The Global Positioning System

(By Morad Ouasti)

TABLE OF CONTENT

Table of figure

The Global Positioning System (GPS) is a satellite-based navigation system that was developed by the U.S. Department of Defence in the early 1970s as the next generation replacement to the Transit system*. It consists of a constellation of 24 operational satellites with subgroups of 4 satellites operating in each of six different orbit planes, and three segments, space, control and user. The U.S. Air Force develops, maintains, and operates the space and control segments.

The space segment consists of a nominal constellation of 24 operating satellites that transmit one-way signals that give the current GPS satellite position and time. (*http://www.gps.gov/systems/gps/index.html*)

The control segment consists of worldwide monitor and control stations that maintain the satellites in their proper orbits through occasional command manoeuvres, and adjust the satellite clocks. It tracks the GPS satellites, uploads updated navigational data, and maintains health and status of the satellite constellation.
(*http://www.gps.gov/systems/gps/index.html*)

The user segment consists of the GPS receiver equipment, which receives the signals from the GPS satellites and uses the transmitted information to calculate the user's three-dimensional position and time. (*http://www.gps.gov/systems/gps/index.html*). (*Figure 1*)

The satellites revolve around the earth once every 12 hours, and they operate at an altitude of 20, 200km. Initially, the GPS was developed as a military system to fulfil U.S. military needs. Today the GPS is available to both military and civilian users. *(Lillesand and Kiefer, 2000)*.

The GPS has revolutionized many fields. Although the system was originally designed for military use, its civilian applications have grown much faster. It has found its way into many applications, mainly as a result of its accuracy, global availability, and cost-effectiveness. GPS has numerous applications in land, marine and air navigation.

Unfortunately there are some situations in which part of the GPS signal may be obstructed to the point that the GPS receiver may not see enough satellites for positioning. This signal-obstruction issue can be overcome by integrating GPS with other complementary system. As I will introduce the most common integrated system, GPS/LRF, GPS/dead reckoning, GPS/inertial navigation system, GPS/Pseudolite, and GPS/Loran-C**, I will also compare these integrated systems with traditional methodologies. Subsequently, I will present the applications where GPS and other systems have been integrated, Utility Industry, Geoarcheology, Vehicle Navigation, Military Industry, and Open-Pit Mining.

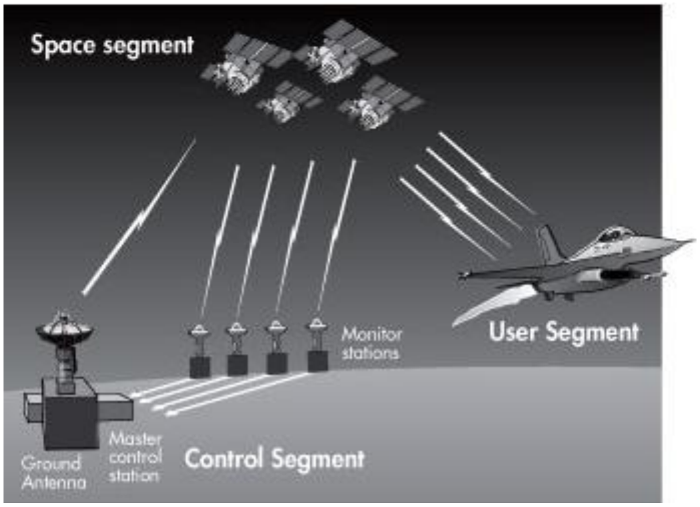

Figure 1. Three Communities

* First prototype satellite successfully launched, in 1960, to examine the operational feasibility of the Doppler System.

** Loran-C replaced Loran-A, developed in early 1940s. It has a greater accuracy.

1. GPS/Laser Range Finder (LRF) Integration

With a digital compass, a reflectorless handheld laser that is co-located with GPS receiver can be used to determine the distance and azimuth to the inaccessible points. It is what is known as the offset function. This integration system was set up the overcome the problem of GPS receivers of loosing lock to the GPS satellites, in areas with heavy tree canopy (*Figure 2*). In addition, real-time differential GPS corrections may not be received as well. This tool is essential for the forestry industry. Other applications of the GPS/LRF include mapping points under bridges, on busy roadways, highway signs, and shore lines, to name a few. (*El-Rabbany,2006*)

