Chapter 1

Introduction

The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense. GPS was originally intended for military applications, but in the 1980s, U.S government made the system available for civilian use. GPS works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS.

GPS can be used to find your location quickly anywhere in the world. The determined location findings can be called as GPS positions or GPS trajectory data set. And, this data set could be displayed over digital map. However, since the inaccuracy exists in GPS positions and also in digital maps, it is not possible to ensure that positions were tracked properly over a digital map. To avoid this problem, various map matching methods can be used to improve accuracy in location finding using GPS over a digital map.

This research focuses on map matching method as an aid to the location finding using GPS to analyze the accuracy. And this research is to improve navigation performance and identifying the conditions or values of key parameters make this research feasible.
1.1 GPS

The Navigation System with Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is a satellite-based navigation system utilized by all over the world. GPS is a system of 24 satellites in asynchronous orbits that are precisely tracked from ground stations. Each ground station has a precisely known geographic location. These ground stations return updated information to each satellite. Each satellite transmits its location to GPS receivers all over the earth. GPS receivers are used in two basic ways:

1. Navigation - To navigate from where you are to where you want to be.

2. Mapping - To record and map detailed routes with data about those locations stored as attributes (Oderwald and Boucher, 1997).

In past two decades, satellite navigation technology, specifically, the Global Positioning System (GPS) has been developed as an inevitable positioning technology for all kinds of navigation like land navigation, sea navigation and air navigation. To understand exactly why it is so useful and important, we should first look at the history of GPS and how GPS works. More importantly, looking at what segments of technological achievements have driven the development of this fascinating positioning system.

1.2 History of GPS

People have developed so many tools and technologies to find their positions on earth and to get the navigation guidance. Early mariners introduced angular measurements between the celestial bodies like sun and stars. In 1920, the more advanced technique, radio navigation allowed the navigators to locate the direction. Later, the development of artificial satellites contributed the more precise radio navigation signals led to the new spark in navigation technology. Satellites were first used in location finding in two dimensional Navy system called Transit. The marine radio
navigation aid LORAN (Long Range Aid to Navigation) was important to the development of GPS, because it was the first system used the time difference of arrival of radio signals in a navigation system.

In the early 1960s, several U.S. government organizations, including the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and the Department of Transportation (DOT), were interested in developing satellite systems for three-dimensional position determination. The optimum system was viewed concerning the attributes global coverage, continuous all seasonal, and high accuracy. When Transit became operational in 1964, it was widely accepted for use on low-dynamic platforms. Concurrently, the Naval Research Laboratory (NRL) was conducting experiments with highly stable space-based clocks to achieve precise time transfer. This program was denoted as Timation. Modifications were made to Timation satellites to provide a ranging capability for two-dimensional position determination. The Air Force conceptualized a satellite positioning system denoted as System 621B. The use of pseudorandom noise (PRN) modulation for ranging with digital signals was proposed. System 621B was to provide three-dimensional coverage and continuous worldwide service. The concept and operational techniques were verified at the Yuma Proving Grounds using an inverted range in which pseudosatellites or pseudolites (i.e., ground-based satellites) transmitted satellite signals for aircraft positioning. In 1969, the Office of the Secretary of Defense (OSD) established the Defense Navigation Satellite System (DNSS) program to consolidate the independent development efforts of each military service to form a single joint-use system. The OSD also established the Navigation Satellite Executive Steering Group, which was charged with determining the viability of the DNSS and planning its development. From this effort, the system concept for NAVSTAR GPS was formed. The NAVSTAR GPS program was developed by the GPS Joint Program Office (JPO) in El Segundo, California.
1.3 Segments of GPS devices

GPS consists of three main segments.

1.3.1 The space segment

This part consists of 24 satellites, are launched into space by rockets. They are about the size of a car, and weigh about 19,000 lbs. Each satellite is in orbit above the earth at an altitude of 11,000 nautical miles (12,660 miles), and takes 12 hours to orbit one time. The orbits are tilted to the equator of the earth by 55 degrees, so that there is coverage of the polar regions. The satellites continuously orient themselves to ensure that their solar panels stay pointed towards the sun, and their antennas pointed towards the earth. Each satellite carries 4 atomic clocks.

![Figure 1.1: Space segment](image)

1.3.2 The control segment

This part consists of worldwide unmanned base-stations that monitor the satellites to track their exact position in space, and to make sure that they are operating correctly. The stations constantly monitor the orbits of the satellites and use very precise radar to check altitude, position and speed. Signals are transmitted to the
satellites by base stations to update ephemeris constants and clock adjustments. The satellites in turn, use these updates in the signals that they send to GPS receivers. The main base-station is in Colorado Springs, Colorado and the other four are located on Ascension Island (Atlantic Ocean), Diego Garcia (Indian Ocean) and Kwajalein and Hawaii (both Pacific Ocean).

