ROYAL CANADIAN AIR CADETS

PROFICIENCY LEVEL THREE

INSTRUCTIONAL GUIDE

SECTION 9

EO C340.07 – IDENTIFY GLOBAL POSITION SYSTEM (GPS) COMPONENTS

Total Time: 60 min

PREPARATION

PRE-LESSON INSTRUCTIONS

Resources needed for the delivery of this lesson are listed in the lesson specification located in A-CR-CCP-803/PG-001, Chapter 4. Specific uses for said resources are identified throughout the instructional guide within the TP for which they are required.

Review the lesson content and become familiar with the material prior to delivering the lesson.

Retrieve current information from reference C3-243 and update the lesson as required.

Create slides of figures located at Annexes Z to AB.

PRE-LESSON ASSIGNMENT

N/A.

APPROACH

An interactive lecture was chosen for this lesson to orient the cadets to GPS components, to generate interest, and emphasize the teaching points.

INTRODUCTION

REVIEW

N/A.

OBJECTIVES

By the end of this lesson the cadet shall be have identified GPS components.

IMPORTANCE

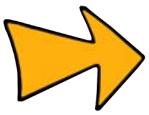
It is important for cadets to be able to identify GPS components so that they will clearly understand the operation and capabilities of GPS when it is used in the field or in an aircraft.

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Teaching point 1 **Explain How the GPS Operates**

Time: 25 min Method: Interactive Lecture

In 1870, an American named Edward Everett Hale suggested a system of four satellites be placed in a circumpolar orbit to provide a global positioning service. This idea was published as a story called *The Brick Moon* in a series of installments in Boston's Atlantic Monthly magazine in 1870 and 1871.



The complete *The Brick Moon* is available at the University of Virginia Library at website http://etext.virginia.edu/toc/modeng/public/HalBric.html.

THE THREE COMPONENTS OF GPS

There are multiple positioning systems that use satellites, including the Russian military's Glonass system and the US military's Navstar system. This lesson describes Navstar, but both systems share the same principles in data transmission and positioning methods, though other details such as orbits differ. Other systems existing or planned include those belonging to Japan and the European Union.

Today's GPS represents a considerable advance from Hale's brick moon idea. It has three components:

- orbiting satellites,
- earthbound control stations, and
- receivers that can be anywhere – earthbound, flying or orbiting.

Satellites

The space segment of GPS consists of 24 operational satellites in six orbital planes (four satellites in each plane). The spacing of the satellites are arranged so that a minimum of five satellites are in view from every point on the globe at any time. The satellites orbit at an altitude of 20 200 km. That altitude, clear of the atmosphere, means that satellites will orbit according to very simple mathematics. Although all the satellites are at the same altitude and their six orbits do cross, the satellites do not collide because they are carefully synchronized.

Control Stations

The control segment of GPS consists of five monitor stations and three ground antennas located around the world. A Master Control Station (MCS) is located at Schriever Air Force Base (AFB) in Colorado. The monitor stations passively track all satellites, gathering information to be processed at the MCS to determine satellite orbits and to update each satellite's navigation message. Updated information is transmitted to each satellite via the ground antennas.

Receivers

The user segment of GPS consists of antennas and receiver-processors that provide positioning, velocity, and precise timing to the user. There is a wide variety of receivers.

Individuals may purchase GPS handsets that are available through commercial retailers. Equipped with these GPS receivers, users can accurately locate where they are and easily navigate to where they want to go, whether walking, driving, flying, or boating. GPS receivers have become a mainstay of transportation systems worldwide, providing navigation for aviation, ground, and maritime operations. Disaster relief and emergency services depend upon GPS receivers for location and timing capabilities in their life-saving missions. Everyday activities such as banking, mobile phone operations, and even the control of power grids, are facilitated by the

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accurate timing provided by GPS receivers. Farmers, surveyors, geologists and countless others perform their work more efficiently, safely, economically, and accurately using the free and open signals of the GPS satellites.

