Introduction

Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations.

GPS uses the constellation of satellites as reference points to calculate positions accurate to a matter of metres. Advanced forms of GPS can provide sub-centimetre measurements.

GPS works in five logical steps:

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

GPS SETUP

There are several things you need to do with your GPS receiver **before** you start using it. Your GPS probably has, through its Main Menu Page, a **Setup or Setup Menu** option. Go to this option **first**.

Set the following features:

1. The first thing you should do is to make certain that the time and date are correct. You can usually set or check these features through sub-options such as *Time* or *System*. Check your manual to make certain.

We set the day and time because it is always important to know "when" you are working.

2. The next feature that should be checked or set is the map datum (or reference ellipsoid). **This is the most important feature to set on your GPS!** It can usually be set through sub-options such as *Navigation* or *Location*. Again, check your manual.

Setting the map datum or reference ellipsoid is critical for every application of GPS use, but in particular it is important for every application where you want to relate your position data (taken from the GPS receiver) to an existing map or chart. Maps and charts are produced using very specific datums or reference ellipsoids that translate latitudes/longitudes or UTM coordinates from the curved surface of the Earth to the flat surface of a map or chart. In order to match your GPS position readings accurately with an associated map, you must match the datum or reference ellipsoid of your GPS with the map. A "good" map should state the datum or reference ellipsoid used during its creation (usually, somewhere on the front). Common North American datums are NAD27 and NAD83. A common global reference ellipsoid is WGS84.

Failure to set the correct datum or reference ellipsoid can cause your GPS position to be off by as much as 200 meters relative to the map.

3. Another feature that should be checked is the geo-referencing format. Again, it can usually be set through sub-options such as *Navigation* or *Location*. Look for *Position Format* or *Location Format*. Check your manual.

Generally, the geo-referencing format is set to either latitude/longitude or UTM coordinates. The decision to use one or the other is often determined by the coordinate system shown on an associated map, especially if the user wants to put their coordinates onto an existing map or chart. If both coordinate systems are shown on the map, the user can choose one or the other based on their personal preferences. Many people find the UTM system easier to map.

4.The GPS user can also set the units to be displayed by the GPS. Sub-options such as *Navigation* or *Location* usually permit access to this feature. Check your manual.

GPS receivers will usually display distances and elevations in either metric (meters) or imperial (feet). Again, the choice is usually left to user preference. However, since UTM coordinates are based on the metric system, the user might choose to use metric units for all their distances. If elevations are more important, then check the map's "contour interval" units before deciding on either metric or imperial.

5.There are several other features that can be set including the compass view, the heading (true north or magnetic north), WAAS (on or off) and a host of other features. **BUT** the most important features have been discussed above. When in doubt, **read your manual** for more details.

WORKING WITH YOUR GPS

Topic 9 (Putting GPS to Work) outlined some of the applications that GPS can be put to. For the average GPS user, the most important ones are Location, Mapping and Navigation. So, this section will concentrate on those specific applications.

Location

While using the GPS receiver, the user's Location, or Position, is constantly displayed as either latitude/longitude or UTM coordinates. As the user moves from one location to the next, the displayed position changes.

The user has the option of saving various positions as *Waypoints*. Waypoints are central to almost every application of your GPS. Your GPS's manual will detail how to create waypoints.

Waypoints are stored in your GPS and become a record of where you have been. Usually, a GPS receiver will assign consecutive numbers as waypoint "names" in the order that the waypoints were created. Many GPS receivers will permit the user to change these numbers to alphanumeric names that have more meaning to the user (e.g. Camp, My House, Route151-Hwy5, etc.).

Information about each waypoint can be recalled by the user. By accessing the "waypoint list", the user can recall information specific to individual waypoints that usually includes the day and time the waypoint was collected, and its coordinates and elevation. Note: Not all GPS receivers will store elevation data.

Some GPS receivers will also display a "route" showing where you have been. More expensive GPS receivers can overlay this route on a "base map" stored within the receiver.

IMPORTANT: Waypoints and Routes have very little meaning unless they are related back to either a paper map or chart, or to a digital map stored in the GPS receiver or on a computer. GPS coordinates should always be related back to a map.

Mapping

Mapping involves taking your waypoint positional data and placing on an existing map, or creating your own map.

Placing positional data on to an existing map or chart is very straightforward. You simple match your waypoint coordinates to the coordinate system on the map, and make a mark on the map indicating the waypoint. It is very important to "indicate" or "associate" other information related to the waypoint somewhere on the map.

To indicate information, the user chooses to write information directly onto the map next to the waypoint. This information may include an appropriate name for the waypoint, the day/time, the coordinates and what is there (e.g. fishing hole, good campsite, large Sitka Spruce, etc.).

To associate information, the user chooses to write an alphanumeric name or code onto the map next to the waypoint. At the same time, the user creates a corresponding entry in a notebook or journal under the same name or code. All information associated with that waypoint is then entered into the journal for future reference. This method tends to keep maps a lot neater.

Creating your own map has its own special challenges. Waypoint coordinates have to be placed on paper or on a computer in a "meaningful" manner. This section will not go into a whole discussion on the elements of cartography (map making). Suffice it to say that the user must first create an accurate coordinate system on paper, correctly orientate that coordinate system to an appropriate north (True, Magnetic or Grid), and then plot the waypoint coordinates over the coordinate system. The user must also include information such as an appropriate title, units for the coordinate system, the datum, a map scale, a symbols and line legend, and so on. It's a lot of work, but it can be very rewarding.

Navigation

Navigation is an incredibly powerful application of GPS. It can permit you to find your way back to camp in the dark. It can help you to find assistance in an emergency. It can permit you to find a special feature years after you were last there.

Finding a place, such as your camp, relates the application of navigation to the same-day collection of waypoints. GPS receivers have a *Go To* or *Track To* function. Find any waypoint on your GPS's waypoint list (such as your camp's waypoint), hit the *Go To* or *Track To* button on the receiver, and the GPS will show you a compass. As you start moving, the compass will show you the direction you are currently heading **and** the direction you must head to get to that waypoint. By changing your direction until your heading lines up with the waypoint direction, the GPS keeps you on track until you reach the waypoint. Some GPS receivers will even beep when you are over the exact point. The beauty of a GPS versus a compass is that if you have to can go off track to get around an obstacle (e.g. gullies, swamps, etc.), the GPS will very quickly put you back on track once you have cleared that obstacle.

