An Application of GPS Systems on A Mobile Robot

Peter (Ming) Cao, Mayank Saxena, Maurice Tedder, Steve Michalske and Ernest L. Hall
University of Cincinnati
Center for Robotics Research
University of Cincinnati
Cincinnati, OH 45221-0072

ABSTRACT

The purpose of this paper is to describe the use of Global Positioning Systems (GPS) as geographic information and navigational system for a ground based mobile robot. Several low cost wireless systems are now available for a variety of innovative automobile applications including location, messaging and tracking and security. Experiments were conducted with a test bed mobile robot, Bearcat II, for point-to-point motion using a Motorola GPS in June 2001. The Motorola M12 Oncore GPS system is connected to the Bearcat II main control computer through a RS232 interface. A mapping program is used to define a desired route. Then GPS information may be displayed for verification. However, the GPS information is also used to update the control points of the mobile robot using a reinforcement learning method. Local position updates are also used when found in the environment. The significance of the method is in extending the use of GPS to local vehicle control that requires more resolution that is available from the raw data using the adaptive control method.

Keywords: Global positioning systems, intelligent robots, mobile robots

1. INTRODUCTION

The GPS[1-7] is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. While there are millions of civilian users of GPS world-wide, the system was originally designed for and is operated by the U. S. Department of Defense (DOD). Nowadays, the GPS is finding its usage into cars, airplanes, ships and could be applied to all other moving facilities. There are five stations around the world (Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs.) monitoring the GPS satellites, checking both their operational functions and their exact position in space. The ground station transmits corrections for the satellite's ephemeris constants and clock offsets back to the satellites. The satellites can then incorporate these updates in the signals they send to the surface of the earth and can be read by GPS receivers. It functions just like assigning each patch of land a unique address. GPS satellites provide specially coded signals that can be processed in a GPS receiver, enabling the receiver to compute altitude, longitude, height, velocity and time. Precise positioning could be achieved by using GPS receivers at different locations providing corrections and reference positioning data for remote receivers. Time and frequency dissemination, based on the precise clocks on board the satellites and controlled by the monitor stations, is another use for GPS. Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers. Research projects also use GPS signals to weight atmospheric parameters.

Generally, at least four satellite signals should be read to determine precisely of one position on earth. The determination of position and time from satellites is shown in Figure 1.
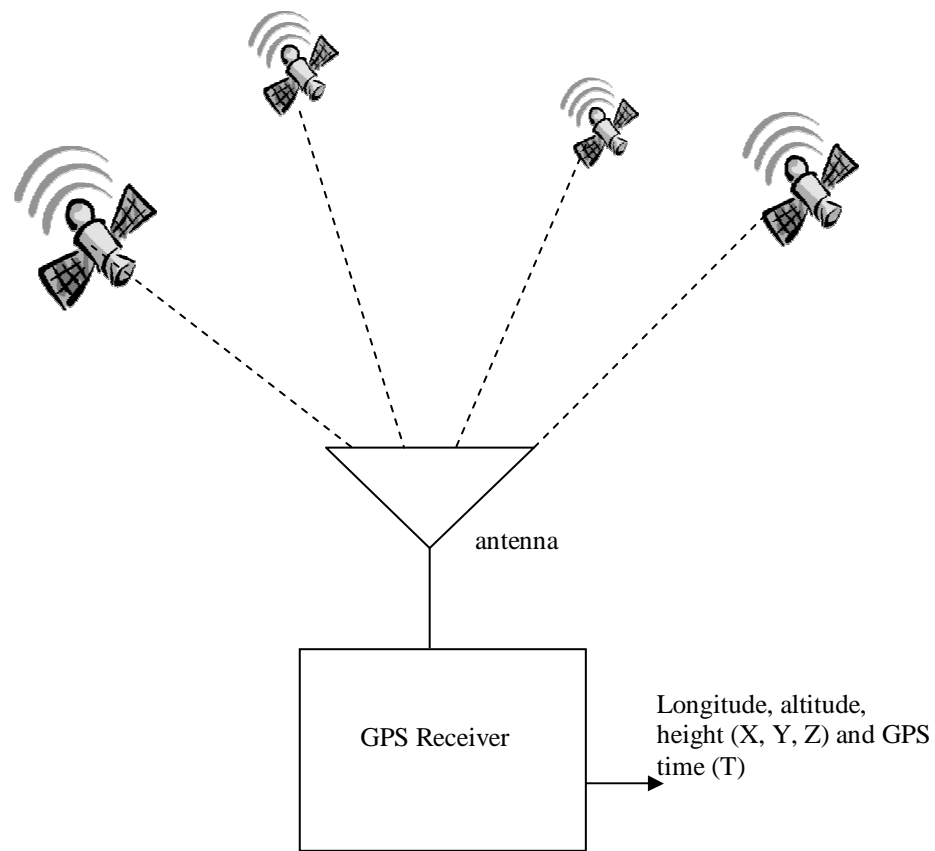
Figure 1. Determination of (x,y,z,t) from four coded time signals[1].