TRILATERATION FROM THREE SATELLITES



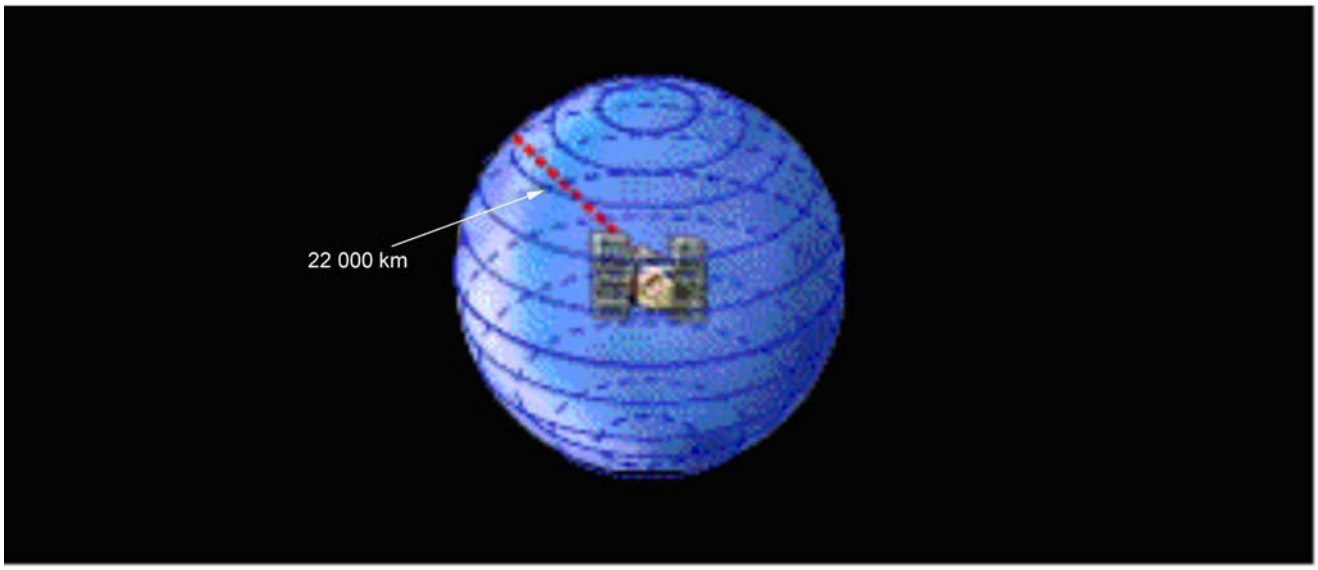
Since angles are not used in the computation, trilateration is a more accurate term than the popular term triangulation. However, the term triangulation is used by most people. For the purposes of this lesson, the two terms are interchangeable.

The principle behind GPS is the use of satellites in space as reference points for describing locations on earth. By very accurately measuring distance from three satellites a position can be trilaterated anywhere on or over the earth.



Show the cadets Figure 15Z-1.

A single measurement of distance from a satellite might find the distance to be 22 000 km. Knowing that this location is 22 000 km from a particular satellite narrows down all the possible locations one could be, to the surface of a sphere that is centered on this satellite and has a radius of 22 000 km.