Finding a point not on your waypoint list requires that you use a map, either a paper map you have brought or a digital map stored in the GPS receiver. The GPS receiver will permit you to create waypoints in one, or both, of two ways. The first way is to "add" a waypoint to your waypoint list and enter in the coordinates for that point from a paper map or chart. Then *Go To* or *Track To* that waypoint. If your GPS receiver comes with a digital base map, it will let you "pan" over the map, place a cursor over a specific point on the map, and identify or create that point as a waypoint. You can then *Go To* or *Track To* that point. This is a great way of navigating out of an area or to a specific feature because, as long as you have a map, you can track to any feature on that map.

Finding a point you have not visited for sometime is easy with a GPS, and relates mapping to navigation. If you mapped the coordinates for a specific feature and included the coordinates for that feature in your records, all you have to do is create a waypoint for that feature, add the coordinates, and then *Go To* or *Track To* it. This application of navigation permits the user to find a specific place accurately every time even though a substantial amount of time may have passed since the last visit (e.g. fishing hole, good campsite, large Sitka Spruce, etc.).

Field Work - DO's

1.Always take spare batteries for your GPS.

2.Always take a paper map (in a waterproof cover) or a digital map stored in your GPS receiver.

3.Always take a compass **and** learn how to use it **before** you go into the field.

4.Always take a basic survival kit or pack, a flashlight and WATER.

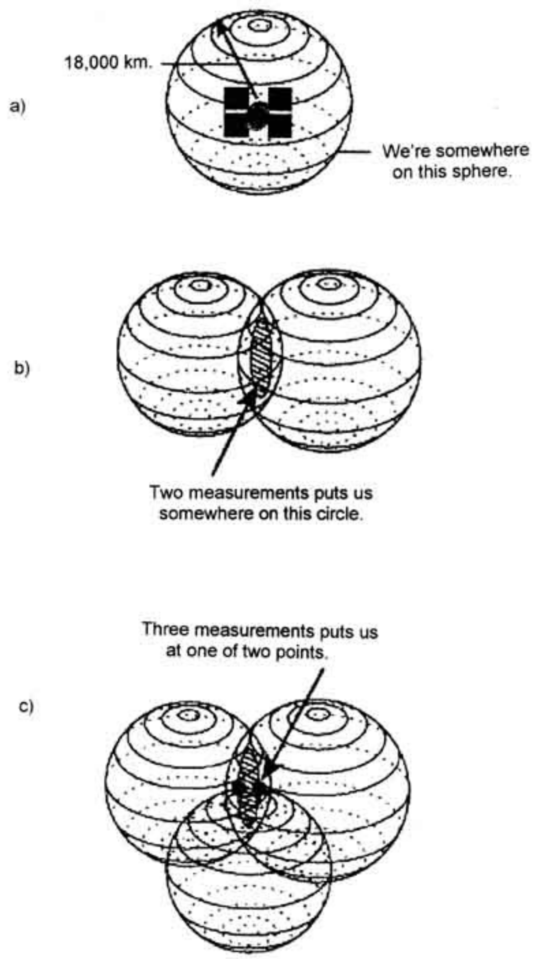
5.Always tell someone where you are going, with whom you are going, and when you can be expected to return.

Step 1: Triangulating from Satellites

The whole idea behind GPS is to use satellites in space as reference points for locations here on earth.

By very accurately measuring our distance from three satellites, we can *triangulate* our position anywhere on earth.

The Big Idea Geometrically



a) single satellite at approx. 18,000 kms - places us on a sphere
b) second satellite at approx. 19,000 kms - places us on a circle
c) third satellite at approx. 20,000 kms - places at one of two points

- minimum of three satellites required
- a fourth satellite can achieve two things: eliminate the second point AND plays a significant role re: timing (to be discussed later)

Step 2: Measuring Distance from a Satellite

Distance is measured to an object floating in space by timing how long it takes for a signal sent from the satellite to arrive at our receiver.

Velocity (m/sec) * Time (sec) = Distance (m)

In the case of GPS, we're measuring a radio signal so the velocity is going to be the speed of light →$3.0*10^8$ m/sec.

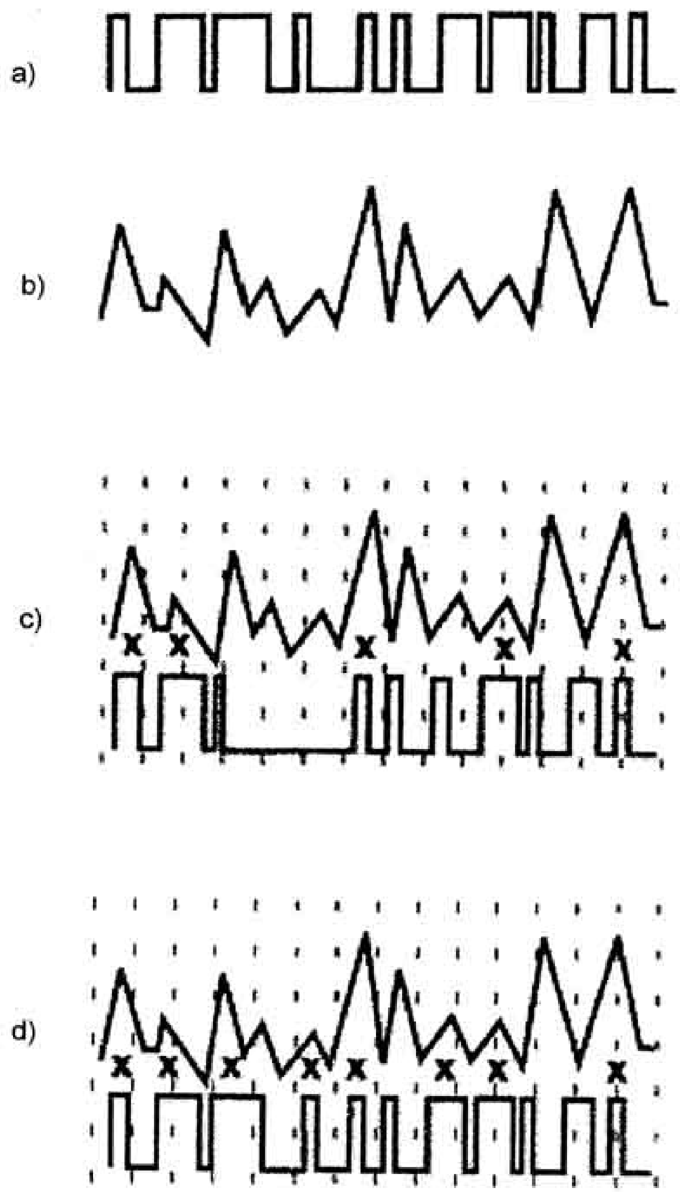
The problem is measuring the travel time.