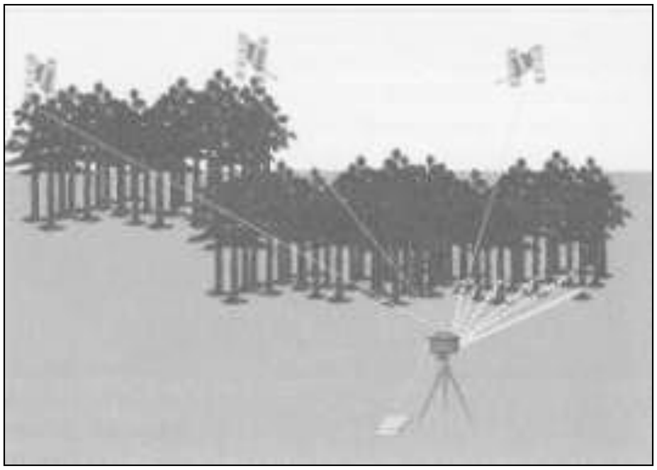

Figure 2. GPS/LRF

GPS for GeoArcheology

Measurements, at *Hacıtug rul Tepe* in Turkey, have been conducted by a team of researchers. Traditionally they used topographic maps and archaeological excavations. Usual methods of topographic mapping, as well as airborne laser scanning and photogrammetry of high resolution satellite images. But these methods appeared to be cost-ineffective for field studies, in term of time, money and labour. They first used LRF technology and a GISystem for their measurements, which came out to be quick and simple to use, fort topographic mapping in and around archaeological sites and heritages. But a problem came up; measuring locations tends to be inaccurate due to error propagation, so the resultant map was only suitable for a preliminary survey. Consequently, they decided to us the integration of the LRF with the DGPS* (*Figure3*). The integration technology provided them with accuracy and appeared to be relatively quick.

And it has been a success, as the mound that have investigated and thought to be circular, is in fact of a polygon shape.(*Hayakawa, Sumura, 2008)*

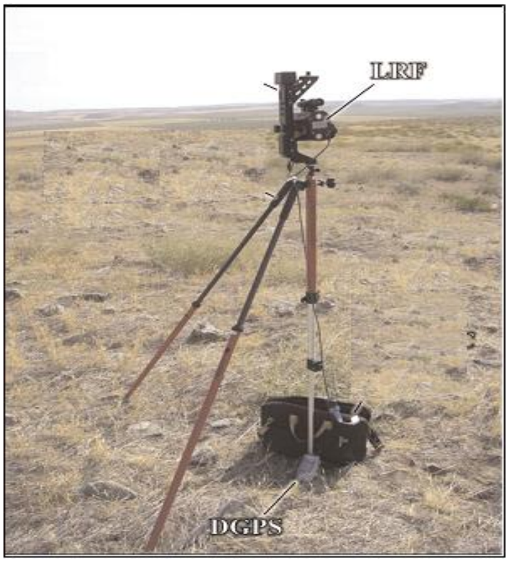

Figure 3. DGPS/LRF

---

* Differential Global Positioning System, (*Differential correction techniques are used to enhance the quality of location data gathered using global positioning system (GPS) receivers*)

GPS for the Utility industry

Accurate and up to date maps are essential for utilities companies, to plan, build and maintain their assets. GPS integrated with a GISys, provides a cost-effective, efficient and accurate tool for creating utility maps. Through GPS, locations of features can be precisely collected, along with their attributes, stored as a collection of layers (Figure 4). A GIS database is, then, created and can be used to create updated utility maps. In situations of poor GPS signal, GPs might be integrated with a LRF system. (*El-Rabbany, 2006*)

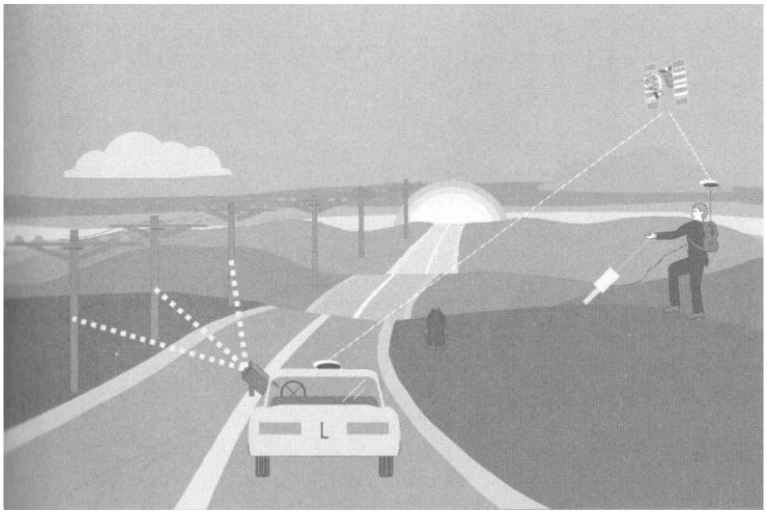

Figure 4. GPS/Utility Industry

2. GPS/ Dead Reckoning (DR) Integration

DR is a low cost system made up with an odometer sensor and a vibration gyroscope. The integrated system GPS/DR is commonly used in automatic vehicle location. One of the requirements of DR is that the vehicle travel-distance or speed, and direction are available continuously.