![Figure 1.2: Control segment](image)

1.3.3 The user segment

This part consists of GPS receivers which are hand-held or, can be placed in a vehicle. All GPS receivers have an almanac programmed into their computer, which tells them where each satellite is at any given moment. The GPS receivers detect, decode and process the signals received from the satellites. The receiver is usually used in conjunction with positioning and map matching algorithms to output the information to the user in the form of a map. As the user does not have to communicate with the satellite there can be unlimited users at one time.

1.4 How GPS works?

GPS satellites transmit signals to GPS receiver on the ground. GPS receivers passively receive satellite signals; they do not transmit. GPS receivers require an unobstructed view of the sky, so they are used only outdoors and they often do not
perform well within forested areas or near tall buildings. GPS operations depend on a very accurate time reference, which is provided by atomic clocks at the U.S. Naval Observatory. Each GPS satellite has atomic clocks on board. Each GPS satellite transmits data that indicates its location and the current time. All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are farther away than others. The distance to the GPS satellites can be determined by estimating the amount of time it takes for their signals to reach the receiver. When the receiver estimates the distance to at least four GPS satellites, it can calculate its position in three dimensions.
1.4.1 Positioning

A GPS receiver "knows" the location of the satellites, because that information is included in satellite transmissions. By estimating how far away a satellite is, the receiver also "knows" it is located somewhere on the surface of an imaginary sphere centered at the satellite. It then determines the sizes of several spheres, one for each satellite. The receiver is located where these spheres intersect.

The basic principle behind GPS is the measurement of distance between satellites and the receiver. The distance to at least 3 satellites must be known in order to find out a position. Satellites and receivers generate duplicate radio signals at exactly the same time. As satellite signals travel at the speed of light (186,000 miles per second), they take a few hundredths of a second to reach the GPS receiver. This difference and the speed at which signal travels is used in the equation to find out the distance between the GPS receiver and the satellite.

\[
\text{Speed} \times \text{Time} = \text{Distance}
\]

So, if it takes 0.09 of a second for a satellite’s signal to reach the GPS receiver, the distance between the two must be 16,740 miles i.e

\[
186,000 \text{ miles} \times 0.09 \text{ seconds} = 16,740 \text{ miles}.
\]

The GPS receiver must be located somewhere on an imaginary sphere that has a radius of 16,740 miles. The GPS calculation in the receiver uses four equations in
the four unknowns \( x, y, z, t_c \), where \( x, y, z \) are the receiver’s coordinates, and \( t_c \) is the time correction for the GPS receiver’s clock. The four equations are:

\[
\begin{align*}
    d_1 &= c(t_{t,1} - t_{r,1} + t_c) = \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} \\
    d_2 &= c(t_{t,2} - t_{r,2} + t_c) = \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2} \\
    d_3 &= c(t_{t,3} - t_{r,3} + t_c) = \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2} \\
    d_4 &= c(t_{t,4} - t_{r,4} + t_c) = \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2}
\end{align*}
\]

where

- \( c \) = speed of light \((3 \times 10^8 m/s)\)
- \( t_{t,1}, t_{t,2}, t_{t,3}, t_{t,4} \) = times that GPS satellites 1, 2, 3, and 4, respectively, transmitted their signals (these times are provided to the receiver as part of the information that is transmitted).
- \( t_{r,1}, t_{r,2}, t_{r,3}, t_{r,4} \) = times that the signals from GPS satellites 1, 2, 3, and 4, respectively, are received (according to the inaccurate GPS receiver’s clock)
• \( x_1, y_1, z_1 \) = coordinates of GPS satellite 1 (these coordinates are provided to the receiver as part of the information that is transmitted); similar meaning for \( x_2, y_2, z_2 \), etc.

The receiver solves these equations simultaneously to determine \( x, y, z, \) and \( t_c \). Thus, the GPS receiver gives the positioning data in the following format

<table>
<thead>
<tr>
<th>Data Id</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude</th>
<th>GPS Date Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>520</td>
<td>13.0077155</td>
<td>80.2070173</td>
<td>105.40</td>
<td>15/4/2012 2:29:26</td>
</tr>
<tr>
<td>524</td>
<td>13.0076304</td>
<td>80.2063965</td>
<td>105.40</td>
<td>15/4/2012 2:29:30</td>
</tr>
</tbody>
</table>

Table 1.1: Sample GPS trajectory data set

### 1.4.2 Computational steps for positioning

1. Sync with an available satellite and download the navigation information.

2. Convert the messages to internal format for calculation. These include clock information, ionosphere data, and ephemeris data.

