optimal for providing the best 3D positioning because any horizontal error from one direction will be offset by the opposing satellites. The fourth satellite directly overhead improves vertical accuracy.

2.8.2 Good Satellite Geometry

The best satellite configuration for optimum receiver positioning is one satellite directly above the receiver, and three or more satellites equally spaced around the horizon (as shown in figure 13). In this configuration satellite geometry is very good since distance measurements are from all directions. The area where all four calculated pseudo-ranges intersect will be much smaller, providing a more precise position (as shown in figure 14) The farther apart the satellites are from each other (better geometry resulting in low PDOP) the smaller the red diamond will be in this diagram. Low PDOP results in a much smaller area of position uncertainty (the diamond in the diagram).

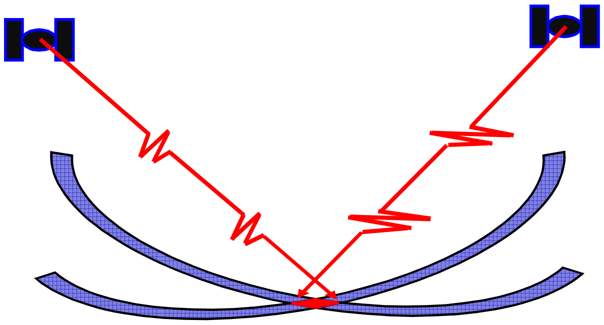


Figure 2.17 - Good Satellite Geometry

A GPS receiver will choose a minimum of four satellites spread out across the sky rather than four satellites bunched close together in one quadrant of the sky. But it should be noted that many receiver types (Garmin included) always try to provide a position, even a poor position, regardless of satellite geometry. The reasoning is that any GPS position information provided by the receiver is better than no position information. This also explains why GPS receivers will provide a 2D (two-dimensional) position even though that position may be off by a considerable distance on the ground.

Most GPS receivers provide some means of determining satellite geometry, either graphically (as in Garmin receivers), or through satellite position information (as in Trimble receivers). Garmin receivers use a sky view display to show the locations of GPS satellites above the receiver. A user can visually check satellite geometry, as well as the strength of the satellite signals, using Garmin's initial startup screen. Other brands of receivers may use a similar or different method of displaying satellite geometry and signal strength. When using Trimble brand receivers, the best way to verify good satellite geometry is through the displayed PDOP value.

2.8.3 Poor Satellite Geometry

The locations of satellites in relation to each other in space at any given time can affect the quality of a GPS receiver's position fix. Spaced low on the horizon, with no satellite directly above the receiver, can result in high PDOP. Similarly, if all satellites acquired by a receiver are bunched closely together in one quadrant of the sky can also result in poor triangulation measurements (and a high PDOP). Topography on the ground also affects satellite geometry. A receiver inside a vehicle, near tall buildings, under dense canopy, or in mountainous terrain can be affected by blocked signals. GPS receivers require clear line of sight to every satellite being acquired.

Satellite set 1: This satellite configuration results in poor PDOP and HDOP, but good VDOP. This is an example of a poor satellite configuration for achieving a precise position

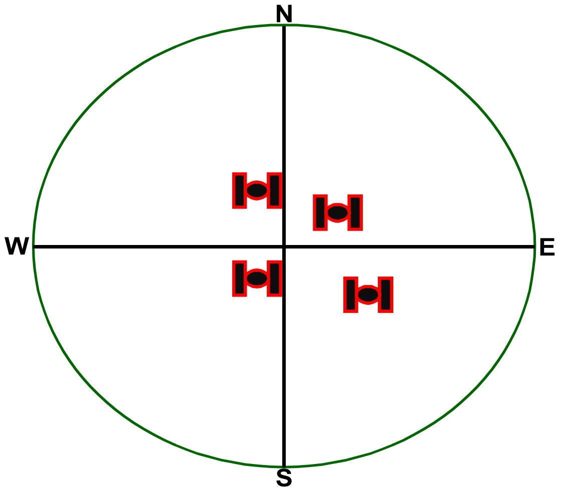


Figure 2.18 - Poor Satellite Geometry (Set 1)

Satellite set 2: This satellite configuration represents poor PDOP and VDOP, but good HDOP. It's important to remember that satellite geometry that is poor for one kind of DOP can actually reduce another kind of DOP. If you need the best horizontal measurements, but don't care about vertical accuracy, then this example is an acceptable satellite configuration.

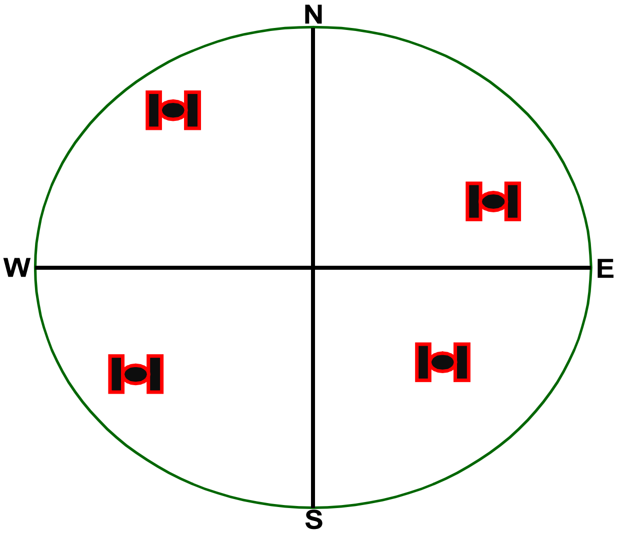


Figure 2.19- Poor Satellite Geometry (Set 2)

Satellite set 3: This satellite configuration represents poor PDOP, VDOP,

And HDOP .This is another example of a poor satellite configuration.

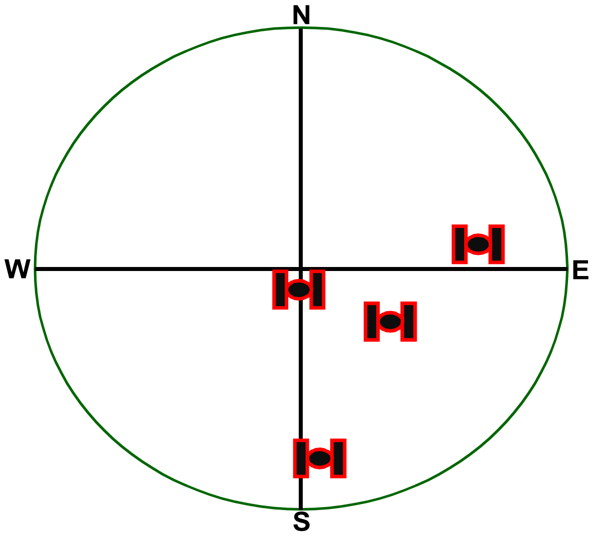


Figure 2.20 - Poor Satellite Geometry (Set 3)

A DOP value of less than 2 is considered excellent-about as good as it gets, but it doesn't happen often, usually requiring a clear view of the sky all the way to the horizon. DOP values of 2 to 3 are considered very good. DOP values of 4 or below are frequently specified when equipment accuracy capabilities are given.

QUALITY	DOP
Very Good	1-3
Good	4-5
Fair	6
Suspect	>6

Table2.3- Dilution of Precision (DOP) [GREGORY T. FRENCH]

DOP values of 4 to 5 are considered fairly good and would normally be acceptable for all but the highest levels of survey precision requirements. A DOP value of 6 would be acceptable only in low precision conditions, such as in coarse positioning and navigation. Position data generally should not be recorded when the DOP value exceeds 6.

2.9 Accuracy and Data Corrections Techniques

2.9.1 Accuracy vs Precision.

"Accuracy is defined as displacement of a plotted point from its true position in relation to an established standard. A datum is the standard in geodesy. Precision is a degree of perfection; a repeatable measurement. You cannot have accuracy without precision. Accurate and precise - Army sniper fire; Precise - Air Force precision bombing; Neither - Naval gunfire. In terms of mapping, accuracy can be associated with replicating the "true" position of a map object to its true position on the earth surface. The accuracy of an object the closeness that the object is replicated to its "true" position. Accuracy has a certain amount of (tolerance) of error depending on the scale of mapping or charts being used. Precision is then the repeatability of how likely you are to return to the same location time and time again. The exactness of a location as it relates between a map object and is true position. If I use a map to navigate to a given location, I might find myself at the same location time and time again (precision) but it might not be the correct position (accuracy)". [Fred T. Henstridge, Bob Nelson, 1999]

Remember that accuracy is not the same as precision (Figure2.21). Locations recorded with GPS are extremely precise (coordinates are recorded out to several decimal places). But how accurate are these coordinates? In other words, how close to the true location are the recorded coordinates?

The accuracy of a GPS position reading is often expressed in terms of the Root Mean Square statistic (1-RMS). This is the radius of the circle containing 68 percent of the individual measurements being made. In other words, with a 1-RMS of 100 feet, 68% of the positions collected will lie within 100 feet of the intended location, and 32% will be located farther than100feet.

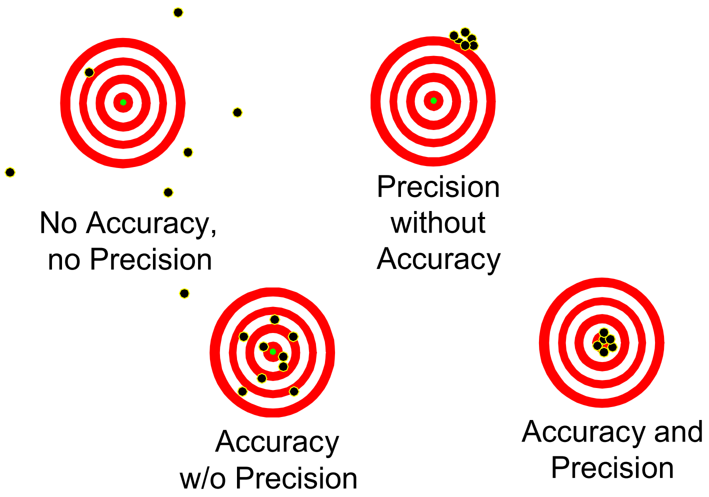


Figure 2.21- Accuracy vs. Precision

2.9.2 Definitions of accuracy

Circular Error Probable (CEP)

The CEP is the radius of a circle in which the true horizontal coordinates will be located 50% of the time.

Spherical Error Probable (SEP)

The SEP is the sphere in which true position fixes will be located 50% of the time.

1 SD = 68%, 2 SD = 95%.

2.9.3 Attainable accuracies

This is the accuracy range that the Department of Defense guarantees from the Standard Positioning Service (SPS), the only service commonly available to civilian users.

25 meters - 10 meters

Cheap handheld receivers in the $300 to $3000 range with basic DGPS can usually achieve accuracies in this range.

5 meters - 1 meter

Better handheld receivers and mapping grade receivers can get down to this level of accuracy. They will cost from $500 to $5000.

1 meter - 10 cm

Better quality mapping receivers and low-end surveying equipment can get this accurate. Such receivers will generally use carrier phase measurement techniques instead of code-based solutions and will cost more than $3000 per unit. Users requiring better accuracy can get it by taking long observations (between 20 seconds and 2 hours) and by surveying multiple points as a network and using network adjustment routines. Sub-centimeter accuracies are possible using these techniques.

10 cm - sub-centimeter

High end surveying receivers and geodetic receivers are used to reach this level of accuracy. Receivers of this class, costing more than $15,000 per unit, will always (correct me if I'm wrong) use carrier phase measurement techniques and will usually use both of the GPS frequencies. A relatively new technique known as ambiguity resolution on the fly (AROF) allows receivers to start producing high-quality solutions very quickly (within 40 seconds) without complicated initialization procedures. [The USCG Navigation center]

2.9.4 Positioning Service (PS)

The GPS Positioning Services are specified in the US Federal Radio navigation Plan. Precise Positioning Service (PPS) and Standard Positioning Service (SPS).

2.9.4.1 Precise Positioning Service (PPS)

• PPS is the most accurate positioning, velocity, and timing information continuously available, worldwide, from the basic GPS. This service is limited to authorized U.S. and allied Federal Governments; authorized foreign and military users; and eligible civil users. • PPS Predictable Accuracy: • 22 metre Horizontal accuracy • 27.7 metre Vertical accuracy • 100 nanosecond time accuracy

PPS information is encrypted to prevent use by unauthorized users. The encryption process is known as Anti-Spoofing. Once encrypted, P code is known as Y code. P code capable military user equipment provides a predictable positioning accuracy of at least 22 meters (2 drms) horizontally and 27.7 meters (2 sigma) vertically and timing/time interval accuracy within 90 nanoseconds (95 percent probability). This improved accuracy is provided in two ways. First, P-code users are not subjected to Selective Availability. Second, access to the L2 channel allows the user to correct for atmospheric propagation errors. Access to P-code equipment is tightly controlled

2.9.4.2 Standard Positioning Service (SPS)

•Civil users worldwide use the SPS without charge or restrictions. Most receivers are capable of receiving and using the SPS signal. The SPS accuracy is intentionally degraded by the DOD by the use of Selective Availability.

•SPS Predictable Accuracy

•100 meter horizontal accuracy •156 meter vertical accuracy •340 nanoseconds time accuracy

•These GPS accuracy figures are from the 1994 Federal Radio navigation Plan. The figures are 95% accuracies, and express the value of two standard deviations of radial error from the actual antenna position to an ensemble of position estimates made under specified satellite elevation angle (five degrees) and PDOP (less than six) conditions. •For horizontal accuracy figures 95% is the equivalent of 2drms (two-distance root-mean-squared), or twice the radial error standard deviation. For vertical and time errors 95% is the value of two-standard deviations of vertical error or time error. •Receiver manufacturers may use other accuracy measures. Root-mean-square (RMS) error is the value of one standard deviation (68%) of the error in one, two or three dimensions. Circular Error Probable (CEP) is the value of the radius of a circle, centred at the actual position that contains 50% of the position estimates. Spherical Error Probable (SEP) is the spherical equivalent of CEP, that is the radius of a sphere, centred at the actual position, that contains 50% of the three dimension position estimates. As opposed to 2drms, drms, or RMS figures, CEP and SEP are not affected by large blunder errors making them an overly optimistic accuracy measure •Some receiver specification sheets list horizontal accuracy in RMS or CEP and without Selective Availability, making those receivers appear more accurate than those specified by more responsible vendors using more conservative error measures. [Peter H. Dana]

2.9.5 Improving Accuracy

Most of the errors listed in (Chapter 2.7) can be corrected by configuring the GPS receiver correctly, and applying differential correction.

