© 2017 IJSRST | Volume 3 | Issue 8 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Global Positioning System (GPS) and its Application

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ABSTRACT

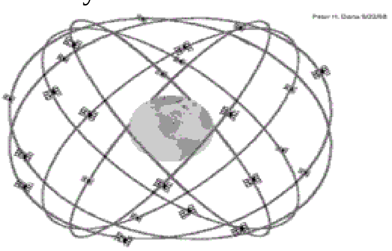
The study represents that with this GPS information you know exactly where you are. Most modern GPS receivers are able to store your track. As you move, the GPS periodically stores your position in its internal memory. It can then show you the path you have followed on the display so that you can see exactly where you have been. Tacks also make backtracking easy. Most modern GPS receivers also support the concept of waypoints and routes. A waypoint is a specific point (longitude and latitude) that you have stored in memory.

Keywords : Global Positioning System, GPS, Application, Satellite

I. INTRODUCTION

Global Positioning System (GPS)

Global Positioning System or GPS is a constellation of 27 satellites orbiting the earth at about 12000 miles. These satellites are continuously transmitting a signal and anyone with a GPS receiver on earth can receive these transmissions at no charge. By measuring the travel time of signals transmitted from each satellite, a GPS receiver can calculate its distance from the satellite. Satellite positions are used by receivers as precise reference points to determine the location of the GPS receiver. If a receiver can receive signals from at least 4 satellites, it can determine latitude, longitude, altitude and time. If it can receive signals from 3 satellites, it can determine latitude, longitude and time. The satellites are in orbits such that at any time anywhere on the planet one should be able to receive signals from at least 4 satellites. The basic GPS service provides commercial users with an accuracy of 100 meters, 95% of the time anywhere on the earth. Since May of 2000, this has improved to about 10 to 15 meters due to the removal of selective availability.



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Fig. 1: GPS Constellation

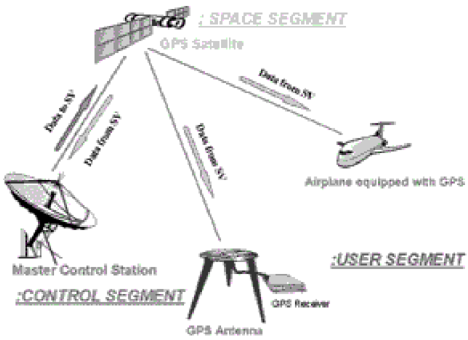


Fig. 2: Different segments of a GPS

II. METHODS AND MATERIAL

GPS Master Plan

The launch of the 24th block II satellite in March of 1994 completed the GPS constellation. Four additional satellites are in reserve to be launched "on need." The spacing of the satellites are arranged so that a minimum of five satellites are in view from every point on the globe. The basic orbits are quite exact but just to make things perfect the GPS satellites are constantly monitored by the Department of Defense. They use very precise radar to check each satellite's exact altitude, position and speed. The errors they're checking for are called "ephemeris errors" because they affect the satellite's orbit or "ephemeris." These errors are caused by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites.

GPS Satellites

Name: NAVSTAR
Manufacturer: Rockwell International
Altitude: 10,900 nautical miles
Weight: 1900 lbs. (in orbit)
Size: 17 ft with solar panels extended
Orbital Period: 12 hours
Orbital Plane: 55 degrees to equatorial
plane Planned Lifespan: 7.5 years
Current constellation: 24 Block II production satellites
Future satellites: 21 Block IIrs developed by Martin Marietta

3. Ground Stations or Control Segment

These stations monitor the GPS satellites, checking both their operational health and their exact position in space. The master ground station transmits corrections for the satellite's ephemeris constants and clock offsets back to the satellites themselves. The satellites can then incorporate these updates in the signals they send to GPS receivers. There are five monitor stations: Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs.

4. How GPS works

- ✓ The basis of GPS is "triangulation" from satellites.
- ✓ To "triangulate," a GPS receiver measures distance using the travel time of radio signals.
- ✓ To measure travel time, GPS needs very accurate timing, which it achieves with some tricks.
- ✓ Along with distance, it is needed need to know exactly where the satellites are in space. High orbits and careful monitoring are the secret.
- ✓ Finally you must correct for any delays the signal experiences as it travels through the atmosphere.

Improbable as it may seem, the whole idea behind GPS is to use satellites in space as reference points for locations here on earth. That's right, by very, very accurately measuring our distance from three satellites we can "triangulate" our position anywhere on earth. Forget for a moment how our receiver measures this distance. First let us consider how distance measurements from three satellites can pinpoint you in space.