Times are going to be very short. If a satellite were directly overhead, the travel time would be something like 0.06 sec. That means we need to have very precise clocks. If we are off by:

Time		**Distance**
0.01 sec.	→	3,000,000 m. or 3,000 km.
0.001 sec.	→	300,00 m. or 300 km.
0.0001 sec.	→	30,000 m. or 30 km.
0.00001 sec.	→	3000 m. or 3 km.
1 microsecond	→	300 m.
1 nanosecond	→	0.30 m. or 30 cm.

Assuming we have very precise clocks, the principle works as follows using an analogy. Queen's *We Will Rock You* is started and played several kilometres from where we are. At precisely the same time as it starts to play at the distant location, we start and play *We Will Rock You* here. If we heard both versions at the same time, they would be out of sync because the distant version has to travel at the speed of sound over land to get to us. If we could measure how much they were out of sync, we could determine the distance to the other location from us.

That's how GPS works! Instead of using *We Will Rock You*, satellites and receivers use something called a *PSEUDO-RANDOM CODE*.



a. The Pseudo Random Code (PRC) is a fundamental part of GPS. It is a very complicated digital code (“on” and “off” pulses). The signal is so complicated that it almost looks like random electrical noise, hence “pseudo-random”.

   GPS satellites transmit signals on two carrier frequencies:

   - L1 carries a pseudo-random code for timing, and a status message at 1575.42 MHz.
   - L2 is for the more precise military pseudo-random code at 1227.60 MHz.

There are two types of pseudo-random codes:

- C/A (Coarse Acquisition) code included in the L1 carrier. It is the basis for civilian GPS use.
- P (Precise) code included in both the L1 and L2 carriers. It is intended for military use. P code is more complicated than C/A code, and is more difficult for receivers to acquire. It can also be encrypted →Y code.

  C/A code is acquired first, then P code.

EACH SATELLITE HAS A UNIQUE PSEUDO-RANDOM CODE

There is also a low frequency signal added to the L1 carrier that gives information about the satellite's orbits, their clock corrections, and other system status.

b. The world is awash in random electrical noise. If we tuned our receivers to the GPS frequency and graphed what we picked up, we'd see a randomly varying line --- the earth's background noise.

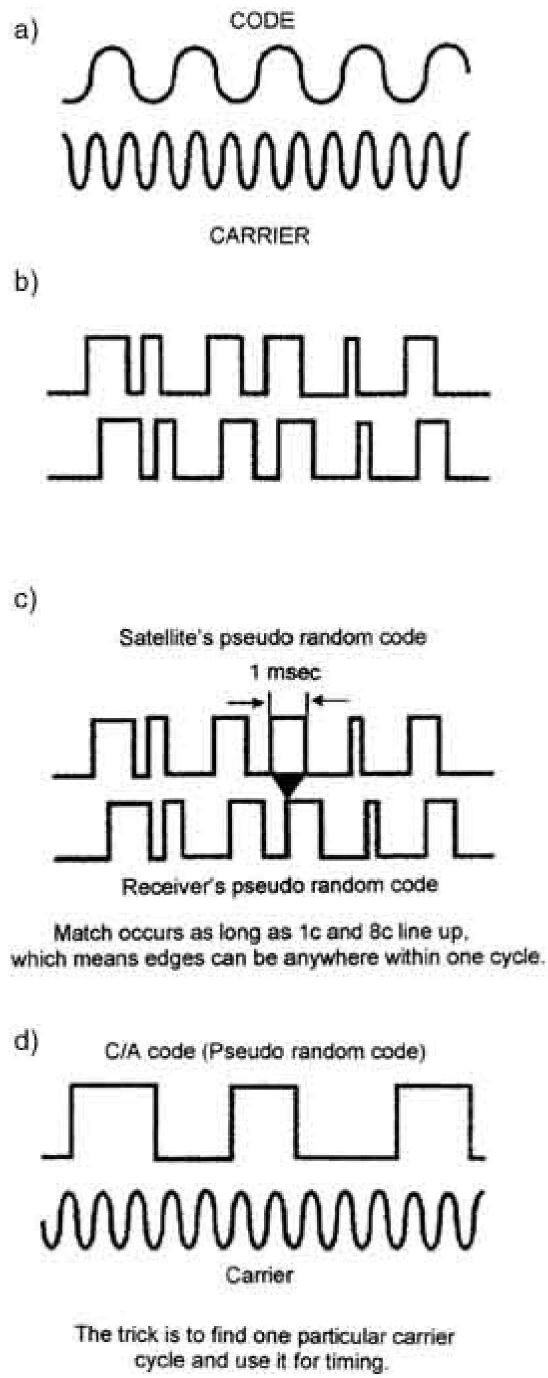
c. The PRC looks a lot like the background noise except we know its pattern. We compare a section of our PRC with the background noise and look for areas where they are both doing the same thing. Mark those areas where they are doing the same thing.

d. By comparing hundreds or even thousands of sections we can match even more by accumulating scores for each match (i.e. resampling). It means that the system can get away with less powerful satellites and our receivers don't need big antennas like satellite T.V.

Step 3: Getting Perfect Timing

Measuring the travel time of a radio is the key to GPS.

Both the satellite and the receiver need to be able to synchronize their pseudo-random codes to make the system work.



a. Comparison of Code-Phase GPS and Carrier-Phase GPS. Using the GPS carrier-phase can significantly improve the accuracy of GPS.

b. The problem with code-phase is that the bits (or cycles) of the PRC are so wide that even if you get synched up there's still lots of slop.

c. Example of an apparent match. Even though they match they are a little out of phase.

d. Survey receivers start with the PRC (code-phase) and then move on to measurements based on the carrier frequency for that code (carrier-phase). Relating back to earlier discussion of codes, the code-phase is a C/A (Coarse Acquisition) code and the carrier-phase is a P (Precise) code.

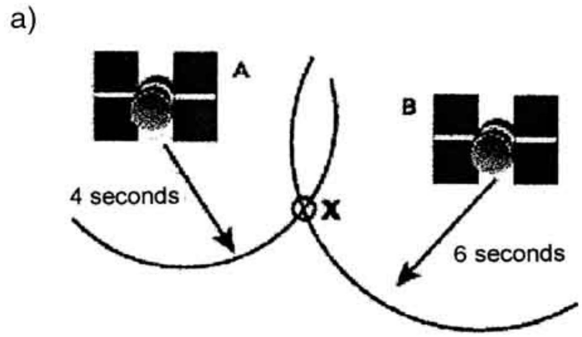
On the satellite side, timing is almost perfect because they have incredibly precise atomic clocks.