2.9.5.1 Differential GPS (DGPS)

Differential GPS (DGPS) is a method of eliminating errors in a GPS receiver to make the output more accurate. This process is based on the principal that most of the errors seen by GPS receivers in a local area will be common errors. These common errors are caused by factors such as clock deviation, selective availability and changing radio propagation conditions in the ionosphere. If a GPS receiver is placed at location for which the coordinates are known and accepted, the difference between the known coordinates and the GPS-calculated coordinates is the error. This receiver is often called a "base station".

The error, which the base station has determined, can be applied to other GPS receivers (called "rovers"). Since the sources of the error are continuously changing, it is necessary to match the error correction data from the base station very closely in time to the rover data. One way of doing this is to record the data at the base station and at the rover. The data sets can be processed together at a later time. This is called post processing and is very common for surveying applications. The other way is to transmit the data from the base station to the rover. The error calculation is made in the rover in real time. This process is called real-time DGPS. [. [The USCG Navigation center]

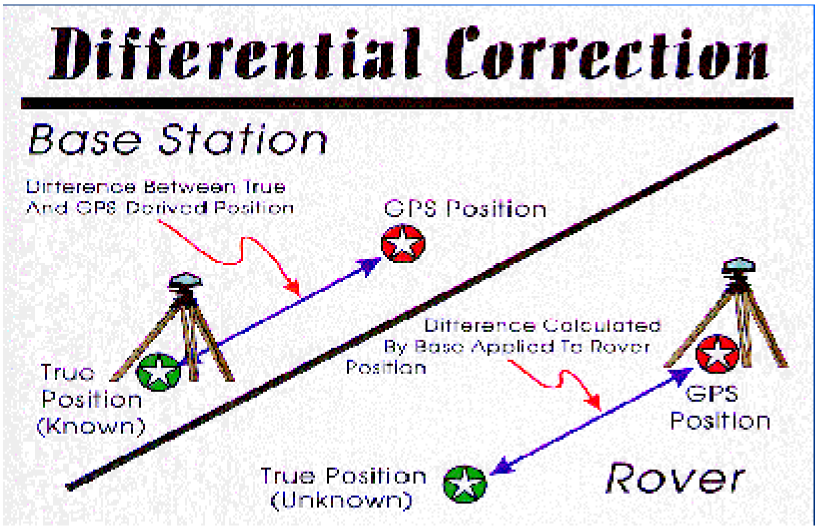


Figure 2.22- differential GPS [GeorgyT.French]

Using Differential GPS to Increase Accuracy

As powerful as GPS is, +/-50 - 100 meters of uncertainty is not acceptable in many applications. How can we obtain higher accuracies?

A technique called **differential correction** is necessary to get accuracies within 1 -5 meters, or even better, with advanced equipment. Differential correction requires a second GPS receiver, a *base station,* collecting data at a stationary position on a precisely known point (typically it is a surveyed benchmark). Because the physical location of the base station is known, a correction factor can be computed by comparing the known location with the GPS location determined by using the satellites.

The differential correction process takes this correction factor and applies it to the GPS data collected by a GPS receiver in the field. Differential correction eliminates most of the errors listed in the GPS Error Budget discussed earlier. After differential correction, the GPS Error Budget changes as follows:

Source	Uncorrected	With Differential
Ionosphere	0-30 meters	Mostly Removed
Troposphere	0-30 meters	All Removed
Signal Noise	0-10 meters	All Removed
Ephemeris Data	1-5 meters	All Removed
Clock Drift	0-1.5 meters	All Removed
Multipath	0-1 meters	Not Removed
SA	0-70 meters	All Removed

Table 2.4- GPS Error Budget With Differential Correction. [The USCG Navigation center]

By eliminating many of the above errors, differential correction allows GPS positions to be computed at a much higher level of accuracy.

2.9.5.2 Post processing

In the post processing method, both the base station and the rover must record data simultaneously. How this is done is dependent on the situation. One way is to record the data right in the GPS receiver. This is common in surveying applications where the base and rover are being used to measure a specific baseline.

Sometimes it is physically inconvenient to record the data in the roving GPS receiver. In such cases the roving user may record the data in a laptop PC, a palmtop PC such as an Apple "Newton" or in a specialized data collector. The usual reason for doing this is that the data collecting device gives the user more flexibility in tagging the GPS data with desired information.

In a situation where the base station will be permanently fixed in one spot and will be used for several rovers, a community base station may be installed. A community base station is nothing more than a GPS receiver permanently connected to a PC. The GPS data is stored in the PC. The PC collects base station GPS data and saves it to files in time-block increments. . [The USCG Navigation center]

Data formats for post processing

Having collected GPS data for post processing, it remains to get the two data sets together. This is not always a straightforward process. Data formats are often proprietary or dependent on the technology used. Users will usually have the same brand of equipment for base stations and rovers so this is not a problem. Sometimes manufacturers will have conversions for different data formats. However, this is not always the case. A data format called RINEX (Receiver INdependent EXchange) may sometimes be used as an alternative.

2.9.5.3 Real-Time Kinematic

Real-time Kinematic (RTK) provides the relative position to be determined instantaneously as the roving receiver occupies a position. The essential difference is the use of mobile data communication to transmit information from the reference point to the rover.

The system requires two receivers with only one positioned over a known point. The base station transmits code and carrier phase data to rover. On-board data processing resolves ambiguities and solves for a change in coordinate differences between roving and reference receivers. This technique can use single or dual frequency receiver.

If the user desires improved accuracy at the time the equipment is being used, real-time processing must be employed. For real-time processing, special formats are employed. There are two predominant formats currently being employed.

NMEA-0183 is a data format commonly employed for communications between ship-borne navigation electronics. This format is a voluntary industry standard originated by the **National Marine Electronics Association.**

The second format, **RTCM-104** is an attempt by **the Radio Technical Commission for Maritime Services** to standardize DGPS operation. The standard is the result of a request by the Institute of Navigation to the RTCM to develop recommendations for DGPS transmission. The RTCM formed Special Committee 104 (SC-104, get it?) titled "Differential NAVSTAR GPS Service". Version 2 of this service is used by many beacon systems (including the US Coast Guard system). Version 2.1 includes additional information for the transfer of real-time kinematic data. . [The USCG Navigation center]

2.9.6 Wide Area Augmentation System

The precision and accuracy of the Global Positioning System still limits its use for aircraft landings and in-flight navigation. As described earlier, satellite position errors, clock drift, and the earth's atmosphere all enhance GPS position errors (both vertically and horizontally). However, the Federal Aviation Administration (FAA) realized the value in enhancing the GPS to provide for better aircraft navigation. Currently under development (the system is operational, but has not yet been approved for commercial civil aviation), the Wide Area Augmentation System (WAAS) is an experimental system designed to enhance and improve satellite navigation over the continental United States, and portions of Mexico and Canada. Unlike the GPS, which is funded and maintained by the U.S. military, the WAAS is funded by the FAA and Department of Transportation. It is specifically meant for civilian and commercial applications within the United States.

Think of WAAS as a highly advanced real-time differential GPS. But instead of using ground based transmitters to broadcast position correction information, WAAS uses its own geostationary satellites in fixed orbit over North America. There are 25 ground reference stations positioned across the United States (including three in southern Alaska, and one each in Puerto Rico and Hawaii) that monitor GPS satellite signals. These stations continuously receive and correct GPS satellite information against their own known precise positions. Each WAAS ground station (referred to as a Wide Area Reference Station or WRS) then sends its corrected GPS data to one of two master control stations located on the Pacific and Atlantic coasts of the U.S. These master control stations create a correction message that weed out atmospheric distortion, GPS satellite orbit and clock errors and time errors. This message is then broadcast to the two WAAS satellites. These in turn re-broadcast the correction information using the basic GPS signal structure: L1 ("Link One") on frequency 1575.42MHz. This allows any WAAS capable GPS receiver to pick up the corrected WAAS signal.

In addition to the space based satellite based WAAS, the FAA is installing ground based Local Area Augmentation System (LAAS) at most major airports in the

U.S. Working in conjunction with the space segment of WAAS, the LAAS will allow for even greater accuracy for WAAS equipped aircraft during takeoffs and landings. The LAAS uses reference receivers located near airport runways, giving much more accurate correction information to incoming and outbound aircraft. However, currently the WAAS has not been approved for aviation by the FAA due to refinements still needed in the system to improve vertical and horizontal accuracy during Category 1 takeoffs and landings (precise landings and takeoffs under low visibility conditions).

Unlike differential GPS which requires additional equipment to work, the WAAS is available to anyone equipped with a WAAS capable GPS receiver in much of the United States and portions of Mexico. However, the System has its limitations at this time, including poor coverage over portions of the northern United States, and very slow signal acquisition time. WAAS capable GPS receivers are now widely available.

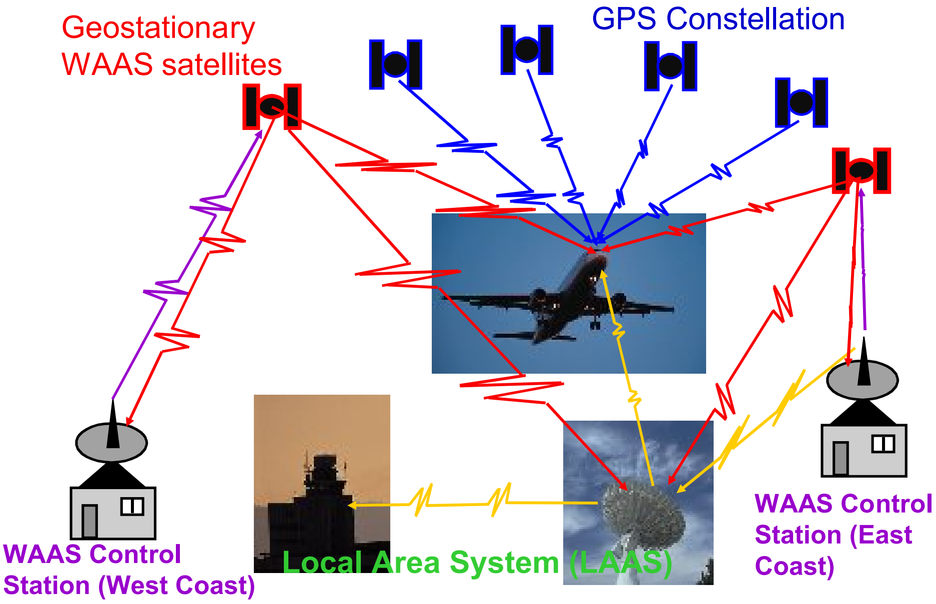
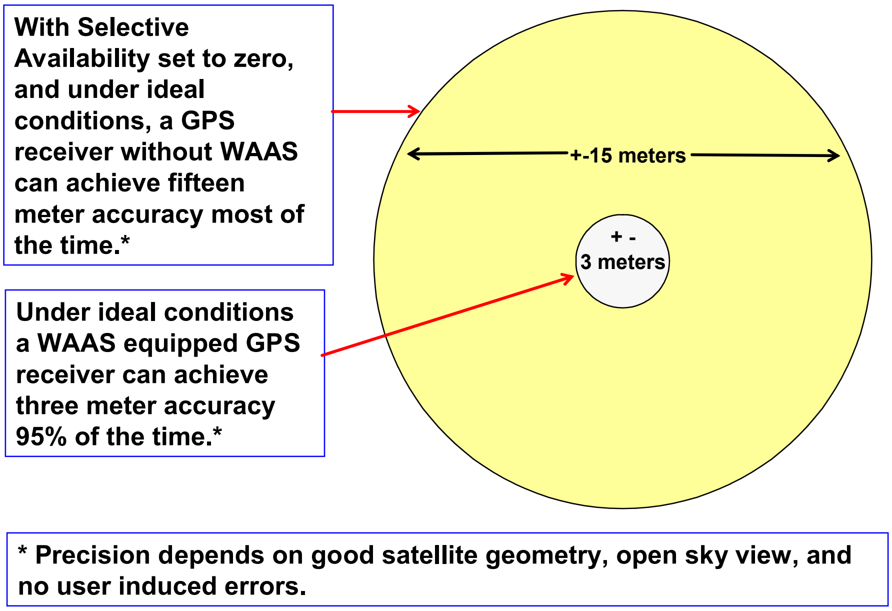


Figure 2.23 - Wide Area Augmentation System

2.9.6.1 Wide Area Augmentation System Accuracy

The Wide Area Augmentation System (WAAS) dramatically improves existing GPS technology for positional accuracy (in the United States and portions of Canada and Mexico). Under ideal conditions, with Selective Availability set to zero, horizontal accuracy with GPS can be fifteen meters or less. Under the same conditions with good WAAS signal acquisition that horizontal accuracy can be reduced to as low as three meters or less on the ground.

Bear in mind that many factors dictate the level of accuracy that can be achieved by any GPS receiver on the ground. Among these factors include errors in the GPS, multipath interference, atmospheric errors, closed canopy or other signal blockers, and human error. Combined, these errors can degrade positional accuracy to 100 meters or more. For WAAS, two downsides are its reduced capability under heavy canopy (trees, canyons, etc.), and its limitation to mostly the contiguous U.S. In fact, some studies have shown that WAAS signals are degraded the further north from the 35 parallel one goes, reducing WAAS reliability in northern latitudes.