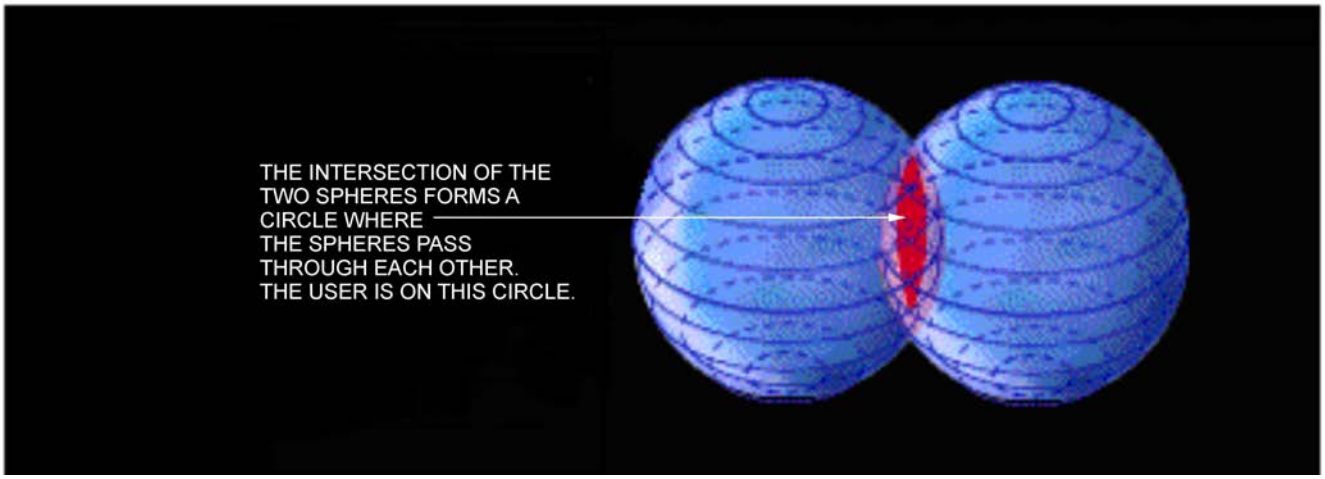


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Figure 1 First Trilateration

If a second measurement shows this same location to be 23 000 km from a second satellite, it is not only on the first sphere but also on a sphere 23 000 km from the second satellite. The location must be somewhere on the circle where these two spheres intersect.

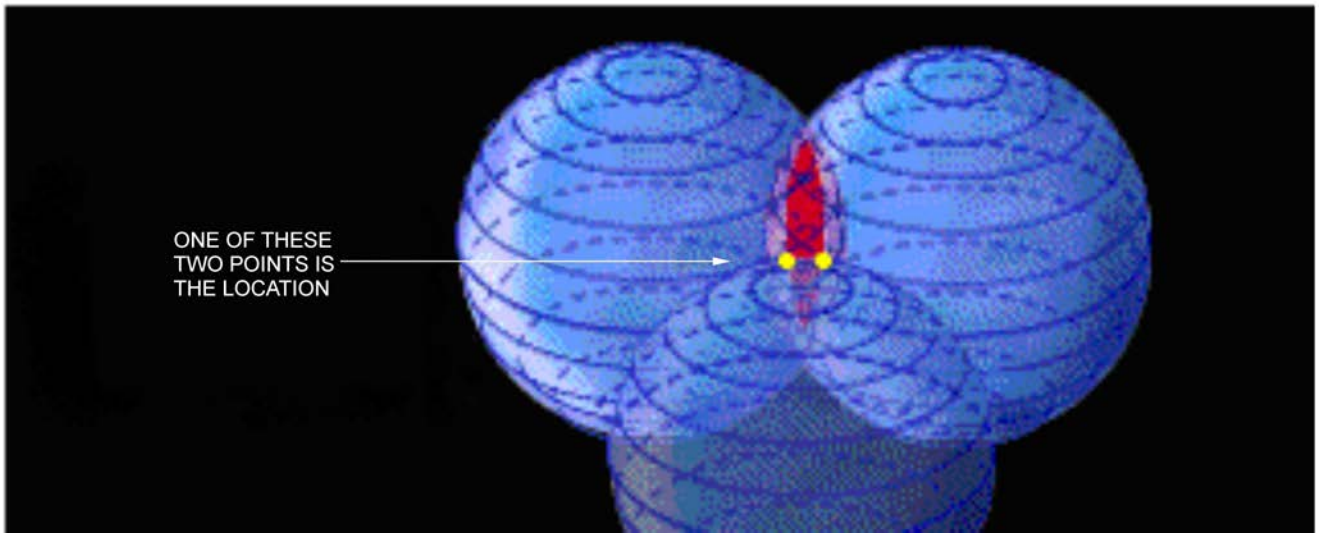
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Figure 2 Second Trilateration

If a third measurement shows the same location to be 24 000 km from a third satellite, it is not only on the first sphere and the second sphere, but also on another sphere that is 24 000 km from the third satellite. This narrows the location down to the two points where the 24 000 km sphere intersects with the circle formed by the intersection of the first two spheres.



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Figure 3 Third Trilateration

From three satellites a location can be determined to be one of just two points in space – only one of which will usually be on the surface of the earth or at the correct altitude above it. To decide which of those two points is the true location, a fourth trilateration measurement is necessary. However, one of the two points may be a ridiculous answer (either too far from Earth or moving at an impossible velocity) and so can be rejected without further measurement.