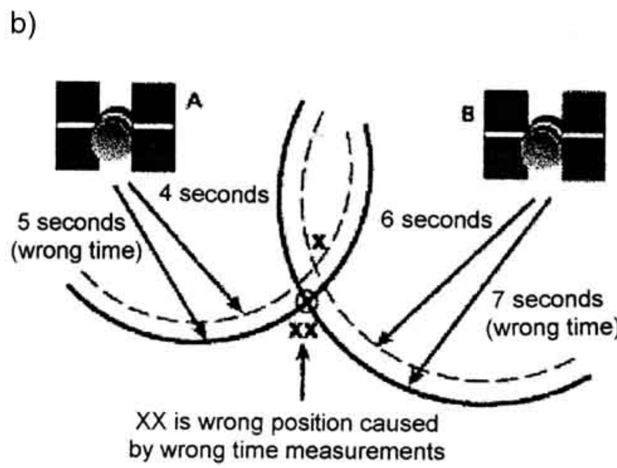
If receivers needed to have atomic clocks, the cost would go up by $50K to $100K, and GPS would be useless to us. The designers of GPS came up with a little trick that allows our receivers to get away with less accurate (less costly) clocks.

The secret to perfect timing is to make an extra satellite measurement.

If three perfect measurements can locate a point in space, the four imperfect measurements can do the same thing.

Eliminating Clock Errors

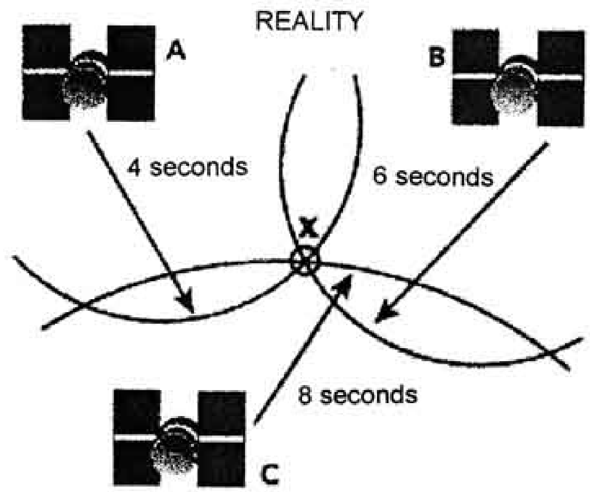




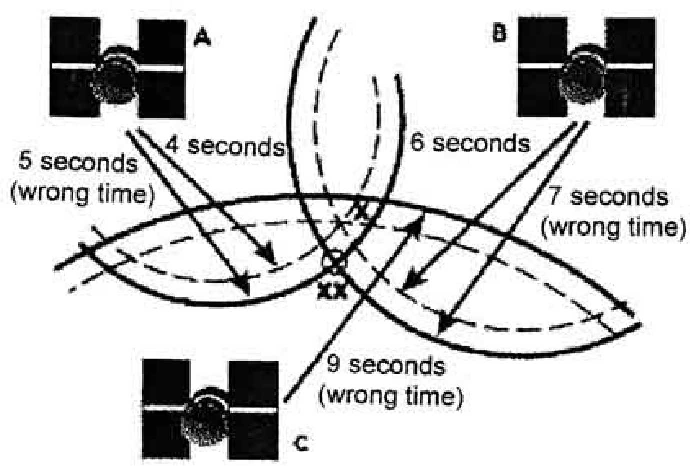
a. Three satellites give two possible points (only two satellites are shown; assume the third is in the third dimension). We discard one point because it is illogical, and are left with point X. Rather than show distance, time is shown as speed of light is constant.

b. If our receiver clock was out by one second, our position would change to XX.

a)



b)



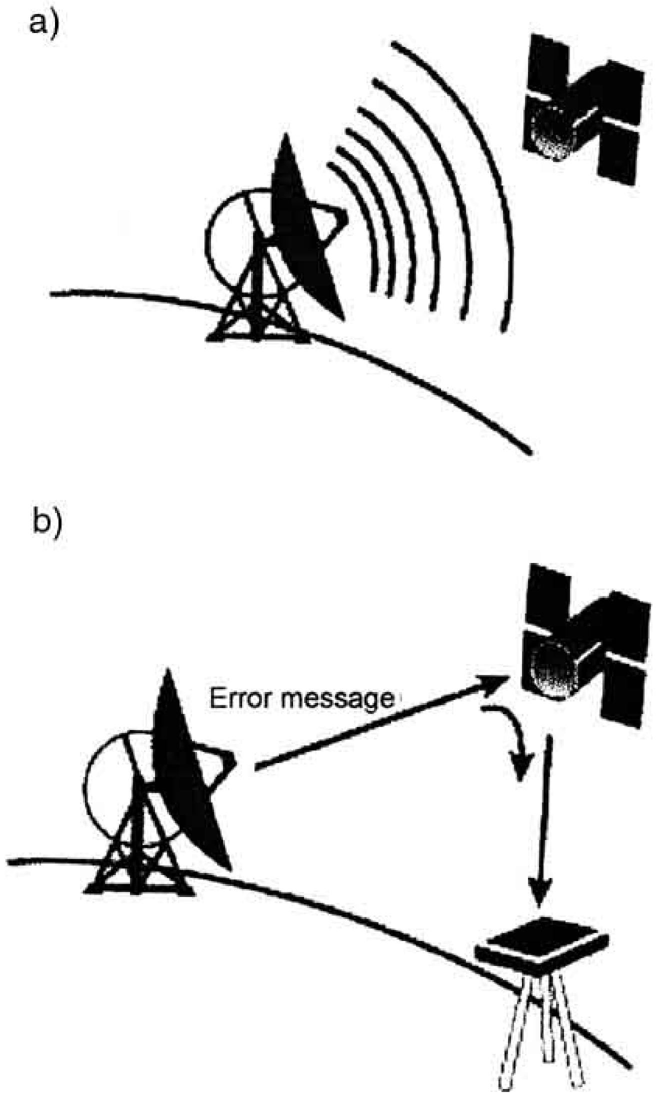
a. With precise timing, adding in the fourth satellite would confirm the location of point X.

b. However, our clock is off. The fourth satellite does not pass through either point X or XX, and the receiver is alerted that there is a discrepancy. It does provide a pseudo-range representing an area where point X should be.