With Selective Availability set to zero, and under ideal conditions, a GPS receiver without WAAS can achieve fifteen meter accuracy most of the time.*

Under ideal conditions a WAAS equipped GPS receiver can achieve three meter accuracy 95% of the time.*

*** Precision depends on good satellite geometry, open sky view, and no user induced errors.**

Figure 2.24 - WASS ACCURACY

CHAPTER 3

MOBILE MAPPING SYSTEM

3.1 INTRODUCTION (BACKGROUND)

Mobile Mapping System is an information technology that has been developed since late 1980s with the advance and progress in mobile positioning technology, modern communication technology, spatial information technology and embedded technology, etc. Integrating divers form advanced technologies above-mentioned, Mobile Mapping System is capable of real time data accessing, mapping, and spatial data visualization. Mobile Mapping System not only collects dynamic data about some object in moving, but also manipulates these data in order to make decision efficiently, and make these data be downloaded into a desktop GIS simultaneously by wireless or wire communication as you like. Now Mobile Mapping System has been applied in many fields, such as intelligent transport, precision agriculture, field surveying and environment engineering and so on for outstanding real time supply is very essential in these fields and Mobile Mapping System can do. (**Wang Ping, Liu Xiang-nan, Huang Fang)**

Mobile mapping has been the subject of significant research and development by several research teams over the past decade.

A mobile mapping system consists mainly of a moving platform, navigation sensors, and mapping sensors. The mobile platform may be a land vehicle, a vessel, or an aircraft. Generally, the navigation sensors, such as GPS (Global Positioning System) receivers, vehicle wheel sensors, and INS (Inertial Navigation System), provide both the track of the vehicle and positional and orientational information of the mapping sensors. Objects to be surveyed are sensed directly by mapping sensors, for instance CCD (Charge Coupled Device) cameras, laser rangers, and radar sensors. Since the orientation parameters of the mapping sensors are estimated directly by the navigation sensors, complicated computations such as photogrammetric triangulation are greatly simplified or avoided. Spatial information of the objects is extracted directly from the georeferenced mapping sensor data by integrating navigation sensor data. Mobile mapping technology has evolved to a stage which allows mapping and GIS industries to apply it in order to obtain high flexibility in data acquisition, more information with less time and effort, and high productivity. In addition, a successful extension of this technology to helicopter - borne and airborne systems will provide a powerful tool for large scale and medium scale spatial data acquisition and database updating.

New configuration of the system contains eight CCD cameras covering a view field of 180o.

Similar configurations were implemented and reported in KiSS (Hock et al 1995) and GPS Vision (He 1996). Processing of the vast amount of mobile mapping data is subsequently a very important task. So far, there is no common commercial software capable of handling the data from different mobile mapping systems. Automation of the procedures of mobile mapping data processing has not been extensively researched since most efforts seem to have been made in the development of the data acquisition systems. However, the automation of processing such large observation databases is of great importance. Automatic matching of corresponding image points in an image sequence was reported by Li et al (1994) and Xin (1995). Extraction of road center lines and curb lines from mobile mapping image sequences was researched by He and Novak (1992), Tao et al (1996) and Li et al (1996a). Three-dimensional coordinates in the object space calculated from the mobile mapping image sequences can be optimized by considering Both the precision and reliability (Li et al 1996b). A discussion of building object - oriented 3D databases from mobile mapping data can be found in Qian (1995). Several land vehicle based systems have been developed. Efforts in realization of the concept in the airborne environment have been made by researchers (Lapine 1991, Merchant 1994, Bossler 1996). **(Dr. Rongxing Li, 2000)**

3.2 OUTLINE

This chapter provides a systematic introduction to the use of mobile mapping technology for spatial data acquisition. Issues related to the basic principle, data processing, automation, achievable accuracies and a break down of errors are given. Application considerations and application examples of the technology in highway and utility mapping are described. Finally, the perspective of the mobile mapping technology is discussed.

3.3 Mobile Mapping System Configuration

Mobile Mapping System consists generally of three parts, which is moving platform, navigation sensors and mapping sensors. Its configuration can be described as follow (figure 1).

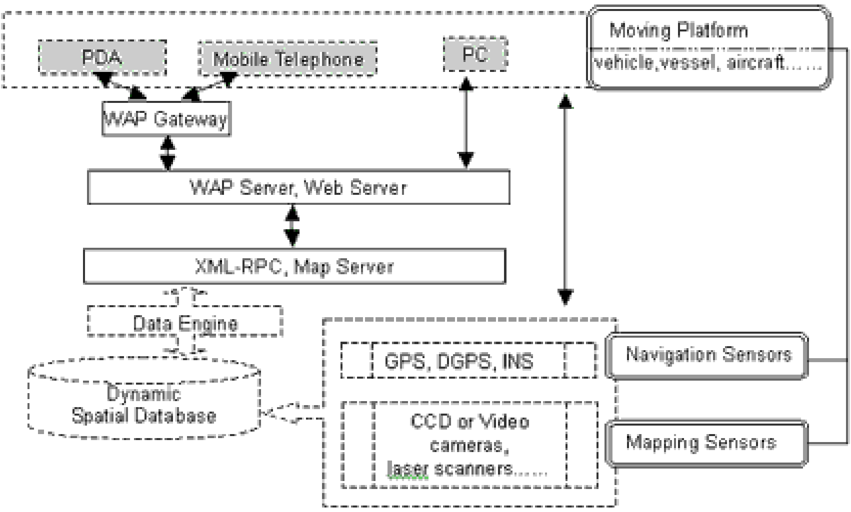


Figure3.1 Mobile Mapping System Configuration. *(gisdevelopment.net)*

The mobile platform - is designed to equip data acquisition devices including mapping sensors and positioning apparatus. It may be a land vehicle, a vessel, or an aircraft. Thus the system can observe objects at closer range flexibly. Generally, Mobile Mapping System monitor objects by ***CCD cameras, video cameras***, ***laser scanners*** and ***radar sensors***. These mapping sensors are selected according by purpose, but they must obtain high flexibility in data acquisition, more information with less time and effort, and high productivity.

Of course ***GPS*** (Global Positioning System) must be connected at the same time in order to record the position and time. Mobile Mapping System is essentially useless without GPS. GPS is developed and initiated by the United States of America. The system has capability of navigation and positioning anywhere on earth, anytime, and under any conditions. Since SA (Selective Availability) was permanently turned off at midnight May 1, 2000, the accuracy of GPS data has been increase. And differential GPS techniques DGPS can help to obtain high positional accuracies. In addition, vehicle wheel sensors and ***INS*** (Inertial Navigation System) are important navigation instruments, too. Integrating with GPS, they can provide both the track of the vehicle and position and orientation information of the mapping sensors.

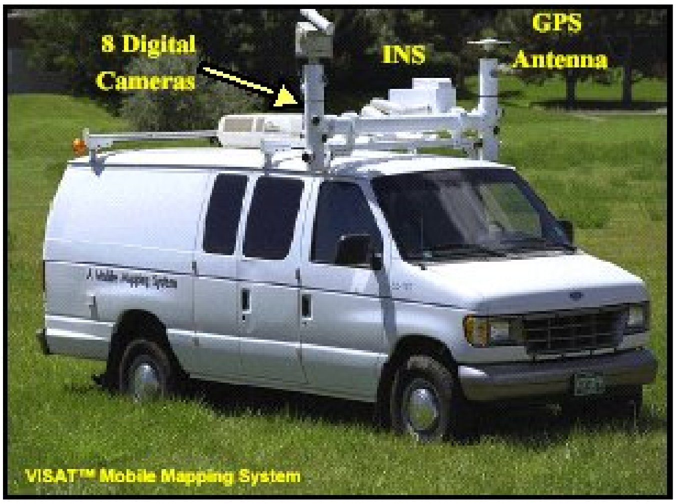


Figure 3.2 Mobile (moving) platforms

All these data acquisition devices can get plenty useful attribute information. The information will be edited and geo-referenced, then stored in the Spatial Database. Geo-reference process is very necessary because these data will be integrated with other information from multi-sources.

Spatial information of the objects is extracted directly from the georeferenced mapping sensor data by integrating navigation sensor data.

Advantages of such a system include: **(Dr. Rongxing Li, 2000)**

- Increased coverage capability, rapid turnaround time, and thus, improved efficiency of the field data acquisition.
- Integration of various sensors so that quality spatial and attribute data can be acquired and associated efficiently.
- Simplified geometry for object measurements supported by direct control data from navigation sensors.
- Flexible data processing scheme with original data stored as archive data and specific objects measured at any time; and strongly georeferenced image sequences which provide an opportunity for automatic object recognition and efficient thematic GIS database generation.

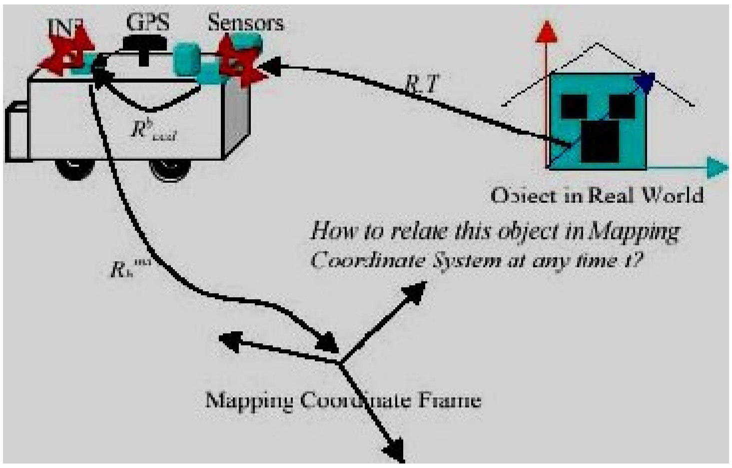


Figure 3.3 Illustration of Geo-referencing*(gisdevelopment.net)*

Field data collection is always a difficulty for cartographers, surveyors and researchers. The tools available for mapping applications have been bulky in size and weight, expensive, and difficult to learn for a long time. Fortunately, the advances of remote sensing, GPS technology, GIS and some data edit and analysis software drive the field data collection. The advance refers not only precision has been improved, but also the hardware has become smaller, lighter, and cheaper. And the software has become easier to learn, and more inexpensive.

So the data collection task becomes easier, more economical and faster to complete. Mobile terminals should be another important component of Mobile Mapping System. Spatial data can be displayed, edited, or analyzed with them. There are different terminals that can finish such task. They are ***PDA, Mobile telephones, and Land Phones***. These handheld equipments can exchange data with desktop PC via serial or USB ports, and some can do this by Internet access. In many cases, Mobile Mapping System is equipped on vehicle, and above functions can be done on PC. Whatever terminals can interchange data with GPS data, and access data from long-distance database by Internet or wireless communication equipment. So the works need the support of modern communication technologies.

3.4 Mobile Mapping Infrastructure and architecture

(U. Srinivas, S. M. C. Chagla, Dr. V. N. Sharma)

Convergence of Internet and Media like Voice and video are opening lot of services to the Mobile user. Mobile mapping is the latest and probably one of the most useful of these services. It has myriad uses and plays a pivotal role in the GIS-information dissipating systems. WAP and other wireless standards enable multidimensional access to the map information and are in the forefront of latest mobile mapping technology. The information is made available on mobile devices like WAP Phones, PDAs, Pagers and even ordinary telephones.

There are different terminals by which the GIS information can be accessed. They are namely Wireless Phones, PDA's and Land Phones. The principle behind the transmission of GIS content to various terminals is briefed below.

3.4.1 Wireless Phones

There are different types of Wireless phones like WAP, GPRS, Imode, and PDA's. They differ in the Wireless Network they use and each of them may have a different methodology to access Map-Information as briefly described below.

3.4.2 WAP Phones

For WAP based mapping solutions, a web server is required that hosts the Mapping Application, has the map database, other components for routing/voice recognition etc (Fig.1). A WAP Gateway is required to transfer information between the Mobile terminal and the web/content server. The Gateway essentially does the protocol conversion, encoding and decoding. A WML browser on the WAP device displays Map and other text based results (Routing results etc).

3.4.3 GPRS Phones

If the GPRS device user is requesting for HTML based map information then the architecture as shown in Fig. 2 will be followed, if the user is requesting WAP based map information than the architecture will be as shown in Fig.1. The only difference being that the wireless network is a Packet switched data network instead of Circuit switched data network, which needs a dial-up.

3.4.4 IMode Phones

The Map services can be delivered to I-Mode phones in more or less similar ways to the WAP model discussed earlier .The difference being that IMode uses CHTML instead of WML. CHTML is a subset of HTML. Imode is implemented with a packet switched system, which is in principle always on while WAP systems in Europe are at present circuit-switched, i.e. dial-up. Packet switching or circuit switching has a technical difference in the telecommunication system on which the services are based; it has nothing to do in principle with the IMode and WAP standards by itself. In principle, IMode and WAP encoded WebPages can be delivered over packet and circuit switched systems.

3.4.5 PDAs

If the PDAs have a WAP browser installed in them, the information comes in similar fashion as discussed under Wireless phones section above. Some PDAs (Mostly WindowsCE based devices) can access Internet content directly. (Fig 2.) Alternatively, applications running on the PDAs can directly connect to remote servers, retrieve and display information without depending on any browser to display the information. The application running on the PDAs should themselves have interfaces to display the information.