Vehicles are fitted with odometer sensors that count the number of revolutions of the wheel, and then they can be converted to a travel distance. This process is known as the odometer scale-factor (OSF) determination. Unfortunately the OSF is affected by changes overtime because of wheel slipping and skidding, tire pressure variation, tire wear, and vehicle speed. All these phenomenon, cause errors of positioning.

Gyros are low cost sensors that measure the angular rate (heading rate) based on the Coriolis acceleration. A vibration outputs a voltage that is proportional to the angular velocity of the vehicle. The vehicle’s heading rate is obtained by multiplying outputs voltage by a scale factor. The odometer sensors gyros are subjected to a repetition of errors, due to temperature that affects the gyro measurement. This is called the “gyro bias”.

The integrated system allows GPS to control the drift of the DR components through frequent calibration, while DR becomes the main positioning system during the GPS outages. (*El-Rabbany, 2006*)

GPS for Vehicle Navigation

When travelling, drivers, often, use paper road maps for route guidance. Besides being inefficient, this method is unsafe when searching for a direction, especially in busy areas. GPS with digital road maps and a computer system, provide route guidance electronically. GPS continuously determine the vehicle’s location. In obstructed areas such as urban canyons and tunnels, GPS is supplemented by a DR system that overcomes GPS signal blockage. (*Figure 5*). DR determines the vehicle’s direction and distance travelled, but it is accurate only over a short period of time. (*El-Rabbany, 2006*)

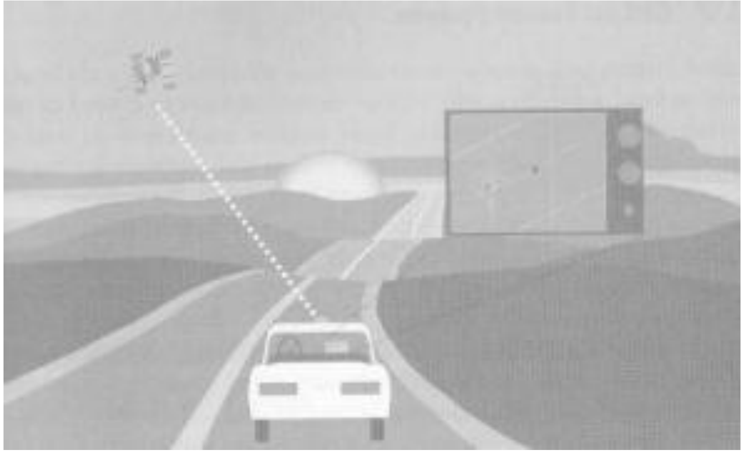

Figure 5. GPS/Dead Reckoning

3. GPS/Inertial Navigation System (INS) Integration

GPS presents a lack of accuracy when orientation is required, for airborne or ocean floor mapping. To overcome these limitations, GPS can be integrated with an environment-independent system, the INS. It can be defined as the process of finding the position, velocity, and orientation of a vehicle from measurements of inertial sensors. Following the initialization, INS provides accuracy for a short period of time, and better updates rate than the GPS. The main inconvenient of the INS is that it drifts if it is left unassisted. This is where the integration with the GPS plays a major role, as GPS provides the initialization and the correction to the inertial system, whereas the INS bridges the GPS gaps when the satellite signal is blocked or temporarily lost. *(Sharaf, Reda Taha, Tarbouchi,· Aboelmagd, 2007)*

GPS for Military Industry

The supersonic guided missile called Jumper, is powered by a two-pulse rocket motor with low radar and acoustic signatures. Jumper uses GPS/INS guidance and has four steering surfaces at its tail. In its basic configuration, Jumper is designed to hit stationary targets designated by geographical coordinates. Accuracy is said to be unaffected by visibility and weather. An optional laser-guidance unit enables the weapon to hit targets with greater precision, and permits a limited man-in-the-loop capability for tracking moving targets.

Israel Aerospace Industries (IAI) sources, report that when compared to electro-optical guidance systems, Jumper's GPS/INS unit can be produced at significantly lower cost, making the missile affordable for tactical formations down to platoons. (*http://www.aviationweek.com/aw/generic/story_channel.jsp?*)

4. GPS/Pseudolite (Pseudo-satellite) Integration

The mining industry needs real-time positioning at centimetre-level of accuracy. Accurate real-time positioning is a key component, which leads to automating the heavy and expensive mining machines.