The computer in the receiver looks for a single correction factor that would allow all measurements to intersect at one point (e.g. subtract 1 second from each measurement). The receiver can then apply that correction to all measurements from then on. ITS CLOCK IS SYNCHED TO UNIVERSAL TIME.

Step 4: Knowing Where a Satellite is in Space

The other critical factor with GPS is knowing where the satellites are so that we relate there position with our position.

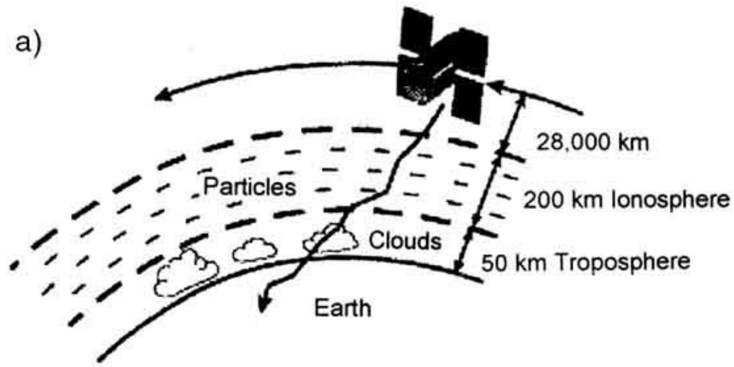


a. For this reason, the satellites are carefully monitored by ground control stations for position, altitude and speed. Even though the satellite orbits were planned very precisely, errors can be caused by gravitational pulls from the sun and moon, and by the pressure of solar radiation on the satellites. Errors may be very slight, but must be accounted for if accuracy is to be achieved.

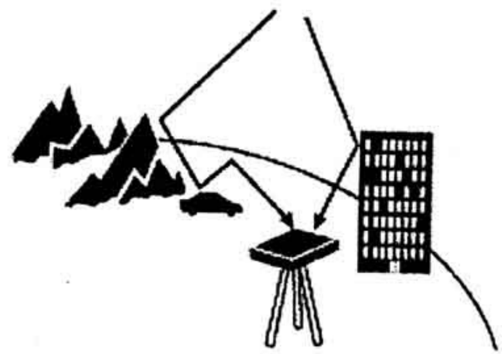
b. Ground control stations relay corrected position information to the satellites. In turn, the corrected information is incorporated in the L1 navigational message, and sent receivers on the ground along with the PRC.

Step 5: Correcting Errors

a)



b)



a. The speed of light is only constant in a vacuum. Radio signals must pass through the ionosphere and the troposphere where they may encounter charged particles, clouds, water vapour, and particulates all of which can cause reflection or refraction of the radio signal.

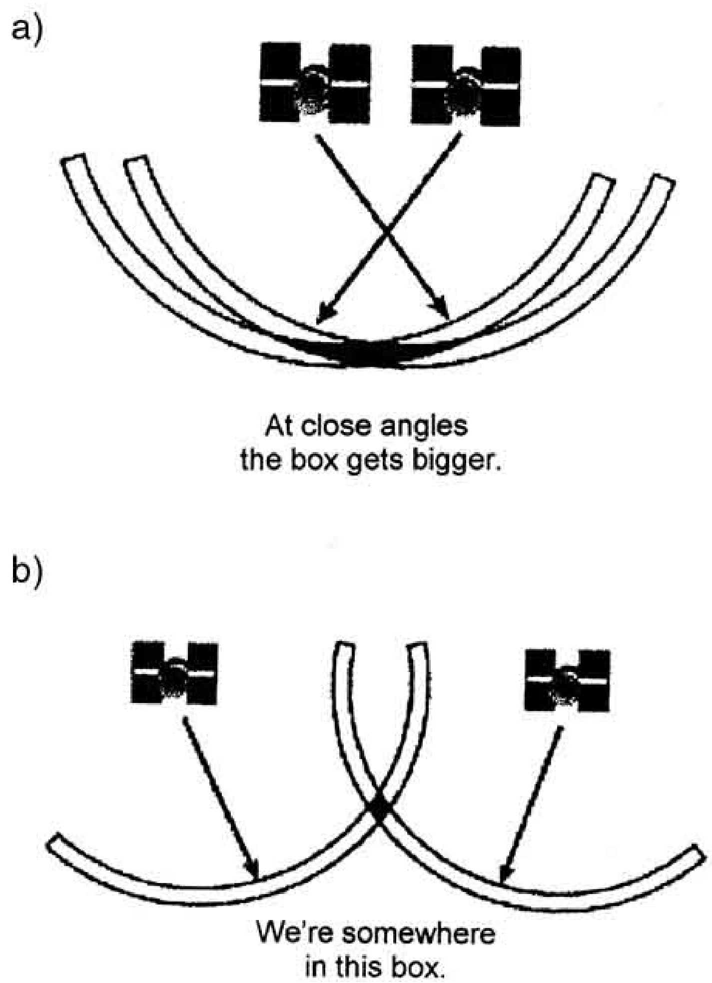
b. Closer to the receiver, the radio signal may bounce off various obstructions before it gets to our receiver --- multi-path error.

Each satellite cannot be monitored 24 hours a day, so slight orbital position errors may be temporarily bypassed.

Atomic clocks are very precise, but not perfect.

All of the above can cause slight timing errors, but even slight errors may result in a loss of accuracy by metres. Monitoring atmospheric conditions and employing a variety of modeling techniques can help, but there will always be some error.

Some satellite angles in relation to our position are better than others. Basic geometry itself can magnify the errors mentioned above with a principle called *Geometric Dilution of Precision* or GDOP.



a. two satellites at close angles, high GDOP.
b. two satellites much further apart, low GDOP.

Good receivers determine which satellite combinations will give the lowest GDOP.

Intentional Errors

The U.S. DoD intentionally degrades the accuracy of the system through a policy called *Selective Availability* or SA.

The DoD introduces some "noise" into the satellite's clock data which, in turn, adds inaccuracy into position calculations. The DoD may also be sending slightly erroneous orbital data to the satellite which is then transmitted to receivers on the ground as part of the navigation message in the L1 carrier. See Table 1 and 2 for a summary of GPS errors.

Table 1: Typical Error in Meters (per satellite)

Error Source	Standard GPS	Differential GPS
Satellite Clocks	1.5	0
Orbit Errors	2.5	0
Ionosphere	5.0	0.4
Troposphere	0.5	0.2
Receiver Noise	0.3	0.3
Multi-path Reflection	0.6	0.6
Selective Availability	30	0

Table 2: Typical Position Accuracy (meters)

Position	Standard GPS	Differential GPS
Horizontal	50	1.3
Vertical	78	2.0
3-D	93	2.8

Much of the positional inaccuracy caused by all these errors can be overcome by using *Differential GPS*.