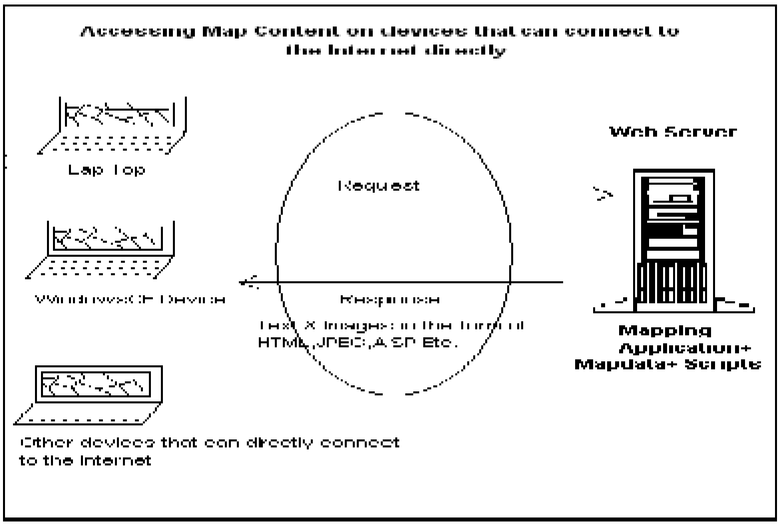


Figure 3.4: Accessing Map content on devices That can connect to the Internet *(gisdevelopment.net)*

3.4.6 PalmOS Devices

For PDAs like PalmVII – which can't access Web content (HTML) directly then Web Clipping comes into picture. In such devices PQA (Palm Query Applications) have to be developed on the Palm devices that clip the web-content and receive the bare minimum to display the Map information

3.4.7 WindowsCE devices

They can connect to the Internet directly as they have in-built soft modems. Thus these devices can directly access Map content from the server, as desktop computers would do.

3.4.8 EPOC devices

These devices can connect to the Internet directly to access Map information. EPOC devices having WAP browsers can have access to the WAP versions of the Map content. There are other mobile devices like Linux and Embedded Linux devices, Neutrino devices etc. Most of these can connect to the Internet through soft/hard modem and access GIS information.

3.4.9 Land Phones

Having access to information from the Internet without actually connecting to the Internet – One of the ways this is possible is by IVR -Interactive voice response (Ma, 1987). The user who subscribes to the voice service will need to dial a toll free number to get map related information. Software on the server understands the speech and converts that to a text based request to the application server (In our case the map application). Since this facility is available for subscriber only- the voice recognition and demographic recognition software can understand the speech of the user.

3.5 GPS-Aided-INS for Mobile Mapping

3.5.1 Introduction

Global Positioning System (GPS) is a network of satellites that continuously transmit coded information, which makes it possible to precisely identify locations on earth by measuring distance from the satellites. GPS offers quick and accurate method of gathering mapping information to meet the geographic data needs but a significant problem can be caused in the data where satellite view is obscured by foliage, buildings or other features, since GPS require line of sight to at least four satellites to achieve full precision. These are costly problems and usually require new surveys to remedy. To address the problem the integrated GPS/INS approach is utilized, which can give accurate result even in the event of temporary GPS signal loss. With GPS and INS hardware becoming ever smaller and less expensive, innovative opportunities for commercial, military, and scientific navigation systems are everywhere-and continue to arise.

3.5.2 Inertial Navigation System (INS)

Navigation is the art of knowing where you are, how fast you are moving and in which direction; and of positioning yourself in relation to your environment in such a way as to maximize your chances for survival. Inertial navigation is accomplished by an Inertial Measurement Unit (IMU) that integrates the output of a set of sensors to compute position, velocity, and attitude. The sensors used are gyros and accelerometers. Gyros measure angular rate with respect to inertial space, and accelerometers measure linear acceleration, again with respect to an inertial frame. Integration is a simple process; complexities arise due to the various coordinate frames encountered, sensor errors, and noise in the system. (Stovall, 1997)

Inertial Navigation is a dead reckoning technique, so it suffers from one serious limitation: drift rate errors constantly accumulate with the passage of time. Because its drift errors relentlessly accumulate, an inertial navigation system that operates for an appreciable length of time must be updated periodically with fresh positioning information. This can be accomplished by using an external navigation reference, such as GPS.

3.5.3 Kalman Filter

Kalman Filter is a recursive algorithm designed to compute corrections to a system based on external measurements. The corrections are weighted according to the filter's current estimate of the system error statistics. The derivations of the filter equations require some knowledge of linear algebra and stochastic processes. The filter equations can be cumbersome from an algebraic point of view. Fortunately, the operation of the filter can be understood in fairly simple terms. All that is required is an understanding of various common statistical measures. (K. Shaikh, A. Shariff, H.Jamaluddin, S.Mansoor, Putra University, Malysia)

Kalman filtering is an extremely effective and versatile procedure for combining noisy sensor outputs to estimate the state of a system with uncertain dynamics. Kalman Filter exploits a powerful synergism between the Global Positioning System (GPS) and Inertial Navigation System (INS). This synergism is possible, in part, because the INS and GPS have very complementary error characteristics. Short-term position errors from the INS are relatively small, but they degrade without bound over time. GPS position errors, on the other hand, are not as good over the short term, but they do not degrade with time. The Kalman filter is able to take advantage of these characteristics to provide a common, integrated navigation implementation with performance superior to that of either subsystem (GPS or INS). By using statistical information about the errors in both systems, it is able to combine a system with tens of meters position uncertainty (GPS) with another system whose position uncertainty degrades at kilometers per hour (INS) and achieve bounded position uncertainties in the order of centimeters [with differential GPS (DGPS)] to meters. (Grewal et al, 2001).

A key function performed by the Kalman filter is the statistical combination of GPS and INS information to track drifting parameters of the sensors in the INS. As a result, the INS can provide enhanced inertial navigation accuracy during periods when GPS signals may be lost, and the improved position and velocity estimates from the INS can then be used to make GPS signal reacquisition happen much faster when the GPS signal becomes available again.

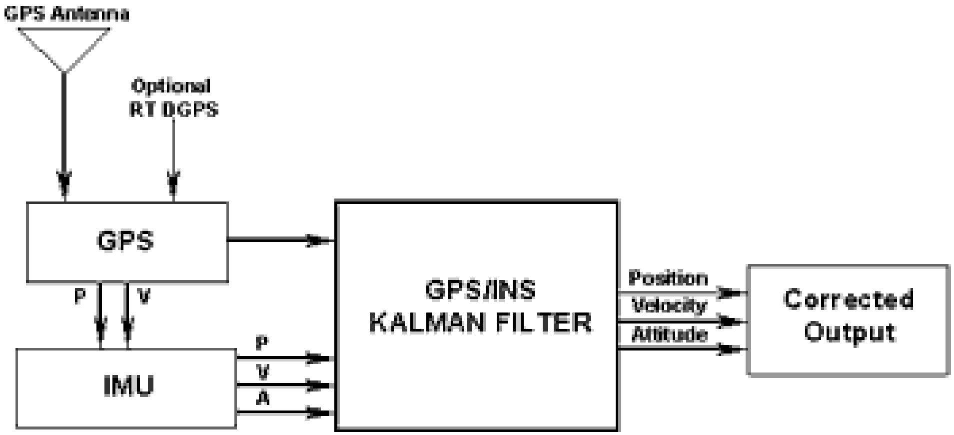


Figure 3.5 Block Diagram of GPS/INS Integration. *(gisdevelopment.net)*

3.5.4 Advantages of GPS/INS integration

GPS Aided INS systems (GAINS) have some real advantages in terms of output rate, reliability, and accuracy. (Farell & Barth, 1999).

- It is autonomous and does not rely on any other external aids or on visibility conditions and maintains the availability of navigation solution during GPS outages due to interference, jamming, etc.
- Optimal mixing of the INS and the GPS information reduces the effect of GPS errors. Therefore GPS-only accuracy is improved on by the integrated solution.
- The INS provides the full navigation (6 degrees of freedom) state without differentiation. The 6 degrees of freedom refer to 3 translational and 3 rotational

degrees of freedom. GPS signals could be used to determine accelerations by differentiation or attitude by techniques.

- The INS provides the navigation solution in real time (i.e. without latency) at rates higher than may be achievable from a GPS receiver.

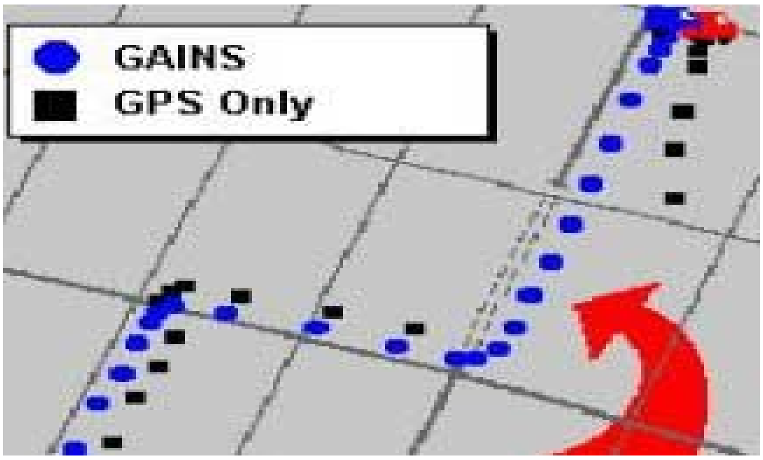


Figure 3.6 GPS may be blocked by Trees, buildings,
And mountains but INS keeps on working.
(gisdevelopment.net)

3.6 Laser Range Finders

While GPS technology has made rapid advances, there are still inherent problems with data collection when utilizing GPS. First, there is the need for occupation of the point where GPS readings are required and sometimes its just not possible to reach the point of interest. Second, the point may be reachable, however, due to other factors, such as disturbance of wild life, areas of high traffic volume, or even evidence in crime mapping, you may not want to get there. Third, in some areas, GPS receivers cannot receive the signals, such as, in heavy tree canopy areas and near high rise buildings. Fourth, GPS mapping is slow if you have to map several features such as trees in a forest or electric poles on a road because you have to occupy each individual feature. **(Ashok Wadhwani)**

Figure 3.7 The Laser Range Finder
(gisdevelopment.net)

To overcome some of the limitations of the GPS technology, laser range finders have now become available at a reasonable price and performance. These units can be used with or without GPS. The key to laser mapping is: you do not have to get there from here and occupy the feature! Instead, just shoot it with the laser.(See Fig3.6)

3.6.1 What makes a laser mapping system work

The eye-safe diode pulse laser measures distance without reflectors and has a tilt sensor built in to provide vertical angles. In addition, it has an option for a digital flux gate compass or angle encoder (not affected by magnetic fields) to provide an azimuth reading. The mapping grade range finders provide an accuracy of about 5 cm to 1.5 meters. Maximum range varies from about 500 ft to 2000 ft. The Laser Range Finder can be used in different ways depending on the application, for example, direct GPS integration, indirect GPS integration, or Independent Laser Mapping

3.6.2 Direct GPS integration

In cases where you have a clear view of the sky and are getting GPS signals, you can place the laser range finder at the same spot where the GPS antenna is placed - in fact on the same range pole if possible. The laser unit sends the distance and azimuth readings to the GPS data collector and the software converts the laser readings to LAT/LONG based on the GPS antenna position as the reference. (See Fig3.7)

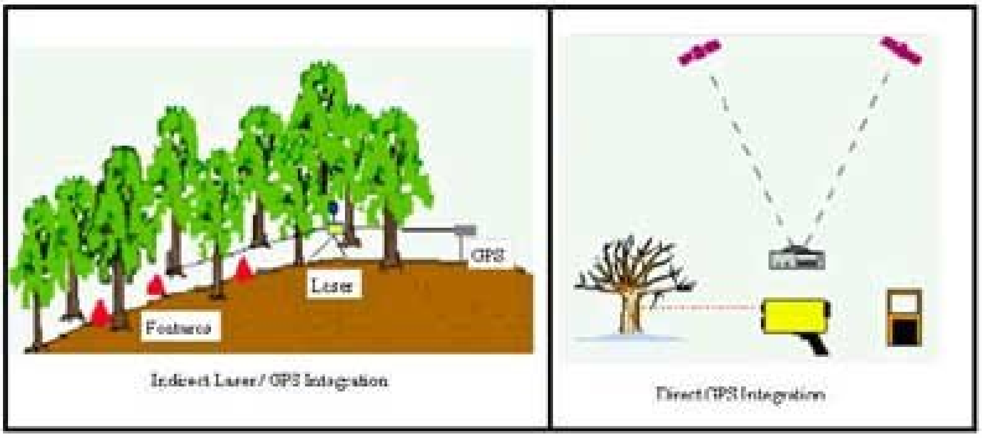


Figure 3.8 Direct and Indirect Laser / GPS Integration. *(gisdevelopment.net)*

3.6.3 Indirect Laser/GPS integration

In cases where GPS signals are not being received, the GPS antenna is placed in a clear area where signals are available and the Laser is placed in any suitable area where maximum number of features are visible. The laser sends the distance and azimuth readings to the data collector and the software calculates the LAT/LONG of the features based on the antenna position. (See Fig 3.7)

3.6.4 Independent Laser Mapping

Laser Range finders can also be used without GPS. Here you place the laser at any reference point (base map coordinates, survey points etc) and call it "ORIGIN". From this origin, you can shoot the laser to various points of interest and the distance and azimuth readings are sent to the data collector and stored. In this method the position of features are accurate to base maps and to each other. The data collected by this method will be relative data only. However, in the future when LAT/LONG positions are available for any reference or points, one can insert that value in the software and all the relative data will be converted to absolute data in LAT/LONG. **(Ashok Wadhwani)**

3.7 Mobile Mapping System Selection Considerations

3.7.1 GPS Receiver Selection Consideration

The most important criteria in selecting a GPS receiver is identifying the accuracy that the application requires. The receivers generally fall into 4 categories. Autonomous - 10-15 meters, 1-3 meters, submeter, and survey grade. For all but the autonomous category, you will need some way to correct the readings. The corrections can be - Post processing, Coast Guard Beacon, and Satellite based.

In the post processing option, you need to ensure that base station data is available from a nearby base station. If the Coast Guard Beacon method is chosen, one needs to identify if a beacon station is available near the site. In the satellite based option, one needs to make sure that the service is available in the area and the subscription paid for.