3. Calculate the exact satellite position. This will include both the elevation and azimuth data.

4. Calculate the pseudo range data and then correct for ionosphere and other modeling errors.

5. Repeat these steps for each available satellite.

6. Correct the satellite position for earth’s rotation based on the time it takes for the signal traversal using the pseudo range data. (If the internal clock is close this can be done once, otherwise it will have to be repeated after the receiver position is computed.)
7. Correct using differential data if available. (This may have to be done after the initial position is computed as part of the refinement step if the internal clock isn’t accurate.) If the differential station is near the GPS receiver it will be able to skip the corrections for modeling errors since this is part of the correction data available. Using DGPS corrections leads to accuracy considerably beyond the capability of a standard receiver.

8. Calculate the initial receiver position as described in the prior section.

9. Convert the data based on whatever datum and grid system you have chosen and display the answer on the position page. Altitude is also corrected for geoid height prior to display.

10. Add in the leap seconds and time offset from UTC time to the computed time data and convert it for display.

11. Refine the position based on additional satellites and the correct time to obtain a 3D fix.

1.4.3 Signals

In order for GPS to work, a network of satellites was placed into orbit around planet Earth, each broadcasting a specific signal, much like a normal radio signal. This signal can be received by a low cost, low technology aerial, even though the signal is very weak. Using different signals from different satellites, the GPS software is able to calculate the position of the receiver.

GPS signals include ranging signals, used to measure the distance to the satellite, and the navigation messages include ephemeris data, used to calculate the position of each satellite in orbit, and the information about the time and status of the entire satellite constellation, called the almanac.

The original GPS design contains two ranging codes.

1. Coarse/Acquisition(C/A) code, which is freely available to the public.
   - 1,023 bit
   - Psuedo Random Noise(PRN)
   - Repeats every millisecond
   - Each satellite transmits the unique PRN code
• The receiver can recognize multiple satellites on the same frequency

2. restricted Precision(P) code, usually reserved for military applications.
   • It is also PRN
   • It is an encrypted P-code to avoid unauthorized access

The navigation message is made up of 3 major components

1. The first part contains the GPS Date time and the satellite status and indication of its health

2. The second part contains the orbital information called ephemeris data and allows the receiver to calculate the position of the satellite

3. The third part, called the almanac, contains information and status concerning all the satellites locations and PRN numbers

A location finding using any satellite cannot be calculated, until the receiver has an accurate and complete copy of that satellite ephemeris data. If the signal from a satellite is lost, while its ephemeris data is being acquired, the receiver must discard the data and start again.

1.4.4 Timing and correction

In a perfect world, the accuracy should be absolute, but there are many different factors which prevent this. Obviously, it is not possible to ensure that all the clocks are synchronized. Since each satellite contains atomic clocks, which are extremely accurate with respect to each other, the most of the problems occur with the clock inside the GPS receiver itself.

Keeping the cost of technology in mind, it is not possible to fit atomic clock in each GPS receiver. Alternatively, when creating the system, the designers designed to check the receiver’s clock accuracy. They are using the fourth satellite to cross check the trilateration process. Thus, the GPS software can also update its’ own internal clock.

1.4.5 Map matching

When the positioning data is ready, the user must have the presentable format of the data, where the map matching algorithms comes in. Various researchers define map
matching algorithm in various aspects. Some of them given below to understand the essential objective of the map matching algorithms.

"Map matching is a software algorithm that is used to integrate various positioning sensor data with digital road map data to give a better position estimate of vehicle."

"Map matching algorithm must be able to reconcile the user’s location with the underlying map."

"Map matching algorithm that can be used to reconcile inaccurate locational data with an inaccurate map/network."

"Map matching is defined as the process of correlating two sets of geographical positional information i.e. GPS records of object positioning versus digital road networks from different vendors."

Map matching algorithms can also be classified into on line map matching and off line map matching. On line map matching method snaps the device captured geo spatial feature position to base reference in real time. Off line map matching counterparts post snaps the point data/linear data after the whole set of data collected.

1.4.6 Computational steps for map matching

1. Data preprocessing: It is the process of checking the reliability of GPS data available

2. Road identification: It is a process of finding a road segment that a vehicle is currently traveling on if map matching algorithm uses map database. Road Identification with the map database is enriched with attribute information. That is the location of a vehicle could be confined to only a limited number of road segments, with the aids of information in map data base

3. Point positioning: It is the process of calculating the point position on the selected road polyline. Vehicle position is acquired by simply projecting the point onto selected polyline.