5. The Big Idea Geometrically

Suppose we measure our distance from a satellite and find it to be 11,000 miles. Knowing that we're 11,000 miles from a particular satellite narrows down all the possible locations we could be in the whole universe to the surface of a sphere that is centred on this satellite and has a radius of 11,000 miles. Next, say we measure our distance to a second satellite and find out that it's 12,000 miles away. That tells us that we're not only on the first sphere but we're also on a sphere that's 12,000 miles from the second satellite. Or in other words, we're somewhere on the circle where these two spheres intersect. If we then make a measurement from a third satellite and find that we're 13,000 miles from that one, that narrows our position down even further, to the two points where the 13,000 mile sphere cuts through the circle that's the intersection of the first two spheres. So by ranging from three satellites we can narrow our position to just two points in space. To decide which one is our true location we could make a fourth measurement. But usually one of the two points is a ridiculous answer (either too far from Earth or moving at an impossible velocity) and can be rejected without a measurement. A fourth measurement does come in very handy for another reason however, but we'll tell you about that later. Next we'll see how the system measures distances to satellites.

6. Triangulating: At a Glance

- ✓ Position is calculated from distance measurements (ranges) to satellites.
- ✓ Mathematically we need four satellite ranges to determine exact position.
- ✓ Three ranges are enough if we reject ridiculous answers or use other tricks.
- ✓ Another range is required for technical reasons to be discussed later.

7. The Big Idea Mathematically

In a sense, the whole thing boils down to those "velocity times travel time" math problems: Velocity (60 mph) x Time (2 hours) = Distance (120 miles) In the case of GPS we're measuring a radio signal so the velocity is going to be the speed of light or roughly 186,000 miles per second.

III. RESULTS AND DISCUSSION

8. The problem is measuring the travel time.

The timing problem is tricky. First, the times are going to be awfully short. If a satellite were right overhead the travel time would be something like 0.06 seconds. So we're going to need some really precise clocks. We'll talk about those soon. But assuming we have precise clocks, how do we measure travel time? To explain it let's use a goofy analogy: Suppose there was a way to get both the satellite and the receiver to start playing "The Star Spangled Banner" at precisely 12 noon. If sound could reach us from space (which, of course, is ridiculous) then standing at the receiver we'd hear two versions of the Star Spangled Banner, one from our receiver and one from the satellite. These two versions would be out of sync. The version coming from the satellite would be a little delayed because it had to travel more than 11,000 miles. If we wanted to see just how delayed the satellite's version was, we could start delaying the receiver's version until they fell into perfect sync. The amount we have to shift back the receiver's version is equal to the travel time of the satellite's version. So we just multiply that time times the speed of light and we've got our distance to the satellite. That's basically how GPS works. Only instead of the Star Spangled Banner the satellites and receivers use something called a "Pseudo Random Code" – which is probably easier to sing than the Star Spangled Banner.

9. A Random Code

The Pseudo Random Code (PRC, shown above) is a fundamental part of GPS. The signal is so complicated that it almost looks like random electrical noise. Hence the name "Pseudo-Random." There are several good reasons for that complexity: First, the complex pattern helps make sure that the receiver doesn't accidentally sync up to some other signal. The patterns are so complex that it's highly unlikely that a stray signal will have exactly the same shape. Since each satellite has its own unique Pseudo-Random Code this complexity also guarantees that the receiver won't accidentally pick up another satellite's signal. So all the satellites can use the same frequency without jamming each other. And it makes it more difficult for a hostile force to jam the system. In fact the Pseudo Random Code gives the DoD a way to control access to the system. But there's another reason for the complexity of the Pseudo Random Code, a reason that's crucial to making GPS economical. The codes make it possible to use "information theory" to "amplify" the GPS signal. And that's why GPS receivers don't need big satellite dishes to receive the GPS signals. We glossed over one point in our goofy Star-Spangled Banner analogy. It assumes that we can guarantee that both the satellite and the receiver start generating their codes at exactly the same time. If measuring the travel time of a radio signal is the key to GPS, then our stop watches had better be darn good, because if their timing is off by just a thousandth of a second, at the speed of light, that translates into almost 200 miles of error! On the satellite side, timing is almost perfect because they have incredibly precise atomic clocks on board.

10. Receivers here on the ground

We have to remember that both the satellite and the receiver need to be able to precisely synchronize their pseudo-random codes to make the system work. If our receivers needed atomic clocks (which cost upwards of $50K to $100K) GPS would be a lame duck technology. Nobody could afford it. Luckily the designers of GPS came up with a brilliant little trick that lets us get by with much less accurate clocks in our receivers. This trick is one of the key elements of GPS and as an added side benefit it means that every GPS receiver is essentially an atomic-accuracy clock. The secret to perfect timing is to make an extra satellite measurement. That's right, if three perfect measurements can locate a point in 3-dimensional space, then four imperfect measurements can do the same thing.