3.7.2 Data Collector Selection Consideration

The weight and size of the unit is an important factor when using these units in the field for a long time. The type of operating system (Palm O/S, Pocket PC, WINDOWS) to be used needs to be considered if integrating with other application platforms. If you require a display of a background map, it will be preferable to have a unit with a larger screen and color display. However, the color display may reduce your battery life. If the application involves use in a rough environment, the data collector selected must be ruggedized for outdoor use. Battery life is also an important factor in the selection of the data collector. The unit selected has to be compatible with the type of GPS receiver to be used

3.7.3 Laser Range Finder Selection Consideration

If you need to collect large amount of data and in areas which are difficult to reach, a laser range finder will be a very helpful tool. If the work involved is in an area where magnetic fields are present, an angle encoder will be a better choice than the digital compass.

3.7.4 Software Selection Consideration

As certain versions of field data collection software have limited features, several factors need to be considered in selecting the right software.The selected software should be compatible with the GPS receiver and the operating system chosen for the data collector. Some software packages do not allow you to create and edit features in the field. This restriction implies that for any changes and or additions to the data dictionary, you will have to stop the project in the field and access a PC to edit the dictionary, reload the new version of the dictionary, and restart the field project. This is a very time consuming process which can be avoided by simply selecting the software with field editing of the data dictionary capability

Often field data projects are handled in different datums and projections, and as a result, one should choose software with capability to select various datums/projections. If laser range finders or any other external devices besides GPS are to be used, make sure that the software is compatible and raw data is converted into the proper units. It is good practice to view the quality of GPS data collected by viewing the DOP number. Hence, one should pick a software package which displays DOP values. If you need to go back to a previously located or known point, you will need the navigation capability in the software. Most often the collected data needs to be imported into a GIS. The software chosen should be able to provide a conversion routine to allow an import of GPS and Feature data into various types of GIS software, such as, ARCVIEW, MAPINFO, and AUTOCAD. **(Ashok Wadhwani)**

3.8 Development of Mobile Mapping Systems Technology

3.8.1 Photo-Logging

In the 1970's, ***photo-logging*** systems were used by many highway transportation departments to monitor pavement performance, signing, maintenance effectiveness, encroachments, etc. These services are typically conducted every two or three years. Often film cameras were used to capture photos through the windshield of a vehicle (e.g., van). Inertial devices such as gyroscopes and accelerometers, and wheel counters were employed to determine the instantaneous positions of the captured photographs. Each photo was stamped with time and geographic position information. These photos were stored mainly as a pictorial record of highway performance (Birge, 1985). Due to the poor accuracy of vehicle positioning and only a single camera configuration in these systems, the functionality of 3-D object measurement was not available. The main drawback of photo-logging is the film-based storage and processing. Accessing the photos for engineering, planning, legal or safety activities was time-consuming because film is fragile and the process requires costly film production. For example, Tennessee Department of Transportation (Tennessee, U.S.A.) maintains the photolog of approximately 27,000 miles of roadway in its state. All pictures were kept on film and they were only viewed by using some special viewing machines. In order to make these photos more accessible, the Department has converted its existing photolog from film to a digital format and developed a client/server based system. The system allows users to point-and-click any location along the roads and views the logging images through a desktop PC connected to the server.

3.8.2 Video-Logging

With the advent of the Global Positioning Systems (GPS) as well as the video imaging Technologies, cumbersome photo-logging systems were replaced by GPS-based video-logging systems. It has been demonstrated by many projects that the GPS-based video-logging systems offer a fast and low-cost approach to highway inventory (Lapucha, 1990; and Schwarz et al., 1990). The collected video images can be georeferenced with respect to a global coordinate system by using continuous GPS navigation and positioning information. The turn-around time of data processing is significantly reduced since no film processing is involved. Furthermore, the digitally georeferenced video data allows quick retrieval and effective management. The capability of interpretation of highway video data is also strengthened through the use of image processing software. This approach has become widely accepted by most transportation departments. Visual Inventory and feature documenting along road corridors remain the major purpose of these kinds of systems. Due to the low resolution of video images, quantitative measurements from these images are still limited. The video images are often stored in a tape system. This may further degrade the quality of images. It is a fact that most of these systems only have a single camera configuration. Therefore, precise 3-D measurements are not possible. However, some alternative methods can be developed to provide relative measurements from a single image, such as height and offset measurements (Tao, 1997).

3.8.3 Mobile Mapping

The evolution of mobile mapping systems from video-logging systems was mainly contributed by the efforts of two research groups in North America, The Center for Mapping at The Ohio State University, U.S.A. and the Department of Geomatics Engineering at The University of Calgary, Canada (Bossler et al., 1991; and Schwarz et al., 1993). Compared to video-logging systems, mobile mapping systems are able to offer full 3-D mapping capabilities that are realized by using the advanced multi-sensor integrated data acquisition and processing technology (El-Sheimy and Schwarz, 1995; Li, 1997; Novak, 1995, and Tao, 1997).

A common feature of mobile mapping systems is that more than one camera is mounted on a mobile platform, allowing for stereo imaging and 3-D measurements. Direct georeferencing of digital image sequences is accomplished by the multi-sensor navigation and positioning techniques. Multiple positioning sensors, GPS, Inertial Navigation System (INS) and dead reckoning (DR) can be combined for data processing to improve the accuracy and robustness of georeferencing. The ground control required for traditional mapping is eliminated. The systems can achieve centimeter accuracy of vehicle positioning and meter or sub-meter 3-D coordinate accuracy of objects measured from the georeferenced image sequences. (Tao et al., 2001)

Another advantage of mobile mapping systems is that the data link to a geospatial database is easy and straightforward. The collected geometric and attribute information can be directly used to build and update a database. With the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through widely distributed Internet and even wireless networks.

3.8.3.1 Mobile Mapping vs. Real-Time Mapping

The objective of mobile mapping is to acquire data for deriving spatial and attribute information digitally and dynamically during the course of surveying. Data processing and production of GIS databases can be carried out in a post processing procedure. On the other hand, real-time mapping requires that the products, such as maps or GIS databases, be delivered during the course of surveying. In many applications the post processing does not cause any problem. For example, it is important to reduce the field survey time when a utility survey along a highway is conducted. However, in some other applications, the post processing becomes an obstacle, when, for example there is no previously acquired spatial data available and the mobile mapping system is employed to produce the spatial information used immediately. Such applications can be found in military situations and in emergency response systems. In the latter cases, real-time mobile mapping is unavoidable.

Currently, there are three major factors affecting real-time mobile mapping: a) Differential GPS corrections are not available until observations at both the master station and rover stations are post processed, so that the determination of the vehicle positions by DGPS cannot be performed. Transmission of the differential GPS corrections between the master station and rovers by radio beacons has been experimented by U.S. Coast Guard (Leick 1995). This makes real-time

Kinematic positioning possible. If high quality corrections for OTF (On-The-Fly) are transmitted, real-time mobile mapping will have one less obstacle. b) Integration of data sets from different sensors sometimes requires accumulative data acquired over a period of time instead of in a moment. An extreme example is when INS data captured within a tunnel have to be integrated with GPS data at the two ends of the tunnel. c) Although some simple features, such as the track of the vehicle, some marked targets, and road centerlines, can be extracted and their positions in the object space can be calculated in a relatively short time (He and Novak 1992, Li 1993, Li et al 1996), measurements of most features require either an interactive or semiautomatic procedure which cannot usually be performed in real-time. Mobile mapping systems may provide some simplified real-time functions, for instance for checking completeness of the data acquired. Data processing and measurements are conducted in post processing sessions.

3.9 Multi-Sensor Integrated Mobile Mapping Technology

A mobile mapping system consists of three components: data acquisition, information extraction and information management. In this section, the data acquisition component is described. This is the first but critical step to the development of a mobile mapping system.

3.9.1 Direct Georeferencing

The most important concept of mobile mapping is direct-georeferencing. The conceptual layout of direct georeferencing is shown in Figure 3.8 Direct-georeferencing refers to the determination of the exterior orientation of the mapping sensor without using ground control points and the photogrammetric block triangulation. For example, if a camera sensor is used, any captured image can be “stamped” with the georeferencing parameters, namely three positional parameters and three attitude parameters. As a result, 3-D object measurements can be achieved directly by using a photogrammetric intersection. There are three modes for direct georeferencing, namely, stand-alone mode, integrated model and combined mode.

Stand-alone mode: Due to the unavoidable occurrences of the GPS satellite signal blockage, the use of GPS alone to provide the positional information is not reliable. Although a number of radio navigation systems as well as recent cellular positioning systems, e.g., Loran-C, CDMA-based systems, are available, they do not yield sufficient accuracies for most mobile mapping applications. The stand-alone mode for georeferencing is not a stable solution for mobile mapping. However, it has been used very often for video-logging applications where the accuracy requirement is not high.

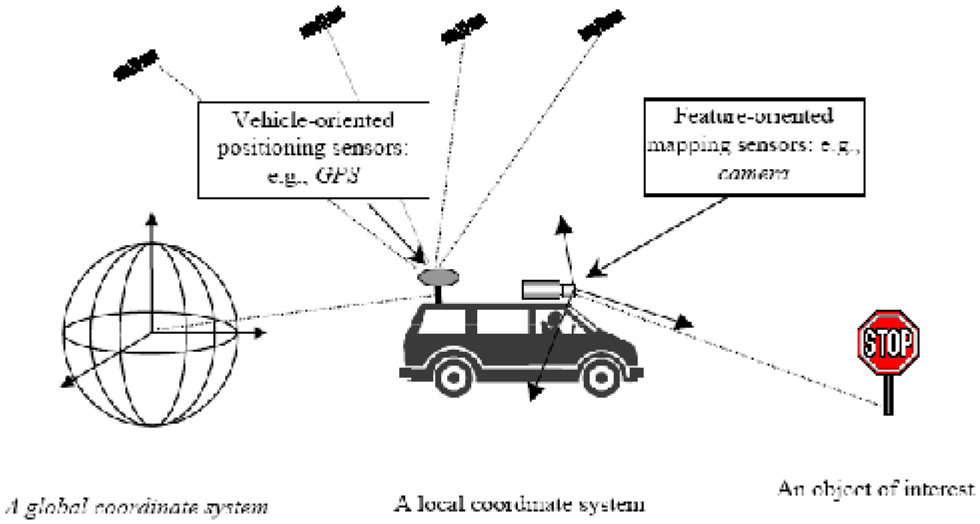


Figure 3.9 the concept of direct georeferencing

Integrated mode: The integrated use of external inertial positioning systems is, currently, widely adopted approach for georeferencing (Schwarz and Wei, 1994; Lithopoulos, 1996; Skaloud et al, 1996; Grejner-Brzezinska, et al., 1999). Depending on the applications, different levels of integration and different ways of sensor combination can be developed, for example, GPS with INS, GPS with DR, etc. This mode will be further discussed next.

Combined mode: In the airborne photogrammetry, combined mode for georeferencing is predominately used in practice due to its high performance, reliability and economic factors. In this mode, the GPS observations and the photogrammetric observations are both combined into a triangulation block adjustment. Thus the systematic GPS errors can be controlled and corrected via the combined adjustment (Ackermann, 1996). Very few control points are required in this combined mode to solve the datum transformation. In mobile mapping systems, it is a fact that the image tie points available from the overlapped image sequences can be used to perform a strip wise photogrammetric triangulation. Thus, the orientation parameters of the camera can also be derived. This technique can be used for quality control of georeferencing data derived from GPS/INS observations, and furthermore, to bridge gaps where the absence of the orientation observations occurs. The new georeferencing approach has been researched at the University of Calgary (Chaplin and Chapman, 1998; and Tao et al., 1999).

Direct georeferencing brings of significant benefits to the mapping procedure in terms of the rapid turn-around time of data processing and reduced cost of ground control surveys. The direct georeferencing technique makes mobile mapping feasible and has also led to the successful development of a new generation of airborne mobile mapping systems, such as airborne LIDAR mapping systems and airborne SAR systems. It is a goal that mapping would be independent of any ground control, and ultimately, mapping becomes completely autonomous. (Tao et al., 2001)

3.10 Positioning and Mapping Sensors

The development of mobile mapping systems is featured by the use of multiple sensors as well as integrated sensor processing methods. In general, there are two primary types of sensors that are involved, namely, positioning sensors and mapping sensors:

3.10.1 Positioning sensors

a) Environment-dependent external positioning sensors: GPS, radio navigation systems, Loran-C, and cellular positioning devices, etc.

b) Self-contained inertial positioning sensors: INS or IMU (Inertial Measurement Unit), dead reckoning systems, gyroscopes, accelerators, compasses, odometers, and barometers, etc.

3.10.2 Mapping sensors

a) Passive imaging sensors: video or digital cameras, multi-spectrum or hyper-spectrum Scanners, etc.

b) Active imaging sensors: Laser range finders or scanners, and synthetic aperture radar (SAR), etc. Other sensors such as voice recording and speech recognition devices, touch-screens, temperature or air pressure meters, gravity gauges, etc. may be of use for integration. The positioning sensors are vehicle-oriented. They are used to determine the absolute locations of the mobile mapping platform with respect to a global coordinate system, e.g., WGS-84. While, the mapping sensors are feature-oriented. They provide the positional information of objects (features) relative to the vehicle in a local coordinate system. In addition, attributes of features can be obtained from the mapping sensors. Precise calibration is required to geometrically align the positioning sensors and mapping sensors together. Accurate synchronization (time referencing) of the sensors is also required.

3.11 Accuracy Assessment of Sensors

The choice of sensors and the effective integration of sensors is a key to the development of a mobile mapping system. Accuracy, cost, reliability, data rate, portability, power consumption as well as integratibility are the most important factors to be considered. Among of them, accuracy and cost are the primary factors for a system design and implementation.

3.11.1 Accuracy of Positioning Sensors

GPS is the most viable choice for the determination of position information due to its wide acceptance and proved performance. GPS can be operated in a variety of modes. The associated accuracies of each mode are summarized in Table 2 (Ellum and El-Sheimy, 2000).