4. Checking Reliability and Integrity: It is the process of making sure the vehicle location is reliably matching to the map road network, while the integrity check tries to identify the wrong matching.
1.5 GPS applications

The applications of the GPS fall into five general categories

- Location
- Navigation
- Timing
- Mapping
- Tracking

1.5.1 Location

This category is for position determination and is the most obvious use of GPS. It is the first system that can give accurate and precise measurements anytime, anywhere and under any weather conditions. Some examples of applications within this category are:

1. Measuring the movement of volcanoes and glaciers
2. Measuring the growth of mountains
3. Measuring the location of icebergs
4. Storing the location of where you were - most GPS receivers on the market will allow to record certain location. This allows to find it again with minimal effort.

1.5.2 Navigation

Navigation is the process of getting from one location to another. This was that what the GPS was designed for. The GPS system allows us to navigate on water, air or land. It allows planes to land in the middle of mountains and helps helicopters save time by taking the best route.

1.5.3 Timing

GPS brings precise timing to all. Each satellite is equipped with an extremely precise atomic clock. This is why we can all synchronize our watches so well and make sure international events are actually happening at the same time.
1.5.4 Mapping

This is used for creating maps recording a series of locations. The best example is surveying where the Differential GPS technique is applied but with a twist. Instead of making error corrections in real time, both the stationary and moving receivers calculate their positions using the satellite signals. When the roving receiver is through making measurements, it then takes them back to the ground station which has already calculated the errors for each moment in time. At this time, the accurate measurements are obtained.

1.5.5 Tracking

An area where GPS based vehicle tracking provides a variety of benefits is in the construction industry. GPS can be used in dispatch systems, to improve the efficiency of vehicle use and also to provide audit information. In mining and construction applications, vast sums can be saved by maximizing the utilization of huge spoil trucks and concrete trucks. Some large mines and construction sites, particularly those in very remote and hostile locations, are investigating the use of autonomous trucks, which are controlled from a central location and are navigated using GPS. For this kind of application, higher GPS accuracy is required. Differential GPS, which yields high precision accuracy is used in a wide range of application areas like avionic navigation, including precision landing and aerial application of fertilizer and pesticides land and hydrographic surveying, crop mapping and the controlling of harvesting machinery.

1.5.6 Others

Many applications use a combination of the above categories. Some of them are Oil exploration, Emergency services, Atmospheric studies, Archaeological explorations, Astronomical telescope pointing, networking and blind aiding.

Further, an important GPS application ADS-B(Automatic Dependent Surveillance - Broadcast) will be replacing radar as the primary surveillance method for controlling aircraft worldwide. The system relies on two avionics components a high integrity GPS navigation source and a datalink (ADS-B unit). ADS-B also provides the data infrastructure for inexpensive flight tracking, planning, and dispatch with the help of GPS.

The development and applications of GPS also gives a prelude to Lunar Nav-
igation. Astronauts won’t be able to use a global positioning system (GPS) to find their way around (Ron Li, Professor of civil and environmental engineering and geodetic science). The moon doesn’t have satellites to send GPS signals. Researchers have learned a lot about navigation from exploring the red planet. New technology sensors, inertial navigation systems, cameras, computer processors, and image processors will make the next trip to the moon easier for astronauts. Li explained how the system will work: images taken from orbit will combine with images from the surface to create maps of lunar terrain; motion sensors on lunar vehicles and on the astronauts themselves will allow computers to calculate their locations; signals from lunar beacons, the lunar lander, and base stations will give astronauts a picture of their surroundings similar to what drivers see when using a GPS device on Earth. The researchers have named the entire system the Lunar Astronaut Spatial Orientation and Information System (LASOIS).

Apart from the application perspective, the commercial uses of Global Positioning System (GPS) are diverse with applications across various industries. Some applications are simple, such as determining a position, whereas others are complex blends of GPS with communications and other technologies. The rapid growth of commercial applications in recent years has surprised many industry observers and firms building GPS satellites and equipment. The differing needs of commercial and civil GPS users and the availability of alternative solutions for meeting them have led to a highly diverse and competitive market for GPS technologies, equipment, and services.

The market for commercial uses of GPS can be segmented by the differing needs of customers for time and spatial information. Initially, one of the original purposes of GPS was to improve en route navigation for military ships and aircraft. However, there are dozens of uses of GPS today, with new applications being reported each month in academic, business, and public media.