The University of Cincinnati Robotics Research Center has been working on improving the ability of the automated guided vehicles for several years. Each year, some new features are added to extend the robot functionalities. Navigation and positioning are crucial to mobile robot navigation and yet the process has always been quite cumbersome. Over the years the Cincinnati Robotics team has successfully developed vision systems and sonar sensors on their robot Bearcat II (Figure 2) to trace landmarks so that the robot could understand where it is. However, this is highly unreliable as it is worked only in local area and also subject to movement or destruction by environmental factors. The quest for greater and greater navigation accuracy has spawned the idea of employing GPS technology to improve the robot navigation functionality. The mobile robot was also brought to the AUVS world wide mobile robot Contest in Detroit, June, 2001.

2. GPS MECHANISIMS

The nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 6 planes.   The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 minutes earlier each day). There are six orbital planes (with four satellites in each), equally positioned in space (60 degrees apart), and inclined at about fifty-five degrees with respect

to the equatorial plane. This constellation provides the user with between five and eight satellites visible from any point on the earth.
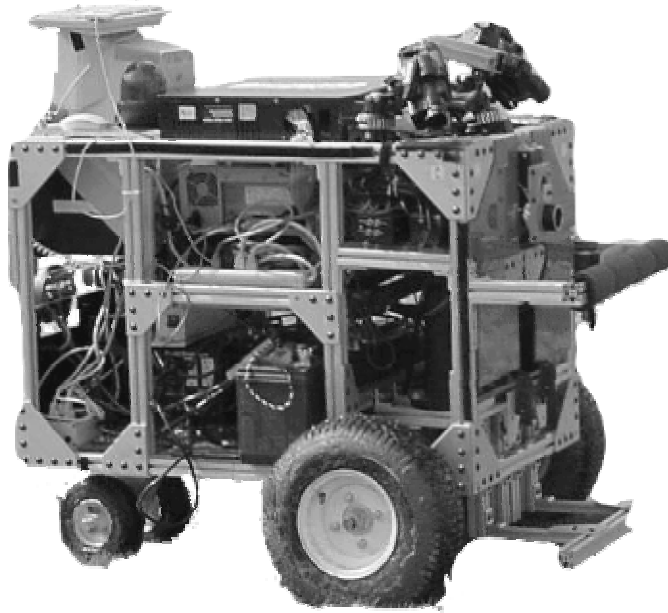

Figure2. Bearcat II, the mobile robot developed by the University of Cincinnati Robotics team.

GPS receivers convert the satellite signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of (altitude, longitude, height and time.) GPS receivers are used for navigation, positioning, time dissemination, and other research. Navigation in three dimensions is the primary function of GPS. Navigation receivers can be made for all moving objects on earth such as vehicles, aircraft, ships, and for hand carrying by individuals.