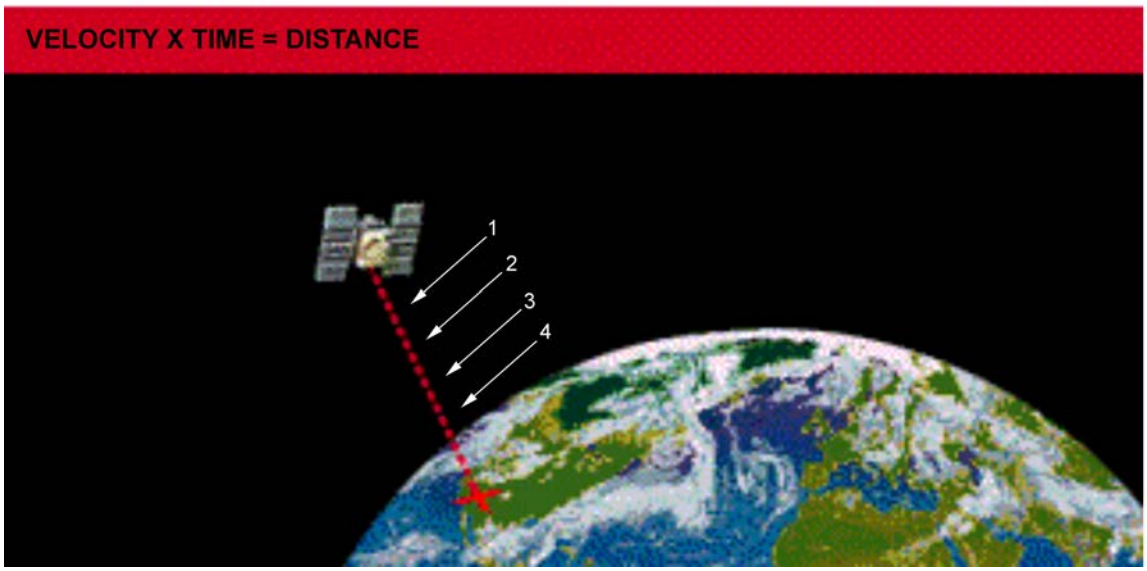
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TIMING RADIO SIGNALS



Show the cadets Figures 15AA-1 and 15AA-2.

Distance to a satellite is determined by measuring how long a radio signal takes to travel from that satellite to the user's receiver. By comparing how long it takes the satellite's coded signal to arrive at the user's receiver, compared to the receiver's internal clock, the travel time can be determined. Finally, comparing that measured travel time to the speed of light gives the distance.

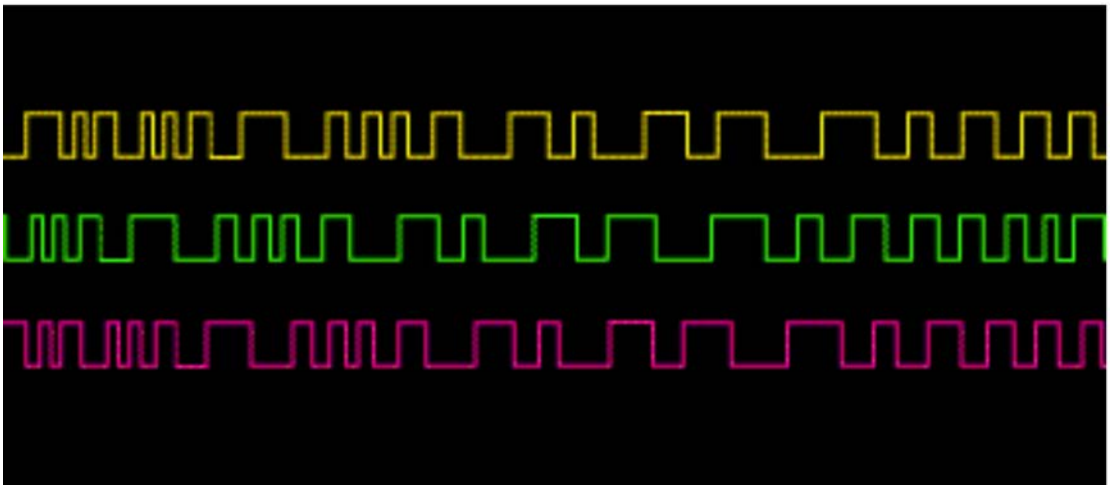


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Figure 4 Travelling Down

Each GPS satellite transmits a coded waveform radio signal (somewhat like those shown in Figure 15-9-5). Notice that the individual pulses, or waves, are of different shapes. This allows the receiver to recognize individual pulses. GPS receivers generate waveforms that are identical to those transmitted by the satellite, for the receiver's internal use. To calculate the travel time of the radio signal from the GPS satellite, the GPS receiver measures how much time the received satellite waveform is behind its own identical internal waveform. It does this by comparing synchronization of its own internal waveforms with that of the waveforms received from each satellite.