GPS signal is partially blocked as the pit deepens. The pseudolite system comes to complete GPS to ensure high-accuracy positioning system at anytime. It is a ground-based electronic system device that transmits a GPS-like signal (code, carrier, and data message), which can be caught by a GPS modified-receiver (*Figure 6*). It improves system availability and geometry.

Although, pseudolites suffer from near-far, multi-path, and time synchronization. (*Especially the near-far problem due to the large variation of the receiver-to-pseudolite range*)

That results from the variation in the received pseudolite signal power, as the receiver pseudolite distance changes. The closer the receiver is to the pseudolite transmitter, the higher the signal power will be, and vice versa. (*Lei*, *2009*)

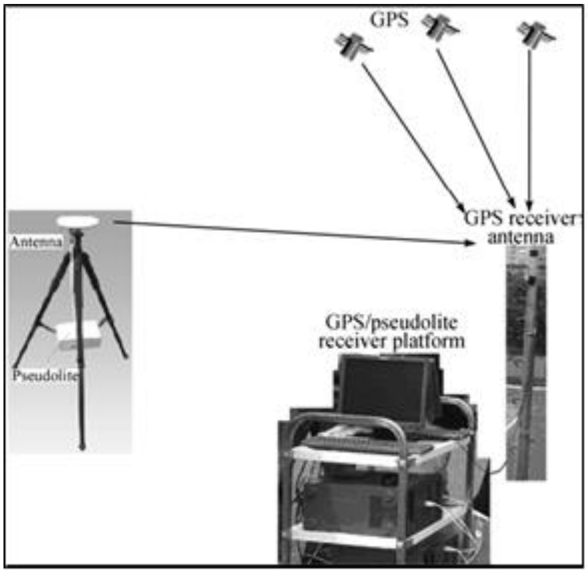

Figure 6. GPS/Pseudolite

GPS for Open-Pit mining

Conventional surveying was the only one method available for stacking drill patterns and other mining surveying tasks. However, stakes were often buried or displaced, and drill operators had difficulties determining the actual drill penetration depth. GPS has improved mining operations such as, drilling, shovelling, vehicle tracking, and surveying. (*Figure 7*). As it provides centimetre-level accuracy, and requires only one base receiver to support any number of rovers.

As the pit deepens, part of the GPS signal may be blocked by the steep walls of the mine. To overcome this problem, GPS has been integrated with the Pseudolite system. (*El-Rabbany, 2006*)

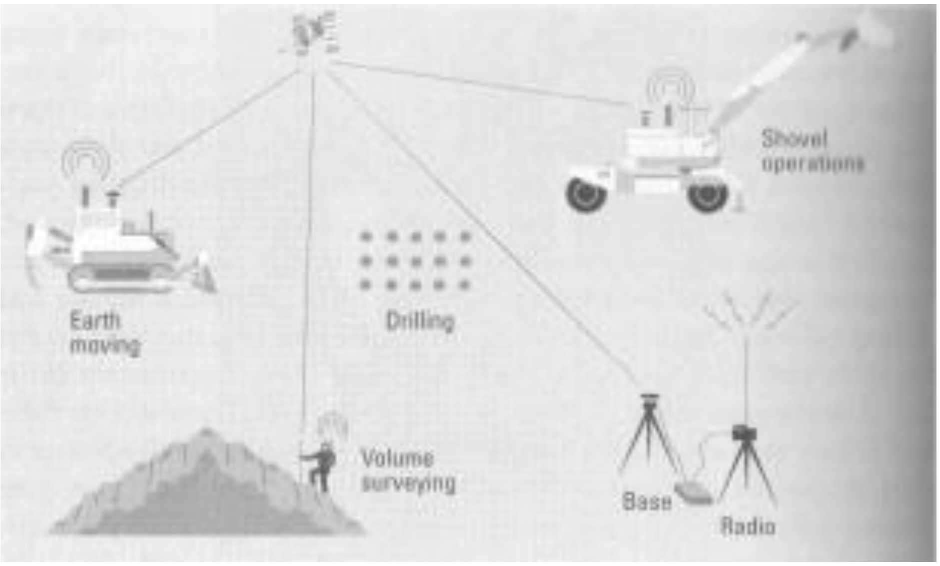

Figure 7. GPS/Pit Mining

5. GPS/LORAN-C

Loran-C[2] stands for Long Range system. It is a terrestrial radio-navigation system, which provides positioning and timing services for users, within its coverage area. A Loran-C receiver operating within a chain's coverage area measures the time difference between the arrival of the pulse groups from the master stations and each of the secondary stations. Loran receivers are programmed to identify and track the arrival time of the third cycle zero crossing within the pulses. Since the locations of the transmitting stations and the emission delays are known, the measured time difference can be converted to distance. This defines a hyperbolic line of position (LOP). The intersection of 2 at least, defines the horizontal position of the receiver. (*Figure 8*)