According to the research report “World GPS Market Forecast to 2013”, it is projected that shipment of GPS devices will grow at more than 20 percent during 2011-2013 to reach around 900 Million units by 2013. Besides, the global navigation satellite systems’ (GNSS) technology, which is expected to be embraced by the positioning facilities through mobile phones and route guidance devices in the car, development of the GNSS market is anticipated by the next 20 years.
1.6 Factors that are affecting accuracy in location finding

Since the applications and commercial uses of GPS increase day by day, the accuracy level expectation from GPS is high. The following are the main possible sources listed and those can be considered when configuring GPS parameters to improve accuracy.

1.6.1 Satellite geometry

Satellite geometry describes the position of the satellite to each other from the view of the receiver. If a receiver sees satellites and all are arranged for example in the north west, this leads to a "bad" geometry. If a position is determined in this case, the error of the positions may be up to 100 to 150 meters. If the satellites are well distributed over the whole firmament, the determined positions will be much more accurate.

1.6.2 Satellite elevations

When a satellite is low on the horizon, the satellite signals must travel a greater distance through the atmosphere, resulting in lower signal strength and delayed reception by the GPS receiver. Position data should be collected using only satellites that are at least 15 degree above the horizon.

1.6.3 Multi path

Satellite signals can reflect off larger nearby objects, such as buildings or cars, causing the GPS antenna to receive an erroneous signal (longer path length = false location). This phenomenon is known as multi path, which can induce errors of dozens of meters. Optimal accuracy can be obtained by collecting data in an environment devoid of large reflective surfaces and that has a clear view of the sky.

1.6.4 Signal-to-Noise Ratio (SNR)

This is a measure of the information content of a signal relative to the signal’s noise. The satellite signals do not penetrate metal surfaces, buildings, tree trunks,
or similar objects. When recording position data, the antenna of the receiver has to be placed away from these obstructions.

1.6.5 Ionosphere - change in the travel time of the signal

Before GPS signals reach the antenna on the earth, they pass through a zone of charged particles called the ionosphere, which changes the speed of the signal. If reference station and receivers are relatively close together, the effect of ionosphere tends to be minimal.

1.6.6 Troposphere - change in the travel time of the signal

Troposphere is essentially the weather zone of our atmosphere, and droplets of water vapor in it can affect the speed of the signals. The vertical component of the GPS position (elevation) is particularly sensitive to the troposphere.

1.6.7 Ephemeris data transmission from base stations

If the ephemeris data are transmitted with lower accuracy, meaning that the transmitted satellite positions do not comply with the actual positions, the inaccuracy of the position will be achieved for several hours.

1.7 Accuracy analysis in location finding

There are several external sources which introduce errors into a GPS position. While the factors listed in the previous section always affect accuracy, another major factor in determining positional accuracy is the type of GPS receiver used. Most handheld GPS units have about 10-20 meter accuracy. Other types of receivers use a method called Differential GPS (DGPS) to obtain much higher accuracy. DGPS requires an additional receiver fixed at a known location nearby. Observations made by the stationary receiver are used to correct positions recorded by the roving units, producing an accuracy greater than 1 meter.

The accuracy level in location finding using GPS is characterized as follows:

- Predictable: The accuracy of a GPS position solution with respect to the charted position solution and the chart must be based upon the same geodetic datum.
• Repeatable: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same GPS receiver

• Relative: The accuracy with which a user can measure position relative to that of another user of the same level GPS receiver at the same time

Analysis of accuracy level in location finding using GPS is very important, because the high accuracy and reliable positional data is required for all the above mentioned applications and the applications that are going to be implemented in future.

1.8 Research objectives

The demand for accuracy outpaced advances in GPS technologies and quickly motivated the search for new ways to improve the accuracy in GPS positioning through the research in positioning techniques and map matching algorithms. Through these kind of researches, issues hindering in location finding using GPS will be highlighted. Researching the issues can help these new technologies give a better edge in science and technology worldwide. The objectives provided in this research can help to achieve the goal.

The following overarching objectives guide my research:

1. Identifying the vital factors that are helpful in deciding the exact location
2. Identifying the factors that are affecting the accuracy in location finding
3. Identifying how these accuracy affecting factors cause the inaccurate data driven from the GPS receivers.
4. Identifying how the inaccurate data identified and processed
5. Identifying the models of map matching algorithms
6. Developing new map matching algorithm for the processed data to remove the error components to the extent possible
7. Implementing and verifying the working behaviors of the new map matching algorithm
8. Analyzing the accuracy of new map matching algorithm
Ideally, this objectives list potentially guide future efforts along a better, faster, and accurate map matching, making GPS a valuable aid to navigation systems.