GPS mode	***Horizontal Accuracy (2-D RMS)***	***Vertical Accuracy (RMS)***
Code Differential (Narrow Correlator, Carrier-phase smoothing)	0.75 m	1.0 m
L1 Carrier-phase RTK (Float ambiguities)	0.18 m	0.25 m
L1/L2 Carrier-phase RTK	0.03 m	0.05 m
L1 and L1/L2 Post-mission Kinematic	0.02 m	0.03 m
L1 Precise ephemeris (with Ionospheric Modeling)	1.0 m	3.0 m

Table 3.1 Position accuracy of GPS

With respect to the attitude determination, there are a number of options. Table 3 gives a list of possible sensors for attitude determination. The accuracies stated are for tilt angles (roll and pitch) below 20 degree. For more information regarding these numbers, one may refer to Ellum and El- Sheimy (2000), and Schwarz and El-Sheimy (1996).

In fact, only the IMU can provide all three attitude angles. For the other systems to provide all three attitude angles, they must be combined with additional sensors. Alternative to the IMU approach is to use GPS multi-antenna systems. It has been used in the airborne and ship-borne. Environments where its accuracy for attitude determination has been acceptable. However, for the land vehicle based mobile mapping applications, such a multi-antenna based GPS system can not reach the acceptable accuracy level due to the fact that the baseline between the antennas is limited. Most mobile mapping systems use navigation grade IMU in order to meet the accuracy requirements. This is one of the reasons that make the initial development cost very high.

Sensor Type	**Accuracy in Roll and Pitch**	**Accuracy in Azimuth**	**Cost (USD)**
Navigation Grade IMU	<0.01	<0.03°	>$100.000
Six-Axis Tactical Grade IMU	0.25°	2°	$12000 – 20000
Twin Antenna GPS	0.5°–1.0°	0.75°	$2,000 –6,000
High-Accuracy Tilt Sensor	0.05°	-	$3500
Low-Accuracy Tilt Sensor	0.25°	-	$700
Magnetic Azimuth Sensors	-	1.0°	$250
3-Axis Magnetometer Integrated with 2-Axis Tilt Sensor	0.25°	1.0°	$700-1,200

Table 3.2 Accuracy of sensors for determining attitude

3.11.2 Accuracy of Mapping Sensors

Considering the error contribution from the imaging component alone, the positioning accuracy of object point coordinates derived from imagery is determined mainly by four factors: the object distance (*Y*), the baseline length (*B*), the focal length (*f*), and the mean square error of image coordinate measurements (*mpxl*). The along-track error component is the predominant error contributing to the total positioning error in mobile mapping applications. Tao (1999a) has conducted a comprehensive analysis of the achievable accuracy from a stereo imaging system. The main conclusions can be summarized as:

a) The maximum baseline length between two cameras is restricted by the desired overlap percentage; the overlap percentage is affected by the field of view angle of the camera; and the field of view angle is determined by the focal length and the camera sensing area. Therefore, a best trade-off is required for the configuration of these imaging parameters. In Tao (1999a), a method to find an optimal combination of imaging parameters was developed.

b) Under the assumption of that the manual measurement accuracy for a single image point is 0.29 pixels; the maximum camera-to-object distance is 35m if the object positioning accuracy of 30 cm is required (with a standard CCD stereo camera system). However, if the image coordinates measurement accuracy of 0.2 pixel can be achieved, the positioned object can be 50m far from the camera. Therefore, development of sub-pixel image measurement algorithms is of significant importance. The use of multiple-image matching for point measurement has been considered as an effective approach (Tao, 1997).

c) The choice of camera types is critical to overall system performance. The camera parameters such as pixel spacing, sensing area, electronic noises, and data capture rate and storage requirement must be considered carefully. Cameras with small pixel spacing, pixel synchronization unit and built-in A/D converter allow for obtaining more accurate

Image coordinates measurements. The use of large sensor cameras will improve the overall system accuracy and permit flexibility on the configuration of imaging parameters. An accurate calibration of interior orientation parameters, rotation angles φ (rotation around the axis Z) and the baseline is required. Based on the theoretical analysis (Tao, 1999a), the calibration accuracies of 0.3 pixel of interior orientation parameters, 0.02° for the rotation angles φ *, 0.03*° for the relative orientation angle and 3.5 mm for the camera baseline have to be achieved, so that the effects of the calibration errors onto the total system positioning accuracy are at the same level of that of errors arising from image coordinate measurements. However, calibration accuracy for the rotation parameter ω and κ is not stringent.

Accuracy for time referencing is also important but is technically achievable. The tests showed that if the error of 10^{-3} second in synchronization can be controlled, the resulting position error is less than 4 cm at a vehicle speed of 60 km per hour (Schwarz and El-Sheimy, 1996).

3.11.3 Accuracy Improvement

The accuracy from an individual sensor component is discussed above. However, effective combination of these sensors and integrated processing of the sensory data will be able to further improve the total system accuracy. There are basically two levels of the integrated processing: (1) integrated processing of multiple positioning sensory data; and (2) integrated processing of positioning and mapping sensory data. For example, if GPS and INS are combined for positioning, the INS drifts with time can be largely controlled by using GPS updates while GPS outages and cycle slips can be corrected by using INS data (Wei and Schwarz, 1990; Schwarz and Wei, 1994; Toth and Grejner-Brzezinska, 1998; and El-Sheimy et al., 1999). As for the second level of integrated processing, image-based sequential triangulation using the tie points from the overlapped images can be used to determine the orientation parameters of each image. This technique can be used to augment the georeferencing accuracy derived from the positioning sensors or to bridge gaps where the GPS signals are lost. However, this technique is not as effective as that being used in the airborne photogrammetry. This is mainly due to the poor triangulation geometry of tie points obtained from the terrestrial images. The accuracy evaluation and the automatic determination of these tie points can be found in Bruce and Chapman (1998). One good example on the use of this technique for georeferencieng of terrestrial digital images can be found in (Silva et al. 2000).(Tao 1998).

CHAPTER 4

SPECIAL APPLICATIONS

4.1 Highway Applications

Because it employs dynamic data acquisition, mobile mapping technology can be directly used in highway related applications, such as traffic sign inventory, monitoring of speed and parking violations, generation of road network databases, and road surface condition inspection when laser technology is jointly applied. There are several advantages to using mobile mapping technology in highway applications. The data acquisition is performed without blocking the traffic assuming that traffic velocity is less than, for example, 70km/h. The information obtained is diverse - single collection can be used for multiple purposes. Moreover, since data can be both collected and processed in a short period of time, frequent and repetitive road surveys and database updating are both possible and affordable. Objects along roads and highways, for example traffic signs, light poles, bridges, road centerlines etc., are usually represented as clear image features in the image sequences. Therefore, they can be identified easily and measured interactively to build a spatial database. In order to extract a road centerline, an image sequence of the road is needed. Each image pair supplies a segment of the centerline. The successive road segments from the sequence are measured continuously and combined to produce the entire road centerline. Road centerlines and separating lines between lanes are painted in white or yellow. They have solid or dashed line patterns. Based on road surface and weather conditions, the quality of the lines in the image sequence vary. Manual extraction of the lines by the operator is relatively time-consuming, although it is superior to other traditional surveying methods. Automation of This procedure has been researched. From the image sequence, centerline features are enhanced and extracted automatically. The corresponding 3D centerline segments are then generated in the object space (He and Novak 1992). Another approach defines a 3D centerline model in the object space as a physical Snake model (Tao et al 1996). The Snake model is optimized to adjust the centerline shape using image features of the centerline as internal constraints, and geometric conditions derived from other sensors of the system (GPS and INS) as external constraints. This method for automatic centerline extraction and reconstruction is reliable for different road conditions and line patterns. On the other hand, road curb lines, as opposed to painted centerlines, are projected onto the images based on their geometric shapes and material types. Therefore, curb lines can be more difficult to extract and identify automatically. Currently, the curb line databases are built using semiautomatic approaches. The system provides the user with projected curb lines in a stereo image pair. The user is asked to confirm if the line pair suggested By the system is correct. Sometimes, because of the image quality, the system cannot provide the suggestion. In this case, the operator is asked to digitize the curb segments manually. It is often required in road surface condition inspection that road surface cracks be located and measured. If the system is equipped with laser sensors, the depths between the sensors and the road surface are available as relative measurements. If the control data from GPS and INS are available, the depth data derived from the laser sensors can be integrated into the global reference system and used to generate a Digital Road Surface Model (DRSM). The DRSM provides a geometric description of the road surface. This can be used to detect the locations, sizes, and shapes of the road surface cracks. If the digital image sequence of the same road is processed and georeferenced, each grid point of the DRSM can be assigned with a gray scale from the corresponding pixel of the image sequence. In this way the images appear to be draped onto the DRSM and a 3D road surface image is generated. By observing this 3D image using 3D visualization tools, road surface conditions including cracks can be illustrated more efficiently. On the other hand, the DRSM can also be built from the stereo image sequence along the road. Corresponding road surface points appearing in a stereo pair can be measured by digital image matching techniques. Since one point may appear in more than one successive stereo pair, a point covered by an obstacle, such as a vehicle, in one stereo pair may be visible in the preceding or subsequent pairs. A gridding procedure is applied to calculate grid points of the DRSM. In comparison to the digital matching method using stereo image sequences, laser sensors generate more reliable surface models, because the depths are always measured directly. However, in the Model built by the matching based method, there may be areas with points that are not measured, but interpolated, because the areas are invisible or do not have sufficient image texture for image matching.

4.2 Application to Facility Mapping

Another useful application of mobile mapping technology is in the area of facility mapping. High voltage power transmission lines can be photographed by the mobile mapping system and their positions can be measured from the image sequences. There are a number of important parameters which can be calculated from the mobile mapping data, for instance the positions of the poles and/or towers; the positions of the insulators on each line which support the suspending transmission line segments; and the lowest points of the suspending line segments. In order to capture these desired transmission line features, the cameras have to be oriented somewhat upwards to aim at the towers and line segments. Consequently, a large portion of the resulting images contains the sky as the background. This makes it easy to distinguish the targets from the background in the images because of the high contrast between them. Based on the same reason, automatic extraction of the transmission line segments in the image space is also possible. However, if epipolar geometry (Moffitt and Mikhail 1980, Li 1996) is used to determine the line segments in the object space, the 3D points along the line segments to be measured are dependent on the intersections between the epipolar lines and the line segments in the images (Figure 4). In case I, two cameras are forward looking, with an upper-left angle. For the k-the image pair, the epipolar line formed by Image left, k and Image right, k are almost parallel to the transmission lines. The intersections thus obtained are of low accuracy considering the effect of both the intersection accuracy and errors of the epipolar lines caused by imperfect orientation parameters. This will consequently affect the accuracy of the 3D line segments in the object space derived thereby. There are three options for solving this problem: a) in case I of Figure 4,
if an appropriate overlapping area is available, subsequent images such as Image left, k and Imageleft,k+1 are used to form a stereo pair so that the Epipolar line(left,k)(left,k+1) has a better intersecting angle with the transmission line. b) In case II of Figure 4, the cameras are oriented toward the left side. This will also result in effective intersecting angles. c) A hardware-based stereo viewing system can be used, for example using a polarized system with a stereo glass and a special monitor. In this case, a 3D stereo model can be reconstructed. The operator is then able to view the transmission line in 3D and measure points along the line three-dimensionally. d) Better results can also be

achieved by combining data acquired by laser ranging by a helicopter if available (Krabill 1989).

Some objects such as fire-hydrants and manholes have symmetric geometric shapes and are less dependent on the camera positions and orientations. Thus, they appear similar in images. Based on the geometric shapes of the objects, simulated lighting sources, and material characteristics, artificial images can be generated. These artificial images can then be compared with the image features in the sequences. A matching procedure between the artificial images and real images is performed. In this way, both the geometric information and attributes of fire-hydrants and manholes appearing in the image sequences can be extracted efficiently.

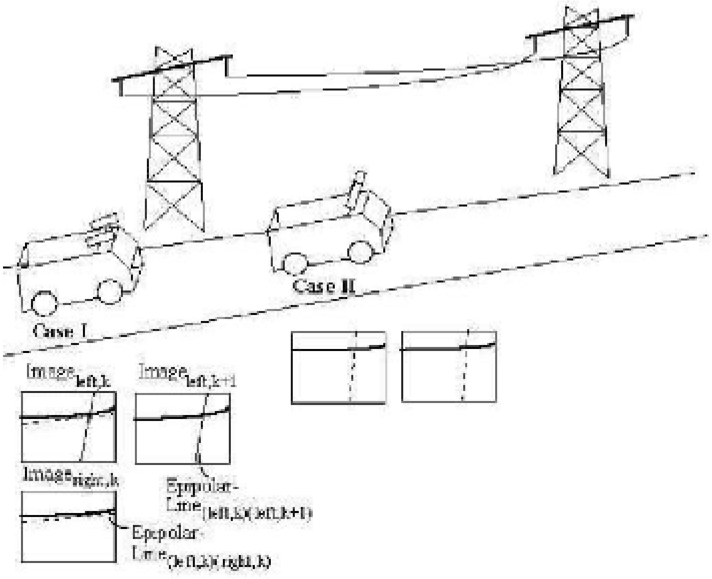


Figure 4.1 Facility Mapping

Utility mapping and inventory

These maps are mainly used by utility and telecommunication companies. The accuracy may not be as strict as land surveying maps. However, it requires more frequent updating. Utility features such as transformers, power lines, telephone lines, street light poles, are need to be geocoded and linked to a road centerline based map database.

Normally, the heights or the offsets of utility poles and cable attachments need to be measured. This information helps companies for design, planning
And maintaining of electric unities, phone or cable routing.

4.3 Application in precision agriculture

What is Precision Agriculture?

Precision agriculture is relative new and lacks a recognized and useful definition. To better understand the need for an accurate definition of precision agriculture lets look at how precision agriculture is being considered. Precision agriculture is considered a concept, management strategy, and even a philosophy.