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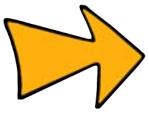
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Figure 5 Coded Signals

Of course, this system requires perfect synchronization. All three of the GPS components – satellites, control stations and receivers – have excellent timekeeping ability.



Show the cadets The Challenge of Timing slide located at Annex AA.



Timing is tricky.

Precise clocks are needed to measure travel time.

The travel time from a satellite directly overhead is about 0.06 seconds.

The time required to synchronize the receiver's internal coded pulses with the satellite's coded pulses is equal to the travel time.

Distance to the satellite is equal to travel time multiplied by the speed of light.

As well as extremely accurate internal timing, the GPS receiver must have one last critical piece of information – the exact time on the satellite's clock. The speed of light is so great, and the travel time of the radio signal is so short, that the clock in the GPS satellite and the clock in the GPS receiver must be synchronized perfectly. This requirement, given the degree of accuracy necessary, is a formidable challenge. The method that was used to accomplish this feat involves high-speed computer processing combined with data from a fourth GPS satellite.

ACTIVITY

Time: 10 min

OBJECTIVE

The objective of this activity is to have the cadets experience the precision of GPS.

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RESOURCES

- One hand-held GPS receiver, and
- Paper and pencil/pen.

ACTIVITY LAYOUT

Training area suitable for drill.

ACTIVITY INSTRUCTIONS

1. Designate a right marker.
2. Face the right marker south.
3. Have the remaining cadets fall in single file and perform a right dress.
4. Give the marker a hand-held GPS receiver.
5. Have the marker call out the coordinates shown on the GPS receiver and pass the receiver to the next cadet.
6. Write down the marker's coordinates.
7. Repeat Steps 5. and 6. for each cadet in the file.
8. List the coordinates on a whiteboard or flip chart.
9. Have the cadets examine the listed coordinates to determine:
    a. How many seconds did the longitude change from one end of the file to the other?
    b. How many seconds did the longitude change per cadet, on average?

SAFETY

N/A.

CONFIRMATION OF TEACHING POINT 1

QUESTIONS

Q1. What are the three components of the GPS?

Q2. How many satellites does it take to mathematically establish a location?

Q3. How is distance to a single satellite determined?

ANTICIPATED ANSWERS

A1. Satellites, control stations and receivers.

A2. Four.

A3. By measuring how long a radio signal takes to travel from that satellite to the user's receiver.

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Teaching point 2 **Describe the Constellation of 24 GPS Satellites**

Time: 5 min Method: Interactive Lecture

THE CONSTELLATION OF 24 GPS SATELLITES

There are more than 24 GPS satellites in orbit. Satellites are constantly being moved or replaced, either temporarily or permanently. However, at any given time, 24 of the satellites are in service.

ORBIT CHARACTERISTICS

The 24 GPS satellites' circular 20 200 km orbits are inclined 55 degrees with respect to Earth's equator. The satellites complete an orbit every 12 hours and rise 4 minutes earlier each day, which adds up to 24 hours in a year. This is necessary because Earth orbits the Sun once a year and, to keep accurate time, the satellite must not change orbital position in the course of a year, relative to the stars.

STATION-KEEPING MANOEUVRES

Once per year each satellite requires a station-keeping manoeuvre, also referred to as repositioning, to move the satellite back to its original orbital position. The satellites have a tendency to drift from their assigned orbital positions. One reason for this is the gravitational pull of the Earth, Moon and Sun. These manoeuvres require, on average, 12 hours of unusable time for each satellite.

ON-BOARD GPS EQUIPMENT

In addition to the radio transmitters required to communicate with the user's GPS receivers on at least two separate frequencies, a GPS satellite will usually also have:

- accurate clocks and computers for generation of coded timing signals,
- radio receivers and transmitters to communicate with the earth-based MCS,
- antennas for the radio equipment,
- rocket thrusters for orbital location and attitude adjustments,
- propellant tanks for the thrusters engines,
- computers for controlling the thrusters engines,
- solar panels to power on-board electrical equipment, and
- batteries for storing the electrical power.