The basis of GPS calculation is to calculate triangulation from the GPS satellites. The GPS receiver measures distance using the travel time of radio signals in space, which needs extremely accurate timing. We also have to know exactly where the satellites themselves are in space, height of their orbits. The delays during signal transmission through the atmosphere need to be considered, too. The idea behind GPS is to use satellites in space as reference points for locations on earth. A position is computed from distance measurements to at least three satellites. Distance to a satellite is determined by measuring how much time a radio signal takes to reach us from that satellite. To make the measurement we assume that both the satellite and our receiver are generating the same pseudo-random codes at the same time. By comparing how late the satellite's pseudo-random code appears compared to the receiver's code, then the time it took to reach us could be determined. Multiply that travel time by the speed of light the distance can be computed. Accurate timing is the key to measuring distance to satellites. Satellites are accurate because they have atomic clocks in use. Receiver clocks don't have to be that accurate because an extra satellite range measurement can remove errors. The basic orbits of satellites are quite exact but in order to make it
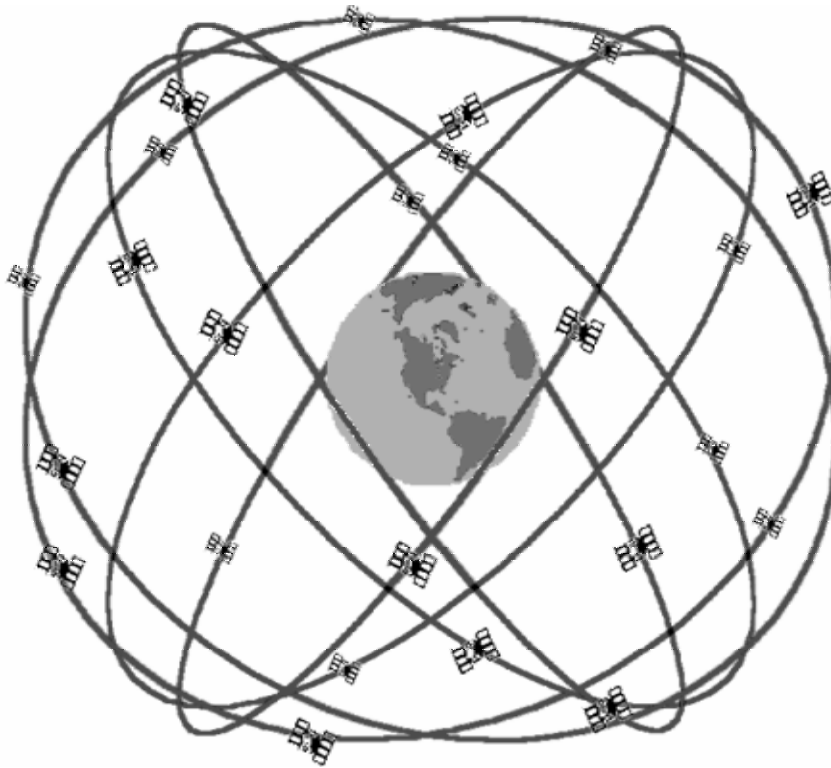
Figure3. GPS constellation, 24 satellites in 6 orbital planes, 4 in each plane, 55 degree inclination[1]. (Adapted from the picture in reference 2.)

reliable the GPS satellites are constantly monitored by the Department of Defense (DoD). They use precise radar to check each satellite's exact altitude, position and speed. The errors they're checking are called "ephemeris errors" because they affect the satellite's orbit or "ephemeris." These errors are generated 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 if you want high level accuracy they must be taken into account. Once the DoD has measured a satellite's precise 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. The ionosphere and atmosphere around the earth cause delays in the GPS signal that translate into position errors. Some errors can be factored out with mathematics and modeling. The configuration of the satellites in the sky can magnify other errors. Differential GPS can eliminate almost all errors.