DIFFERENTIAL GPS

Why we need Differential GPS?

Basic GPS is the most accurate radio-based navigation system ever developed. And for many applications it's plenty accurate. But it's human nature to want MORE! So, some engineers came up with "Differential GPS" … a way to correct the various inaccuracies in the GPS system thereby pushing its accuracy even farther.

Differential GPS or "DGPS" can yield measurements good to a couple of meters in moving applications and even better in stationary situations. That improved accuracy has a profound effect on the importance of GPS as a resource. With it, GPS becomes more than just a system for navigating boats and planes around the world. It becomes a universal measurement system capable of positioning things on a very precise scale.

How does Differential GPS work?

Differential GPS involves the cooperation of two receivers, one that's stationary and another that's roving around making position measurements. The stationary receiver is the key. It ties all the satellite measurements into a solid local reference.

Here's how it works:

The Problem

Remember that GPS receivers use timing signals from at least four satellites to establish a position. Each of those timing signals is going to have some form of error or delay, depending on what sort of perils have befallen the signal on its trip down to us at the Earth's surface.

Since each of the timing signals that go into a position calculation has some error that calculation is going to be a compounding of those errors.

The Solution

Fortunately, the sheer scale of the GPS system comes to our rescue. The satellites are so far out in space that the little distances we travel here on earth are insignificant. So, if two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have traveled through virtually the same slice of atmosphere, and so will have virtually the same errors.

That's the idea behind Differential GPS. We have one receiver measure the timing errors and then provide correction information to the other receivers that are roving around. That way virtually all errors can be eliminated from the system, even the Selective Availability error that the DoD puts in on purpose.

The idea is simple. Put the reference receiver on a point that's been very accurately surveyed and keep it there. This reference station receives the same GPS signals as the roving receiver, but instead of working like a normal GPS receiver it attacks the equations backwards.

Instead of using timing signals to calculate its position, it uses its known position to calculate timing. It figures out what the travel time of the GPS signals should be, and compares it with what they actually are. The difference is an "error correction" factor.

The receiver then transmits this error information to the roving receiver so it can use it to correct its measurements.

Since the reference receiver has no way of knowing which of the many available satellites a roving receiver might be using to calculate its position, the reference receiver quickly runs through all the visible satellites and computes each of their errors. Then it encodes this information into a standard format and transmits it to the roving receivers.

It's as if the reference receiver is saying: "OK everybody, right now the signal from satellite #1 is ten nanoseconds delayed, satellite #2 is three nanoseconds delayed, satellite #3 is sixteen nanoseconds delayed..." and so on.

The roving receivers get the complete list of errors and apply the corrections for the particular satellites they're using.

Where to get differential corrections?

In the early days of GPS, private companies such as groups of surveyors or oil drilling operations established reference stations. These companies had big projects demanding high levels of accuracy. Their approach was to buy a reference receiver and set up a communication link with their roving receivers. For a price, these companies would sell their correction signals to other usually smaller users and companies.

But now there are enough public agencies transmitting corrections that you might be able to get them for free. The United States Coast Guard and other international agencies are establishing reference stations all over the place, especially around popular harbors and waterways. These stations often transmit on the radio beacons that are already in place for radio direction finding (usually in the 300kHz range).

Anyone in the area can receive these corrections and radically improve the accuracy of their GPS measurements. Most ships already have radios capable of tuning the direction finding beacons so that adding DGPS will be quite easy.

Many new GPS receivers are being designed to accept corrections, and some are even equipped with built-in radio receivers.

OTHER WAYS TO WORK WITH DGPS

Post Processing DGPS

Not all DGPS applications are created equal. Some don't need the radio link because they don't need precise positioning immediately. It's one thing if you're trying to position a drill bit over a particular spot on the ocean floor from a pitching boat, but quite another if you just want to record the track of a new road for inclusion on a map.

For applications like the later, the roving receiver just needs to record all of its measured positions and the exact time it made each measurement. Then later, this data can be merged with corrections recorded at a reference receiver for a final clean up of the data. So you don't need the radio link that you have to have in real-time systems.

If you don't have a reference receiver, there may be alternative source for corrections in your area. Some academic institutions are experimenting with the Internet as a way of distributing corrections.

Inverted DGPS: an example

There's another permutation of DGPS, called "inverted DGPS," that can save money in certain tracking applications.

Let's say you've got a fleet of buses and you'd like to pinpoint them on street maps with very high accuracy (maybe so you can see which side of an intersection they're parked on or whatever). Anyway, you'd like this accuracy but you don't want to buy expensive "differential-ready" receivers for every bus.

With an inverted DGPS system the buses would be equipped with standard GPS receivers and a transmitter and would transmit their standard GPS positions back to the tracking office. Then at the tracking office the corrections would be applied to the received positions.

It requires a computer to do the calculations, a transmitter to transmit the data but it gives you a fleet of very accurate positions for the cost of one reference station, a computer and a lot of standard GPS receivers.

DGPS: Advanced Concepts

If you want to know where DGPS might be headed, take a look at your hand, because soon DGPS may be able to resolve positions that are no farther apart than the width of your little finger. Imagine the possibilities. Automatic construction equipment could translate CAD drawings into finished roads without any manual measurements. Self-guided cars could take you across town while you quietly read in the back seat.

To understand how this kind of GPS is being developed you need to understand a little about GPS signals. If two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have traveled through virtually the same slice of atmosphere, and so will have virtually the same line.

Code Phase vs. Carrier Phase

The words "Code-Phase" and "Carrier-Phase" may sound like electronic mumbo-jumbo but, in fact, they just refer to the particular signal that we use for timing measurements. Using the GPS carrier frequency can significantly improve the accuracy of GPS. The concept is simple but to understand it let's review a few basic principles of GPS.

Remember that a GPS receiver determines the travel time of a signal from a satellite by comparing the "pseudo random code" it's generating, with an identical code in the signal from the satellite. The receiver slides its code later and later in time until it syncs up with the satellite's code. The amount it has to slide the code is equal to the signal's travel time. The problem is that the bits (or cycles) of the pseudo random code are so wide that even if you do get synced up there's still plenty of slop.

Consider these two signals:

If you compared them logically you'd say they matched. When the top is a one, the bottom signal is also one. When the top signal is a zero, the bottom signal is also zero.

But you can see that while they match they're a little out of phase. Notice that, even though they are the same most of the time, the top signal may change state a little before the bottom signal. This is the source of positioning error.