CONFIRMATION OF TEACHING POINT 2

QUESTIONS

Q1. How many GPS satellites are in orbit?

Q2. What is the shape of a GPS satellite orbit?

Q3. What is a station-keeping manoeuvre for?

ANTICIPATED ANSWERS

A1. More than 24.

A2. Circular.

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A3. To move the satellite back to its original orbital position after it drifts.

Teaching point 3 **Describe the Network of Earth-Based Control Stations**

Time: 5 min Method: Interactive Lecture

THE NETWORK OF EARTH-BASED CONTROL STATIONS

The GPS satellite orbits are exact and the satellites are constantly monitored. Radar is used to check each satellite's exact altitude, position and speed. Errors 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. The errors are usually very slight but they must be corrected to achieve the required accuracy.



Show the cadets Figure 15AA-1.

The control component of GPS consists of five monitor stations, three ground antennas and one MCS. The monitor stations passively track all satellites in view, accumulating ranging data. This information is passed to the MCS where it is processed to determine satellite orbits and to update each satellite's navigation message. Updated information is transmitted to each satellite via the ground antennas.

FIVE MONITOR STATIONS

The five monitor stations are located at:

- Hawaii, in the eastern Pacific Ocean,
- Kwajalein, in the western Pacific Ocean's Marshall Islands east of Hawaii,
- Ascension Island, in the south Atlantic Ocean,
- Diego Garcia, in the Indian Ocean, and
- Colorado Springs, in central USA.

THREE GROUND ANTENNAS

The three ground antennas are at Ascension Island, Diego Garcia and Kwajalein. These are necessary for transmitting control signals from the MCS to the satellites.

THE MASTER CONTROL STATION (MCS)

The MCS is located at the US Schriever AFB in Colorado. Only the MCS communicates with the GPS satellites, using the three ground antennas at Ascension Island, Diego Garcia and Kwajalein.

CONFIRMATION OF TEACHING POINT 3

QUESTIONS

Q1. In which US state is the MCS located?

Q2. What do monitor stations do?

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Q3. Name the location of one ground antenna.

ANTICIPATED ANSWERS

A1. Colorado.

A2. The monitor stations passively track all satellites in view, accumulating ranging data.

A3. Ascension Island, Diego Garcia, or Kwajalein.

Teaching point 4 **Describe the User Receivers**

Time: 15 min Method: Interactive Lecture

GPS USER RECEIVERS

By obtaining a GPS receiver, users automatically get the use of the space component and the control components of the system. GPS receivers are designed and built to interact correctly with the space and control components of GPS. All GPS receivers have an almanac programmed into their computers that tells them where in the sky each satellite is, moment by moment. It only remains to measure how far away the satellites are and then the receiver can calculate its own location.

TIME CORRECTION FOR THE USER RECEIVER

As well as extremely accurate timing, the GPS receiver must have one critical piece of information to measure the distance to a satellite – the exact time on the satellite's clock. The speed of light is so great, and the travel time of the radio signal is so short, that the clock in the GPS satellite and the clock in the GPS receiver must be synchronized perfectly. This requirement, and the degree of accuracy necessary, is a formidable challenge. The method that was used to accomplish this feat involves high-speed computer processing combined with additional data from a fourth GPS satellite.

If the GPS receiver's clocks and the GPS satellite's clocks are perfectly synchronized to universal time, then all the satellite ranges would intersect at a single point (which is the position of the receiver). With imperfect clocks such as those found in the real world, a measurement taken from a fourth GPS satellite, done as a crosscheck, will not intersect with the first three. Since any offset from universal time will affect all measurements equally, the GPS receiver's computer searches for a single correction factor. The correction factor that the receiver must find is the one that it can subtract from all its timing measurements to cause them to intersect at a single point – the location of the receiver. This solution is accomplished by high-speed computing. Once the correction factor is found, the receiver will know not only its own location, but also the precise time on all the satellite's clocks.

USER RECEIVER APPLICATIONS

Many uses for GPS have been found, but there are five main categories: locating, navigating, tracking, mapping, and timing.