3. GPS SYSTEM SETUP IN THE MOBILE ROBOT

The main part of the new system are Motorola M12 Oncore GPS receiver[8,9] and Bearcat II motion control system. In general the robot motion includes moving forward and backward, turning left and right or stopping. It often happened during the Bearcat I operation that the robot will miss the control line when there is a small radius turn on the track. This requires a built in mechanism that can move the robot in a sharp turn and motivated the ZTR design. The motor amplifier drives the motor. The motor amplifier gets its control signal from a control board, which is connected to the control computer. The control board is an information center. It gets the motor rotation condition via the encoder. Then, it transfers the encoder signal into a proper data format and then sends it to the main computer. The computer is the final decision-maker on the machine. It gets information from both vision systems and the sonar system, integrates the information, make decisions based on those signals and then send the command to the control board. The commands are then transferred into voltage (analog) control signal that is applied to the amplifier.
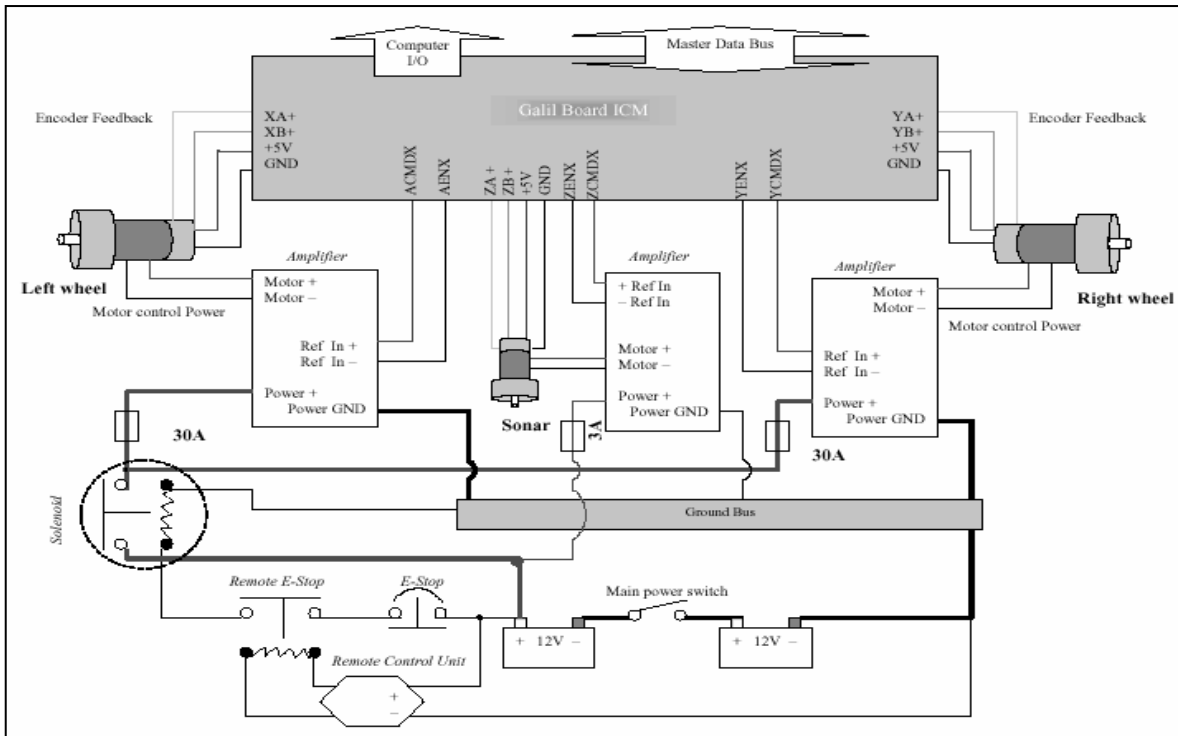
Figure-4 BEARCAT II Motion Control Systems Architecture