From other hand "Precision Agriculture refers to the use of an information and technology-based system for within-field management of crops." It basically means adding the right amount of treatment at the right time and the right location within a field—that's the precision part," Farmers want to know the right amounts of water, chemicals, pesticides, and herbicides they should use as well as precisely where and when to apply them. (Herring, 2001)" (K. Shaikh, A. Shariff, H.Jamaluddin, S.Mansoor, Putra University, Malysia)

Concept

It is said, "Precision agriculture is a phrase that captures the imagination of many concerned with the production of food, feed, and fiber." The concept of precision agriculture offers the promise of increasing productivity while decreasing production cost and minimizing environmental impacts. Precision agriculture conjures up images of farmers overcoming the elements with computerized machinery that is precisely controlled via satellites and local sensors and using planning software that accurately predicts crop development. This image has been called the future of agriculture.(**Michael Rasher)**

4.3.1 Precision agriculture

Precision agriculture is a new agriculture technology system development quickly in recent years. Integrating agronomy, geography, biology, agrology, botany, geo-spatial science, and precision agriculture can be defined as a comprehensive system designed to help farming. It involves various problems in crop planning and includes tillage, planting, chemical applications, harvesting, and post harvest processing of the crop.

Precision farming is a pro-active approach that reduces some of the risk and variables common to agriculture, so we think that it has the potential of optimizing cost and ecological effects through the application of crop information, advanced technology and management practices. Accordingly, how to get these information and data quickly and accurately becomes the foundation of precision agriculture construction, while how to manage the information and make decision quickly and intelligently is the key technology in precision agriculture.

It is obvious that information technologies are foundation of precision agriculture, and positioning, timing, mapping and analysis are most important among them. Accordingly Mobile Mapping System can help agriculturist with a new capability of gathering information for implementing decision-based Precision Agriculture.

4.3.2 Mobile Mapping System in Precision Agriculture

For precision farming, information technologies are so essential that Mobile Mapping System is important or beneficial. Equipped with mapping sensors and navigation sensors, Mobile Mapping System can collect field data anytime, anywhere, in any manner. At the same time, Mobile Mapping System can connect with a GIS or combine GIS software in its mobile terminals directly. Thus Mobile Mapping System can monitor planting process all along. Moreover it can contrast multi-temporal data collected or stored in database and find what changes occurred, where, when and how, then give an efficient plant plan. What function the Mobile Mapping System has in precision agriculture is narrated in Figure 4.2

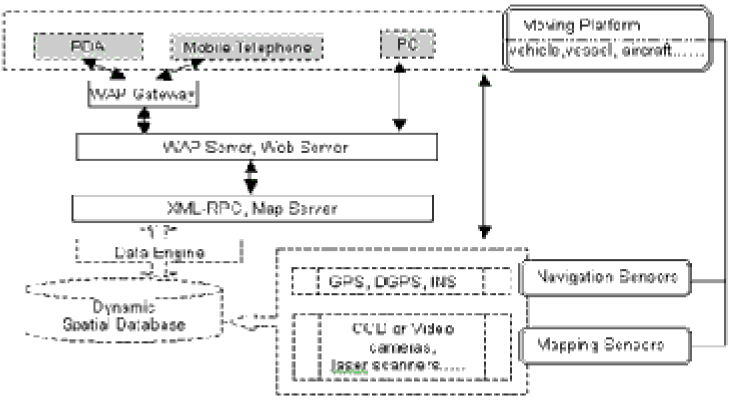


Figure 4.2 Function of Mobile Mapping System in precision agriculture

4.3.2.1 Improve the Accuracy of Soil Sampling

Soil conditions and soil quality influence crop growth greatly. Usually how often do farmers fertilize the soil or water the land depends on the soil conditions and plant type. So it is a basic work to master the soil conditions. From the view of precision agriculture, soil is different meter by meter. Thereby soil sampling becomes the foundation step. The accuracy of soil sampling is requested higher.

Accuracy of soil sampling refers mainly to accurate degree of the position information where the soil samples were taken. With the accurate knowledge about the coordinate location of the soil samples, a soil data layer can be developed accordingly. With the accurate position information, navigating back to those locations for re-sampling is possible.

Mobile Mapping System has equipped navigation sensors, such as GPS and INS, so the time and position information can be recorded at the same time when soil samples are taken. Consequently a soil difference map can be create, on which physical attribute of soil is described

4.3.2.2 Plant Growth, Diseases and Insect Pests Monitor

Generally precision agriculture is constructed in a large area. Hereby it is impossible for all plants growing in like manner. Sometime only a single part suffers the diseases and insect pests. Then it is unnecessary and even harmful for all plants to spray pesticide or other medicine in the same way. Different solution should be taken according to the real conditions of plants

Mobile Mapping System can finish the monitor task of all the plants. Using the scanners, the peculiar plants can be found quickly, and its position also can be recorded. In fact satellite remote sensing data also can provide such distinction information. Compare with Mobile Mapping System, its spatial range is much larger but space resolution is lower and constrained by satellite calendar.

4.3.2.3 Analysis of the Crop and Field Information

The purpose to get so much data about the soil, plant and so on is to master the planting conditions and to make decisions for all planting process. Accordingly GIS and Agriculture Expert System are usually imported in precision agriculture in order to edit, process, integrate and analyze the crop and field information and get corresponding resolve scheme.

Mobile Mapping System may Load multi-source information and different types of agricultural data to master the conditions of the field. Comparing the information or data, relationships within and between data sets can be found. That is the relationships among different factors can be made certain. By the relation, agronomist or Agriculture Expert System can make production plan

After the production plan has been made, farmers can command the farming machines to work automatically, for these machines has been equipped intelligent implement and positioning devices. Moreover the entire process of one year farming also can be recorded and evaluated, and the experience can be analyzed to help next year work.

4.4 Infrastructure mapping for emerging responses

Due to the wide implementation of E-911 services for emerging responses in North America. Positions and attributes of buildings, important landmarks, telephone booths etc. are required for the establishment of emergence response databases. It helps decision makers to layout the response routing and dispatch emergency vehicles. The images collected can be used to assist the appraisal, evaluate the condition and prepare for any special treatment.

It is worth mentioning that Intelligent Transportation Systems (ITS) presents a huge potential market for mobile mapping applications. It is projected that $209 billion will be invested in ITS between now and the year 2011 in the form of consumer products and services. The full-scale deployment of mobile mapping technology will take place for ITS data acquisition, database updating and information management.

4.5 Some Papers on New Developments and Applications of Mobile Mapping Systems

(Presented *during the 3rd International Symposium on Mobile Mapping Technologies,* FIG XXII International Congress Washington, D.C. USA, April 19-26 2002*)*

4.5.1 New Applications:

1. Automatic Bald Digital Terrain Model Reconstruction from Digital Surface Data Acquired from an Airborne SAR System: Two approaches for automatic reconstruction of bald DTMs from Digital Surface Models (DSMs) are presented in this paper; namely hierarchical and non-hierarchical approaches. The non-hierarchical approach is mainly used for urban areas while the hierarchical approach is suitable to different terrain types and data with different spatial resolutions. Test results show that for the hierarchical approach the accuracy of the reconstructed bald DTM, when referenced against bald terrain surface models generated from a Lidar mapping system, is typically less than 1.25 meters RMSE in urban and low mountain areas. This is obviously an acceptable result as the accuracy of the original SAR DSM is at 1-2 meter (RMSE) level.

2. Automatic Generation of a Hierarchical DEM for Mars Rover Navigation: This paper Presents techniques for the generation of a hierarchical DEM using descent and rover Imagery for Mars mapping and rover localization. During a descending process of a Mars spacecraft, ten descent images may be taken at approximately every half of the altitude. The images can be used to generate an initial DEM of the landing site. The paper proposed a further refinement technique for the DEM both in accuracy and resolution to form a five-layer hierarchical DEM, with the resolution ranging from one centimeter in the immediate area of the landing center to one meter in the boundary region about 1 km away from the center. The DEM is generated by using the hierarchical descent images with an increasing sequence of resolutions. The produced hierarchical DEM can be used for an interactive system to assist rover traverse design and for landmark extraction for automatic Mars rover localization. The authors mentioned that in future research, the rover images will also be used to expand the hierarchical DEM as the rover traverses farther from the landing center. The DEM will be refined and expanded as more new rover images become available.

3. Integrating Data from Terrestrial Mobile Mapping Systems and Aerial Imagery for

Change Detection Purposes: Data fusion from different sources is one of the key problems facing the photogrammetric and computer vision research communities. In this Paper, a new approach for combining data from terrestrial Mobile Mapping Systems (MMS) and aerial imagery. Road network data, captured by a MMS, is used to determine the Exterior Orientation Parameters (EOP) of an aerial image - Single Photo Resection(SPR).

4. Integrating photogrammetric data from mobile ship-borne and airborne systems for support conservation process, and environmental analysis of cost heritage along the “CinqueTerre” coast in the Gulf of Liguria region, Italy: The project is directed to emphasize the environmental heritage, on which Levanto and Bonassola base their own tourist economy, focusing the guide lines and the analysis required for the landscape insertion of the recovering project of the old railway tunnel faced to the seacoast, work over land and work over sea, through 3D virtual navigation on the gulf of Levanto and on urban centre.

5. Automatic Building extraction from airborne laser systems: This paper introduces a series of building extraction techniques in compatible with Airborne Laser-ranging and Multiple-spectral Imaging Mapping System (ALMIMS), including shadow-based method for large buildings in urban area with sparse laser ranging points, and direct laser-point segmentation method for buildings in rural area. These techniques perform well in semi real- time, thus provide a fast data source for GIS system.

6. Integration of Mobile Phone Location Services into Intelligent GPS Vehicle Navigation Systems: GPS for position determination in vehicle navigation systems in stand alone mode works quite well only for open areas. It is obvious that in the case of obstruction of satellite-receiver visibility either position accuracy is bad or no position determination is possible. Especially in cities with high-rise buildings, satellite visibility is a very critical issue for intelligent vehicle navigation systems. Therefore GPS positioning has to be combined with other methods, e.g. dead reckoning (DR) and map matching. Apart from this, other new technologies are available nowadays which can also be employed in navigation systems. In particular, mobile phones of the next generation, the so-called 3G (Third Generation) phones, will provide the ability to determine the location of any mobile phone subscriber anywhere, anytime, with a precision required for navigation systems. Thereby different strategies for position determination can be employed. It is claimed that the position fix can be obtained with accuracy in the order of ± 125 m using current technologies in the widespread second generation GSM network. For the use of 3G mobile phones in the UTMS network, however, an increase in accuracy for the position determination by a factor up to 10 is expected. In this paper, preliminary results on the integration of mobile phone location services for temporary position determination into the system design is investigated.

4.5.2 New Development

1. Helicopter Based Portable Handheld MMS for Avalanche Mapping: The system is developed by the Photogrammetric lab of the Institute of Geomatics at Swiss Federal Institute of Technology. It integrates light aerial camera and GPS/INS components to a platform that is free of the helicopter in 6 degrees of freedom. Experimental studies performed in the avalanche test site of "Vallée de la Sionne" allow determining the correct ratio between the system accuracy versus its flexibility. Experiments performed during the last two years in "Vallée de la Sionne" avalanche test site showed that helicopter based photogrammetry is able to provide snow volume measurements with an accuracy of 20-30cm when good conditions for accurate exterior orientation and contrast are fulfilled.

2. A Portable MMS for the Survey Community: The system is developed by the Department of Geomatics Engineering at the University of Calgary. The goal of the system development is to overcome the drawbacks of current mobile mapping systems - namely their high cost, large size, and complexity - which have restricted their widespread adoption in the survey industry. The development of such a system satisfies the demand for a mobile mapping system that can compete both cost-wise and in user friendliness with current backpack GPS systems and conventional terrestrial survey systems, while realizing the significant gains in efficiency typical for MMS. The system integrates a digital magnetic compass, dual-frequency GPS receiver and consumer digital camera into a multi-sensor mapping system. First system testing indicates that with three images at a 20m object-to-camera distance, absolute accuracies of under 25 cm are achieved. This is comparable to current single-frequency GPS data acquisition systems. The internal agreement of points surveyed using the system is under 10 cm.

3. Airborne Laser-ranging and Multi-spectral Imaging Mapping System (ALMIMS): The system is a multi-sensor mapping system developed by the Institute of Remote Sensing Applications of Chinese Academy of Sciences. It is integrated with multispectral imaging scanner, laser ranging scanner, Global Positioning System (GPS), and Inertia Navigating System (INS), all of which are tightly coupled and synchronized, insuring the pixel-level correspondence of image and laser ranging points. The result is a high-resolution multi-spectral image overlapped with laser ranging grids at certain intervals. It can produce ortho-rectified image, digital surface model, contour map, and perspective map at near real-time without ground control points. It can be used for automatic buildings/tree extraction, and semi-automatic roads tracing.

4. DORIS (Differential Ortho-Rectification Imagery System): DORIS is an airborne multi-sensor mapping system which has been under development for years at Alberta Research Council. DORIS combines a laser-scanning technology with digital imaging technology to produce high-resolution and highly accurate ortho-rectified planimetric image map. The focus of DORIS is on acquiring data for fundamental biophysical entities of sustainable forest eco-systems and reducing the cost of the planning and conduct of forest operations.(Naser El-Sheimy Report on Kinematic and Integrated Positioning Systems)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

One of the criteria used to measure the quality of the system is the accuracy of the location of objects measured using the acquired data. This accuracy is strongly influenced by the control data collected by the navigation sensors and the quality of the mapping sensors. The components of mobile mapping systems function efficiently and reliably as individual and independent systems in various applications. A mobile mapping system requires that these components work cooperatively.

Another factor to consider is cost. A highly accurate strap down INS is currently the most costly component in the system. Low level INS and gyroscopes may be used, but they do not supply the same quality angular parameters which can be employed, for example, in camera orientation.