That's the problem with code-phase GPS. It's comparing pseudo random codes that have a cycle width of almost a microsecond. And at the speed of light a microsecond is almost 300 meters of error!

Code-phase GPS isn't really that bad because receiver designers have come up with ways to make sure that the signals are almost perfectly in phase. Good machines get within a percent or two. But that's still at least 3-6 meters of error.

Survey receivers beat the system by starting with the pseudo random code and then move on to measurements based on the carrier frequency for that code. This carrier frequency is much higher so its pulses are much closer together and therefore more accurate.

If you're rusty on the subject of carrier frequencies consider your car radio. When you tune to 94.7 on the dial you're locking on to a carrier frequency that's 94.7 MHz.

Obviously we can't hear sounds at 94 million cycles a second. The music we hear is a modulation (or change) in this carrier frequency. So when you hear someone sing an "A" note on the radio you're actually hearing the 94.7 MHz carrier frequency being varied at a 440 cycle rate.

GPS works in the same way. The pseudo random code has a bit rate of about 1 MHz but its carrier frequency has a cycle rate of over a GHz (which is 1000 times faster!) At the speed of light the 1.57 GHz GPS signal has a wavelength of roughly twenty centimeters, so the carrier signal can act as a much more accurate reference than the pseudo random code by itself. And if we can get to within one percent of perfect phase like we do with code-phase receivers we'd have 3 or 4 millimeter accuracy!

In essence this method is counting the exact number of carrier cycles between the satellite and the receiver. The problem is that the carrier frequency is hard to count because it's so uniform. Every cycle looks like every other. The pseudo random code on the other hand is intentionally complex to make it easier to know which cycle you're looking at.

So the trick with "carrier-phase GPS" is to use code-phase techniques to get close. If the code measurement can be made accurate to say, a meter, then we only have a few wavelengths of carrier to consider as we try to determine which cycle really marks the edge of our timing pulse. Resolving this "carrier phase ambiguity" for just a few cycles is a much more tractable problem and as the computers inside the receivers get smarter and smarter it's becoming possible to make this kind of measurement without all the ritual that surveyors go through.

Augmented GPS

You've got to hand it to the FAA. They think big! They realized the great benefits GPS could bring to aviation, but they wanted more. They wanted the accuracy of Differential GPS and they wanted it across the whole North American continent … maybe the whole world.

Their plan is called the "Wide Area Augmentation System" or "WAAS," and it's basically a continental DGPS system.

The idea grew out of some very specific requirements that basic GPS just couldn't handle by itself. It began with "system integrity." GPS is very reliable but every once in a while a GPS satellite malfunctions and gives inaccurate data. The GPS monitoring stations detect this sort of thing and transmit a system status message that tells receivers to disregard the broken satellite until further notice. Unfortunately this process can take many minutes that could be too late for an airplane in the middle of a landing.

So, the FAA got the idea that they could set up their own monitoring system that would respond much quicker. In fact, they figured they could park a geosynchronous satellite somewhere over the U.S. that would instantly alert aircraft when there was a problem. Then they reasoned that they could transmit this information right on a GPS channel so aircraft could receive it on their GPS receivers and wouldn't need any additional radios.

But wait a second! If we've got the geosynchronous satellite already transmitting on the GPS frequency, why not use it for positioning purposes too? Adding another satellite helps with positioning accuracy and it ensures that plenty of satellites are always visible around the country.

But wait another second! Why not use that satellite to relay differential corrections too? The FAA figured that with about 24 reference receivers scattered across the U.S. they could gather pretty good correction data for most of the country. That data would make GPS accurate enough for "Category 1" landings (i.e. very close to the runway but not zero visibility).

This system is currently operational, but it has some limitations for land-based GPS receivers. Since the geosynchronous satellite is placed over the equator, it becomes increasingly more difficult to pick up WAAS signals as you travel further North (or South) of the equator. The solution is to add more WAAS satellites, a solution that the FAA is working on.

The ramifications of this go well beyond aviation, because the system guarantees that DGPS corrections will be raining out of the sky for everyone to use. There are now dozens of handheld GPS receivers in production that are capable of receiving the WAAS signals, and these receivers are very affordable.

Local Area Augmentation

To complete the system the FAA wants to eventually establish "Local Area Augmentation Systems" near runways. These would work like the WAAS but on a smaller scale. The reference receivers would be near the runways and so would be able to give much more accurate correction data to the incoming planes. With a LAAS, aircraft would be able to use GPS to make Category 3 landings (zero visibility).

Other government agencies, such as larger municipalities, are investing in LAAS systems as an aid to their surveying and works crews. They also make their correction signals available for a nominal fee to private individuals and companies.

PUTTING GPS TO WORK: AN OVERVIEW

Location

"Where am I?"

The first and most obvious application of GPS is the simple determination of a "position" or location. GPS is the first positioning system to offer highly precise location data for any point on the planet, in any weather. That alone would be enough to qualify it as a major utility, but the accuracy of GPS and the creativity of its users are pushing it into some surprising realms.

Knowing the precise location of something, or someone, is especially critical when the consequences of inaccurate data are measured in human terms. For example, when a stranded motorist was lost in a South Dakota blizzard for 2 days, GPS helped rescuers find her.

GPS is also being applied in Italy to create exact location points for their nationwide geodetic network which will be used for surveying projects. Once in place it will support the first implementation of a nationally created location survey linked to the WGS-84 global grid.

Sometimes an exact reference locator is needed for extremely precise scientific work. Just getting to the world's tallest mountain was tricky, but GPS made measuring the growth of Mt. Everest easy. The data collected strengthened past work, but also revealed that as the Khumbu glacier moves toward Everest's Base Camp, the mountain itself is getting taller.

Navigation

"Where am I going?"

GPS helps you determine exactly where you are, but sometimes important to know how to get somewhere else. GPS was originally designed to provide navigation information for ships and planes. So it's no surprise that while this technology is appropriate for navigating on water, it's also very useful in the air and on the land.

On the Water

It's interesting that the sea, one of our oldest channels of transportation, has been revolutionized by GPS, the newest navigation technology. Trimble introduced the world's first GPS receiver for marine navigation in 1985. And as you would expect, navigating the world's oceans and waterways is more precise than ever.

Today you will find Trimble receivers on vessels the world over, from hardworking fishing boats and long-haul container ships, to elegant luxury cruise ships and recreational boaters. A New Zealand commercial fishing company uses GPS so they can return to their best fishing holes without wandering into the wrong waters in the process.

But GPS navigation doesn't end at the shore.