Locating

The first and most obvious application of GPS receivers is the determination of a position or location. A GPS receiver 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 an important tool, but GPS accuracy makes it useful in special applications.

Besides just identifying a location, an exact reference locator is sometimes needed for extremely precise scientific work. When a GPS receiver was used to measure Mount Everest, the data collected improved past work, but also revealed that the mountain is getting taller.

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Navigating

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

Tracking

Tracking is the process of monitoring something as it moves from one location to another. Commerce relies on fleets of vehicles to deliver goods and services either across a city or across a nation. Effective fleet management has important 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.

A GPS receiver 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 is no surprise that police, ambulance, and fire departments have adopted GPS to pinpoint both the location of the emergency and the location of the nearest response vehicle on a computer map. With this clear visual picture of the situation, dispatchers can react immediately and confidently.

Mapping

Using a GPS receiver to survey and map precisely saves time and money. A GPS receiver makes it possible for a single surveyor to accomplish in a day what used to take weeks with an entire team. Even at that faster speed surveyors can do their work with a higher level of accuracy than was possible without a GPS receiver.

Mapping is the art and science of using a GPS receiver to locate items, then create maps and models of everything in the world: mountains, rivers, forests and other landforms, roads, routes, and city streets as well as precious minerals and resources.



The Longitude of Greenwich describes some of the problems that prevent GPS technology from meshing perfectly with the standard maps that are used throughout the world. Even Britain's Royal Observatory was stumped. Details of this Prime Meridian location puzzle can be found at the Royal Observatory website http://www.nmm.ac.uk/server/show/conWebDoc.416.

The accuracy of GPS receivers can reveal serious problems with standard mapping methods and that can cause problems that are not easy to solve. One case involves the Prime Meridian.

The problem: Why does a GPS receiver operating on the zero meridian at Greenwich indicate a longitude differing by about 100 m from zero?



Show the cadets Figure 15AB-1.

The Prime Meridian was defined, in classical navigation and map-making, to be the line of longitude passing through Greenwich in England. All other lines of longitude were measured relative to this meridian, which was originally established to be 0 degrees. That was how the International Date Line came to be on the opposite side of the earth, at 180 degrees longitude in the middle of the Pacific Ocean.

However, longitudes, latitudes and heights in the system that the GPS uses are all measured relative to a theoretical spheroid that best fits mean sea level over the whole globe. While this represents a level of accuracy

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that was unavailable to previous generations of cartographers (map-makers), the difference of 100 m in the location of the Prime Meridian obviously poses a problem for today's surveyors and cartographers.

When using a GPS receiver in conjunction with standard maps, it is possible to find significant conflicts between the two systems. The information from a GPS receiver will be precisely accurate, but the information it provides can be confusing when used with a standard map.

Timing

Although a GPS receiver is well known for navigation, tracking, and mapping, it is also used to disseminate precise time, time intervals, and frequency. Time is a valuable resource and knowing the exact time is more valuable still. Knowing that a group of timed events is perfectly synchronized is often very important. A GPS receiver makes synchronization and coordination easy and reliable.

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

CONFIRMATION OF TEACHING POINT 4

QUESTIONS

Q1. What critical piece of information does a GPS receiver need to find to calculate its position?

Q2. What are the five main categories of GPS applications?

Q3. Why must a GPS receiver always calculate a correction factor for its internal clock?

ANTICIPATED ANSWERS

A1. The exact time on the satellite's clock.

A2. Locating, navigating, tracking, mapping, and timing.

A3. All clocks are imperfect and the GPS must have time that is perfectly synchronized with the GPS satellite.

END OF LESSON CONFIRMATION

QUESTIONS

Q1. What are the three components of the GPS?

Q2. How many GPS satellites are in orbit?

Q3. In which US state is the MCS located?

ANTICIPATED ANSWERS

A1. Satellites, control stations, and receivers.

A2. More than 24.

A3. Colorado.

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CONCLUSION

HOMEWORK/READING/PRACTICE

N/A.

METHOD OF EVALUATION

N/A.

CLOSING STATEMENT

Few pieces of information are as useful as a clear and precise description of one's location. GPS describes location, trajectory and speed of any object of interest, making GPS service invaluable to transportation, industry and commerce – as well as leisure pursuits.

INSTRUCTOR NOTES/REMARKS

N/A.

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