The high cost of the INS makes the entire system relatively expensive. If high accuracy is not essential, low cost gyroscopes can be used in order to make the system more affordable. The image resolution of the cameras has a great influence on the accuracy of the photogrammetric intersections of object points. This is especially critical because the physical baseline of the cameras is limited by the dimension of the land based vehicle. For an object far from the cameras, the intersecting angle is small, and one pixel error in the image will result in to a large error along the track. High resolution cameras up to 4096pixels x 4096pixels are available but are rather expensive. In addition, the images acquired by high resolution cameras occupy a large memory and storage space. If multiple high resolution color cameras are employed, the problems of efficient image data transmission and medium storage during the data acquisition, efficient object measurement and attribute extraction, and data archiving will be addressed. GPS should provide "continuous" and consistent data for absolute positional control. However, there are cases where GPS signals are blocked by high-rise buildings, tunnels, and other objects. An integration of GPS signals at the last point before the signal blocking and the first point of signal recovery with INS trajectories bridges the gap of the control data. On the other hand, there are situations in which GPS signals are only blocked for a very short period, affecting one or two exposure stations. If not detected and corrected, these errors will distort both the positions of the camera exposure centers, and the object points derived from the image sequences. Therefore, an automated systematic quality checking procedure should be implemented to examine the GPS and INS data. If such an inconsistency exists, positions of a point derived from different image pairs of different exposure stations will show a large difference. Otherwise, they should have the same position within a certain tolerance. This quality checking procedure guarantees the quality of the control data used for camera orientation.

5.2 RECOMMENDATIONS

To overcome the difficulties and to improve the mobile mapping technology, the following further research and development should be conducted:

- If a secondary local navigation network were available in areas where GPS signals are blocked, vehicle positioning and sensor control would be more reliable anytime and anywhere. Further improvement in downloading the mapping data acquired from the vehicle by using wireless communication technology should be explored.
- Larger format CCD chips should be employed to increase the resolution of the images and consequently, the accuracy of the photogrammetrically intersected object points. This is especially important if a similar configuration is used on helicopters or aircrafts where one pixel represents a much larger area on the ground.
- More efficient image processing and sequential estimation algorithms should be researched and developed in order to make a good use of the large amount of high resolution data and characteristics of sequential images.
- Enhancement of the automation of object recognition and attribute extraction would improve the efficiency of GIS database generation from the georeferenced image sequences. This would also contribute to the reduction of the significant difference between the speed of mobile mapping data acquisition and that of the subsequent data processing.

- An alternative way to bridge a period of GPS outage using INS is to perform a terrestrial photogrammetric triangulation. A strip of overlapping photos is relatively oriented to form a strip model covering the GPS gap. The GPS data available at the two ends of the strip can be used to orient the strip model absolutely. Automation of this labor-intensive and time consuming procedure is deemed necessary. Important issues involved in the automation include automatic tie point selection, conjugate tie point searching, and absolute strip orientation using GPS data. Ideally, depending on the degree of the automation, the terrestrial photogrammetric triangulation may be performed using all images.

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APPENDIX A

GLOOSARY

- A -

Almanac - the Almanac is a file which contains positional information for all of the GPS satellites. The Almanac is used by the GPS receiver to determine which satellites to track, and can also be used for mission planning.

Attribute - a characteristic which describes a Feature. Attributes can be thought of as questions which are asked about the Feature.

Anywhere fix - The ability of a receiver to start position calculations without being given an approximate location and approximate time.

Anti-Spoofing (A-S) - For the NAVSTAR system, anti-spoofing (A-S) is the process whereby The P code used for the precise positioning service is encrypted. The resulting encrypted code is called the Y code. The encryption data can only be decoded by GPS receivers with special decryption circuitry, guarding against fake transmissions of satellite data.

- B -

Bandwidth - The range of frequencies in a signal.

- C -

C/A code - The standard (Course/Acquisition) GPS code. A sequence of 1023 pseudo-random, binary, biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. Also known as the "civilian code."

Carrier - A signal that can be varied from a known reference by modulation. **-** The signal that carries the C/A Code from the satellite to the GPS receiver.

Carrier-aided tracking - a signal processing technique that uses the GPS carrier signal to achieve an exact lock on the pseudo random code generated by the GPS satellite. Carrier-aided tracking is more accurate than standard C/A Code tracking.

Carrier frequency - The frequency of the unmodulated fundamental output of a radio transmitter.

Carrier phase GPS - GPS measurements based on the L1 or L2 carrier signal.

Channel - A channel of a GPS receiver consists of the circuitry necessary to receive the signal from a single GPS satellite.

Chip - The transition time for individual bits in the pseudo-random sequence. Also, an integrated circuit. Also a snack food. Also a betting marker.

Clock bias - The difference between the clock's indicated time and true universal time.

Code phase GPS - GPS measurements based on the pseudo random code (C/A or P) as opposed to the carrier of that code.

Control segment - A world-wide network of GPS monitor and control stations that ensure the accuracy of satellite positions and their clocks.

Cycle slip - A discontinuity in the measured carrier beat phase resulting from a temporary loss of lock in the carrier tracking loop of a GPS receiver.

- D -

Data message - A message included in the GPS signal which reports the satellite's location, clock corrections and health. Included is rough information on the other satellites in the constellation

Differential Correction - the technique of comparing GPS data collected in the field to GPS data collected at a known point. By collecting GPS data at a known point, a correction factor can be determined and applied to the field GPS data.

Dilution of Precision (DOP) - an indicator of satellite geometry for a unique constellation of satellites used to determine a position. Positions tagged with a higher DOP value generally constitute poorer measurement results than those tagged with lower DOP.

Dynamic Positioning - the process of collecting GPS data while the GPS antenna is in motion. Often associated with Line or Area Features.

Differential positioning - Accurate measurement of the relative positions of two receivers tracking the same GPS signals.

Dilution of Precision - The multiplicative factor that modifies ranging error. It is caused solely by the geometry between the user and his set of satellites. Known as DOP or GDOP

Dithering - The introduction of digital noise. This is the process the DoD uses to add inaccuracy to GPS signals to induce Selective Availability.

Doppler-aiding - A signal processing strategy that uses a measured Doppler shift to help the receiver smoothly track the GPS signal. Allows more precise velocity and position measurement.

Doppler shift - The apparent change in the frequency of a signal caused by the relative motion of the transmitter and receiver.

- E -

Ephemeris - The predictions of current satellite position that are transmitted to the user in the data message.

Ephemeris Errors - errors which originate in the ephemeris data transmitted by a GPS satellite. Ephemeris errors are removed by differential correction.

EPOC - An operating system from Psion Software, designed specifically for mobile, ROM -based computing devices. *EPOC16* is a 16-bit version of the operating system that has been available for several years and is embedded in many handheld devices. *EPOC32* is a newer, 32-bit operating system that supports preemptive multitasking. EPOC is competing head-to-head with Windows CE in the grow PDA market.

eXtensible Markup Language (XML) - XML is a semantic computer language, it identifies information 'types' and through an XML schema, information relationships.

- F -

Fast switching channel - A single channel which rapidly samples a number of satellite ranges. "Fast" means that the switching time is sufficiently fast (2 to 5 milliseconds) to recover the data message.

Frequency band - A particular range of frequencies.

Frequency spectrum - The distribution of signal amplitudes as a function of frequency.

Feature - the object which is being mapped for use in a GIS system. Features may be points, lines or areas.

Featuring - the process of collecting GPS and GIS information simultaneously

Full Operational Capability - For NAVSTAR, defined as the capability that will occur when 24 operational GPS satellites (Block II/IIA) are operating in their assigned orbits and are available for navigation use.

- G -

Geometric Dilution of Precision (GDOP) - See Dilution of Precision.

Geographic Information System (GIS) - a mapping system which combines positional data with descriptive information to form a layered map.

Global Positioning System (GPS) - a system for providing precise location which is based on data transmitted from a constellation of 24 satellites

GROUSE SMSC - The GROUSE Short Message Service Centre, (*SMSC*), is a well proven store-and-forward platform that receives, processes, stores, and sends all Short Messages (SMS) within a mobile network and supports interconnect to other fixed/wireless networks.

- H -

Hard over word - The word in the GPS message that contains synchronization information for the transfer of tracking from the C/A to P code.

- I -

Ionosphere - The band of charged particles 80 to 120 miles above the Earth's surface.

Ionospheric refraction - The change in the propagation speed of a signal as it passes Through the ionosphere

Initial Operating Capability - For NAVSTAR, defined as the capability that will occur when 24 GPS satellites (Block I/II/IIA) are operating in their assigned orbits and are available for navigation use.

I-mode - The NTT DoCoMo I-mode is the Japanese equivalent of a WAP device (e.g. mobile phone). A wireless communications service by NTT DoCoMo offering wireless web browsing and e-mail from mobile phones.

. **- L -**

L-band - The group of radio frequencies extending from 390 MHz to 1550 MHz. The GPS carrier frequencies (1227.6 MHz and 1575.42 MHz) are in the L band. **-** The group of radio frequencies which carry the GPS data from the satellites to the GPS receivers.

L1 Frequency Band - One of the two radio frequency bands (1602.5625 MHZ - 1615.5000 MHz) transmitted by the GLONASS satellites. Unlike NAVSTAR satellites, each GLONASS satellite transmits on a separate frequency within this band.

L1 Frequency - One of the two radio frequencies (1575.42 MHz) transmitted by the NAVSTAR satellites. Unlike GLONASS satellites, all NAVSTAR satellites transmit on the same frequencies. This frequency carries the C/A code used for the standard positioning service (SPS) and the P code used for the precise positioning service (PPS).

L2 Frequency Band - One of the two radio frequency bands (1246.4375 MHz - 1256.5000 MHz) transmitted by the GLONASS satellites. Unlike NAVSTAR satellites, each GLONASS satellite transmits on a separate frequency within this band.

L2 Frequency - One of the two radio frequencies (1227.6 MHz) transmitted by the NAVSTAR satellites. This frequency carries only the P code used for the precise positioning service (PPS).

LDGPS - Local area Differential GPS - A real-time DGPS system that is made available over a small area - possibly 150 miles or less.

- M -

Multipath error - Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. Usually caused by one path being bounced or reflected. The interference to a signal that has reached the receiver antenna by multiple paths; usually caused by the signal being bounced or reflected. Signals from satellites low on the horizon will have high multipath error. Receivers that can be configured to "mask out" signals from such satellites can help minimize multi-path.

Multi-channel receiver - A GPS receiver that can simultaneously track more than one satellite signal.

Multiplexing channel - A channel of a GPS receiver that can be sequenced through a number of satellite signals.

- N -

NAGU - Notice Advisory to GLONASS Users - a periodic bulletin alerting users to changes in system performance.

- P -

P-code - The Precise code. A very long sequence of pseudo random binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz which repeats about every 267 days. Each one week segment of this code is unique to one GPS satellite and is reset each week.

Precise Positioning Service (PPS) - The most accurate dynamic positioning possible with standard GPS, based on the dual frequency P-code and no SA.

Pseudolite - A ground-based differential GPS receiver which transmits a signal like that of an actual GPS satellite, and can be used for ranging.

Pseudo random code - A signal with random noise-like properties. It is a very complicated but repeating pattern of 1's and O's.

Pseudo range - A distance measurement based on the correlation of a satellite transmitted code and the local receiver's reference code, which has not been corrected for errors in synchronization between the transmitter's clock and the receiver's clock.
Pseudo range - an uncorrected measurement of the distance between a GPS satellite and a GPS receiver determined by comparing a code transmitted by the satellite to a code generated by the receiver.

- R -

Residual - a quality indicator for a GPS position that is determined during the differential correction process. Indicates uncorrectable error. High residuals are not desirable

RAIM - Receiver Autonomous Integrity Monitoring - A GPS receiver system that would allow the receiver to detect incorrect signals being transmitted by the satellites by comparing solutions with different sets of satellites. Would require 6 satellites in view at any one time, which in turn would require 30 total satellites, more than are now available.

- S -

Satellite constellation - The arrangement in space of a set of satellites.

Selective Availability (SA) - A policy adopted by the Department of Defense to introduce some intentional clock noise into the GPS satellite signals thereby degrading their accuracy for civilian users. This policy was discontinued as of May 1, 2000 and now SA is turned off

Slow switching channel - A sequencing GPS receiver channel that switches too slowly to allow the continuous recovery of the data message.

Space segment - The part of the whole GPS system that is in space, i.e. the satellites.

Spread spectrum - A system in which the transmitted signal is spread over a frequency band much wider than the minimum bandwidth needed to transmit the information being sent. This is done by modulating with a pseudo random code, for GPS.

Standard Positioning Service (SPS) - The normal civilian positioning accuracy obtained by using the single frequency C/A code.

Static positioning - Location determination when the receiver's antenna is presumed to be stationary on the Earth. This allows the use of various averaging techniques that improve accuracy by factors of over 1000.

Static Positioning - the process of averaging GPS positions taken successively over a period of time with a stationary antenna to increase accuracy.

Stop-and-Go Surveying - A precision DGPS surveying technique, also called semi-kinematics surveying. The roving user is only required to collect data at a point for a few seconds or minutes.

- U -

User interface - The way a receiver conveys information to the person using it. The controls and displays.

User segment - The part of the whole GPS system that includes the receivers of GPS signals.

- V -

Value - descriptive information about a Feature. Values can be thought of as the answers to the questions posed by Attributes.

- W -

Windows CE - A version of the Windows operating system designed for small devices such as personal digital assistants (PDAs) (or *Handheld PCs* in the Microsoft vernacular). The Windows CE graphical user interface (GUI) is very similar to Windows 95 so devices running Windows CE should be easy to operate for anyone familiar with Windows 95.

[June, 1996 by: Corvallis Microtechnology] , [The USCG Navigation center http://www.navcen.uscg.mil/] & http:// www.cmtinc.com/gbsbook/#Glossary#Glossary