In the Air

Flying a single-engine Piper Cub or a commercial jumbo jet requires the same precise navigation information, and GPS puts it all at the pilot's fingertips as safely as possible.

By providing more precise navigation tools and accurate landing systems, GPS not only makes flying safer, but also more efficient. With precise point-to-point navigation, GPS saves fuel and extends an aircraft's range by ensuring pilots don't stray from the most direct routes to their destinations.

GPS accuracy will also allow closer aircraft separations on more direct routes, which in turn means that more planes can occupy our limited airspace. This is especially helpful when you're landing a plane in the middle of mountains. And small medical evacuation helicopters benefit from the extra minutes saved by the accuracy of GPS navigation.

But you don't need your head in the clouds to use GPS for navigation.

On Land

Finding your way across the land is an ancient art and science. The stars, the compass, and good memory for landmarks helped you get from here to there. Even advice from someone along the way came into play. But, landmarks change, stars shift position, and compasses are affected by magnets and weather. And if you've ever sought directions from a local, you know it can just add to the confusion. The situation has never been perfect.

Today hikers, bikers, skiers, and drivers apply GPS to the age-old challenge of finding their way. Borge Ousland used Trimble GPS to navigate the snow and ice to ski his way to the top of the world and into the record books. And two wilderness rangers employed GPS to establish a route across the Continental Divide for horse riders and packers.

Tracking

"Where is it?"

If navigation is the process of getting something from one location to another, then tracking is the process of monitoring it as it moves along.

Commerce relies on fleets of vehicles to deliver goods and services either across a crowded city or through nationwide corridors. So, effective fleet management has direct bottom-line implications, such as telling a customer when a package will arrive, spacing buses for the best scheduled service, directing the nearest ambulance to an accident, or helping tankers avoid hazards.

GPS used in conjunction with communication links and computers can provide the backbone for systems tailored to applications in agriculture, mass transit, urban delivery, public safety, and vessel and vehicle tracking. So it's no surprise that police, ambulance, and fire departments are adopting systems like Trimble's GPS-based AVL (Automatic Vehicle Location) Manager to pinpoint both the location of the emergency and the location of the nearest response vehicle on a computer map. With this kind of clear visual picture of the situation, dispatchers can react immediately and confidently.

Chicago developed a GPS tracking system to monitor emergency vehicles through their streets, saving precious time responding to 911 calls. And on the commercial front, two taxi companies in Australia track their cabs for better profit and improved safety.

Mapping

"Where is everything else?"

It's a big world out there, and using GPS to survey and map it precisely saves time and money in this most stringent of all applications. Today, Trimble GPS makes it possible for a single surveyor to accomplish in a day what used to take weeks with an entire team. And they can do their work with a higher level of accuracy than ever before.

Trimble pioneered the technology which is now the method of choice for performing control surveys, and the effect on surveying in general has been considerable. You've seen how GPS pinpoints a position, a route, and a fleet of vehicles. If mapping is the art and science of using GPS to locate items, then we can create maps and models of everything in the world. And we do mean everything including: mountains, rivers, forests and other landforms; roads, routes, and city streets; endangered animals, precious minerals and all sorts of resources; damage and disasters, trash and archeological treasures. GPS is mapping the world.

For example, Trimble GPS helped firefighters respond with speed and efficiency during the 1991 Oakland/Berkeley fire to plot the extent of the blaze and to evaluate damage. In a less urgent yet equally important situation, the city of

Modesto, California improved their efficiency and job performance by using GPS and mountain bikes to create a precise map of its network of water resources and utilities.

Timing

"When will it all happen?"

Although GPS is well-known for navigation, tracking, and mapping, it's also used to disseminate precise time, time intervals, and frequency. Time is a powerful commodity, and exact time is more powerful still. Knowing that a group of timed events is perfectly synchronized is often very important. GPS makes the job of "synchronizing our watches" easy and reliable.

There are three fundamental ways we use time. As a universal marker, time tells us when things happened or when they will. As a way to synchronize people, events, even other types of signals, time helps keep the world on schedule. And as a way to tell how long things last, time provides an accurate, unambiguous sense of duration.

GPS satellites carry highly accurate atomic clocks. And in order for the system to work, our GPS receivers here on the ground synchronize themselves to these clocks. That means that every GPS receiver is, in essence, an atomic accuracy clock.

Astronomers, power companies, computer networks, communications systems, banks, and radio and television stations can benefit from this precise timing. One investment banking firm uses GPS to guarantee their transactions are recorded simultaneously at all offices around the world. And a major Pacific Northwest utility company makes sure their power is distributed at just the right time along their 14,797 miles of transmission lines.

GPS MAPPING EXERCISE

Objectives

1. Use GPS to plot specific locations on the campus starting at BM#113.
2. Practice setting up the GPS unit, entering waypoint data, extracting waypoint data, and plotting locations using UTM coordinates.

Procedure

From the unit's MAIN MENU, apply the following set up:

POSITION FRMT:	UTM/UPS
MAP DATUM:	NAD 27 CANADA
CDI:	+ 0.25
UNITS:	METRIC
HEADING:	AUTO
	DEGREES

LAB ASSIGNMENT

In teams of 2, assemble at BM#113 (campus center). Turn on the GPS unit and allow it to stabilize for approximately 3 minutes. After 3 minutes, press MARK then ENTER and the UTM coordinates for BM#113 will be stored (you can compare them later to N5367620; E477019). These coordinates will be stored as Waypoint 1.

Now, choose a route leading from BM#113 leading to Ring Road. As you travel towards Ring Road, MARK-ENTER 2 or 3 more waypoints ensuring that one of them is at the point where your exit route meets Ring Road. When you reach Ring Road, proceed counter-clockwise around Ring Road periodically recording more waypoints (12 to 16, or more if you wish). Re-enter the campus from Ring Road where you came out, and record 2 or 3 more waypoints with the last one being at BM#113.

NOTE: With the exception of the benchmark waypoints, you do NOT need to stop or even slow down to record waypoints.

In the lab, access the Waypoint List and record on paper the Waypoint #s with their corresponding Northings and Eastings. Plot all the waypoints on centimeter graph paper at a scale of either 1 cm to 40 meters OR 1 cm to 50 meters. In order to establish the gradations for the X-axis (Eastings) and Y-axis (Northings) you will first have to find the waypoint with the lowest Easting value and the waypoint with the lowest Northing value.

HAND IN:

- Your written Waypoint List.
- Your plot (graph) of the waypoint locations with all appropriate meta-data (title, name, date, course, coordinate system w/labels, GN arrow, etc.).