11. Extra Measurement Cures Timing Offset

If our receiver's clocks were perfect, then all our satellite ranges would intersect at a single point (which is our position). But with imperfect clocks, a fourth measurement, done as a cross-check, will NOT intersect with the first three. So the receiver's computer says "Uh-oh! there is a discrepancy in my measurements. I must not be perfectly synced with universal time." Since any offset from universal time will affect all of our measurements, the receiver looks for a single correction factor that it can subtract from all its timing measurements that would cause them all to intersect at a single point. That correction brings the receiver's clock back into sync with universal time, and bingo! – You've got atomic accuracy time right in the palm of your hand. Once it has that correction it applies to all the rest of its measurements and now we've got precise positioning. One consequence of this principle is that any decent GPS receiver will need to have at least four channels so that it can make the four measurements simultaneously. With the pseudo-random code as a rock solid timing sync pulse, and this extra measurement trick to get us perfectly synced to universal time, we have got everything we need to measure our distance to a satellite in space. But for the triangulation to work we not only need to know distance, we also need to know exactly where the satellites are.

12. Getting Perfect Timing

- ✓ Accurate timing is the key to measuring distance to satellites.
- ✓ Satellites are accurate because they have atomic clocks on board.
- ✓ Receiver clocks don't have to be too accurate because an extra satellite range measurement can remove errors.

The errors are usually very slight but if you want great accuracy they must be taken into account.

13. Getting the message out

Once the DoD has measured a satellite's exact position, they relay that information back up to the satellite itself. The satellite then includes this new corrected position information in the timing signals it's broadcasting. So a GPS signal is more than just pseudo-random code for timing purposes. It also contains a navigation message with ephemeris information as well. With perfect timing and the satellite's exact position you'd think we'd be ready to make perfect position calculations. But there's trouble afoot.

14. Satellite Positions

- ✓ To use the satellites as references for range measurements we need to know exactly where they are.
- ✓ GPS satellites are so high up their orbits are very predictable.
- ✓ Minor variations in their orbits are measured by the Department of Defense.
- ✓ The error information is sent to the satellites, to be transmitted along with the timing signals.

15. Uses of GPS

- ✓ GPS receivers are used for navigation, positioning, time dissemination, and other research.
- ✓ Navigation in three dimensions is the primary function of GPS.
- ✓ 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.
- ✓ Research projects have used GPS signals to measure atmospheric parameters.
- ✓ Georeferencing: that is assigning correct latitude and longitude to the control points of satellite imageries and topographic maps.

16. Measuring Distance: Summary of Discussion

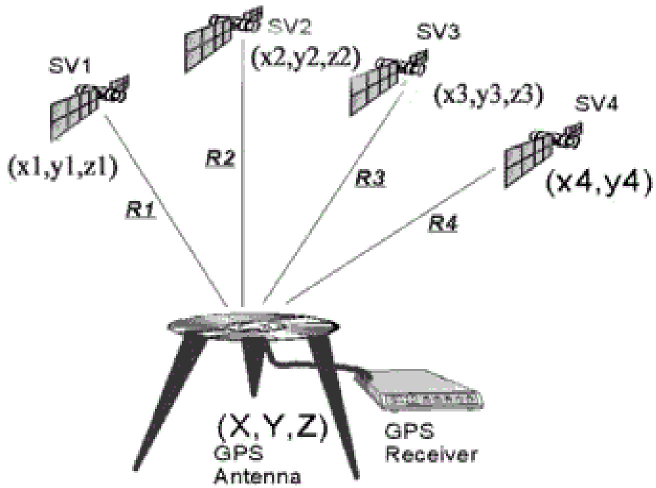


Fig.3: Calculation of Position

A GPS receiver determines its position by using the signals that it observes from different satellites. Since the receiver must solve for its position (X, Y, Z) and the clock error (x), four SVs are required to solve receiver's position using the following four equations:

$$R_1^2 = (X - X_1)^2 + (Y - y_1)^2 + (Z - z_1)^2 + x^2$$

$$R_2^2 = (X - X_2)^2 + (Y - y_2)^2 + (Z - z_2)^2 + x^2$$

$$R_3^2 = (X - X_3)^2 + (Y - y_3)^2 + (Z - z_3)^2 + x^2$$

$$R_4^2 = (X - X_4)^2 + (Y - y_4)^2 + (Z - z_4)^2 + x^2$$

Where (x1,y1) (x2,y2) (x3,y3) and (x4, y4) stand for the location of satellites and R1, R2, R3, R4 are the distances of satellites from the receiver position (Figure-3). Hence solving the four equations for four unknowns X, Y, Z and x, the position or location of the station is calculated.

1. Distance to a satellite is determined by measuring how long a radio signal takes to reach us from that satellite.
2. To make the measurement we assume that both the satellite and our receiver are generating the same pseudo-random codes at exactly the same time.
3. By comparing how late the satellite's pseudo-random code appears compared to our receiver's code, we determine how long it took to reach us.
4. Multiply that travel time by the speed of light and you've got distance.

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