Loran-C and GPS complete each other. Among many characteristics; the most important is that Loran-C is available in urban canyons and under foliage, while the GPS signal may be blocked. (*El-Rabbany, 2006*)

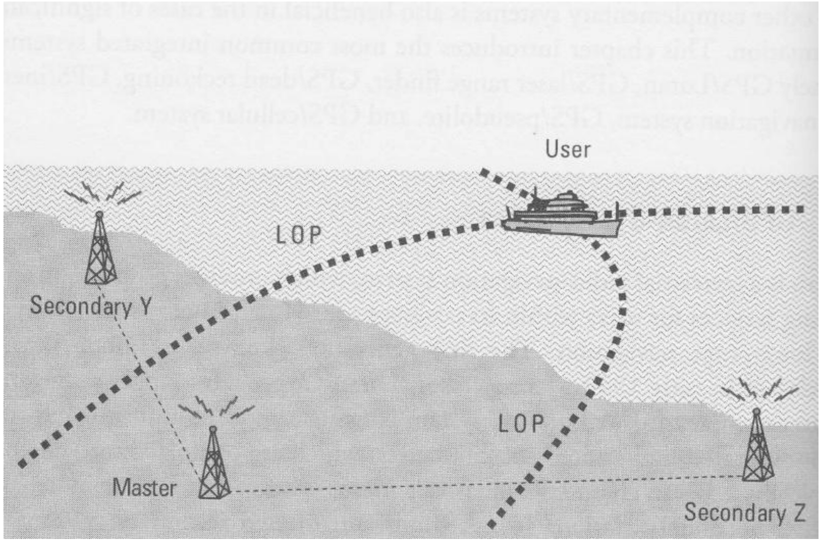

Figure 8. GPS/Loran-C

Loran-C fills the gaps of the GPS as for problems related to noise, fading and interference. This integration system is used in the Suez Canal, where the weather and the visibility can be affected by darkness, fog, and sandstorm. Boats can collide against each other, such a system prevent these kinds of accident, in such a busy and strategic maritime route. (*Abd EL-Kader, Abo EL-Soud, EL-Serafy and Ezzat, 2003*)

6. Conclusion

GPS was developed for military use first, and later on, had been made available for civilians. It has been integrated with other systems in the environmental research field. Mainly to overcome the problem of signals being blocked by obstacles. GPS on its own is, therefore, not enough. However, traditional methodologies had problems of accuracy and timing.

In overall, Global Navigation Satellite Systems (GNSS), should have, in the future, an important role in the worldwide geospatial information infrastructure. Over the last 10 years GPS, has been the key tool for scores of applications that needed better positioning and timing, such as car navigation, boat navigation, mining industry etc… GPS has raised the awareness of the importance of location information. Maybe we can expect in the future to have an accurate location information, for any object in real-time and at any time.

We can imagine in the future a more efficient generation of GPS Satellites. GPS and other Navigation systems like the European one, Galileo, could be used by users at the same time, for more accuracy and better results. But on the other hand, that means users will have to pay more money to be equipped with both systems. And also, that would cause more noise and interference environment.

7. References

Introduction to GPS, El Rabbany, Artech House, 2006

An Integrated Navigation System For Suez Canal (SCINS)Farouk Abd EL-Kader, M. Samy Abo EL-Soud, Kamel EL-Serafy and Ezzat, the Journal of Navigation, 2003

Merits and limitations of using fuzzy inference system for temporal integration of INS/GPS in vehicular navigation. Rashad Sharaf · Mahmoud Reda Taha · Mohammed Tarbouchi · Aboelmagd Noureldin, 2007

Remote Sensing and Image Analysis: 4th Edition. T.M. Lillesand and R.W. Kiefer. John Wiley and Sons, New York, 2000

Simulation on C/A codes and analysis of GPS/pseudolite signals acquisition, ZHANG Lei, 2009

Utilization of Laser Range Finder andDifferential GPS for High-Resolution Topographic Measurement at Hacıtug rul Tepe, Turkey, Yuichi S. Hayakawa, Hiro'omi sumura, 2008

www.gps.gov/

(*http://www.aviationweek.com/aw/generic/story_channel.jsp?*)