The are Motorola M12 Oncore GPS receiver is built utilizing Motorola's custom radio frequency integrated circuit, MRFIC1504, and the ultra-low power MCORE based MMC2003, a 32 bit RISC microcontroller. The M12 Oncore also has a 2.75 to 3.2 supply voltage and includes support capability for inverse differential GPS, which allows for improved positioning at a central base station to support services requiring higher accuracy. This highly integrated single board GPS receiver module is optimized specifically for automotive applications. The M12 GPS receiver tracks NAVSTAR GPS constellation satellites as described above. The satellite signals received by an active antenna are tracked with 12 parallel channels of code then down converted to an IF frequency and digitally processed to obtain a full navigation solution of position, velocity, time and heading. The solution is then sent over the serial link via the 10 pin RS232 connector. The main controller will then compare the GPS position data with the target data and determine which command to send to the motion system. The block diagram of the Bearcat II mobile robot is shown in Figure 5.
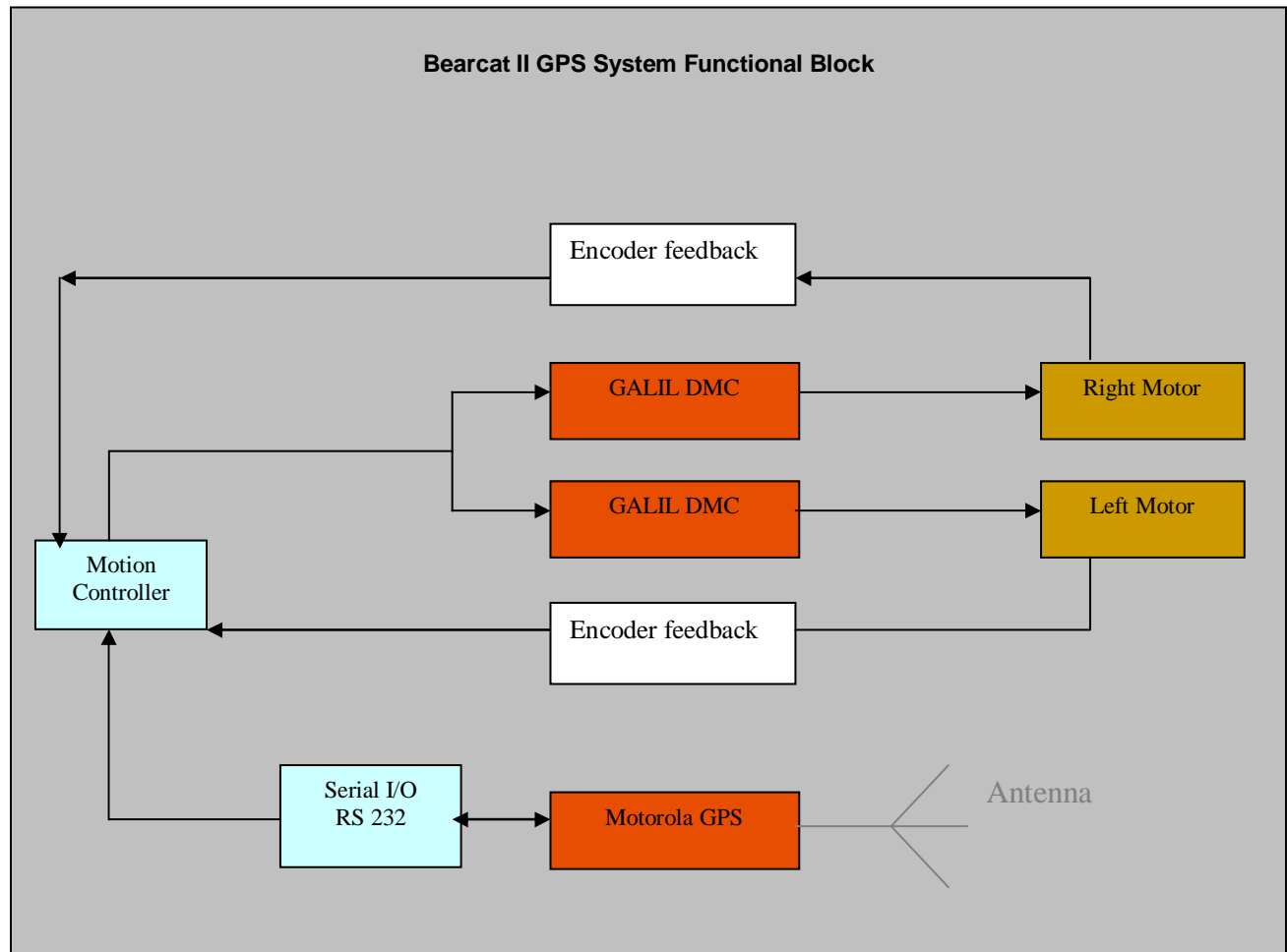
Bearcat II GPS System Functional Block

Figure 5. GPS system functional block diagram in Bearcat II

4. ALGORITHM AND ANALYSIS

For the International Ground Robotics Contest navigation contest, five fixed base points are set as the target position, which is about 100 yards apart between each other. The GPS is used to get the original position, then tracking is used to move the robot itself from one point to the next, updating the new base with every pass. When M12 GPS receiver works, it outputs position (altitude, longitude, height) and velocity information at a rate of 1 second per output to 255 seconds per output. The accuracy of the output varies between 5 feet to 25 feet. The normal robot speed is about 5 feet /second, and the motion command delay is about 0.5 second. The main issue in handling with GPS feedback is to maximize the accuracy. In order to do this, several sample data should be accumulated and then taking their average and also get the variance through least squares method. Also since the contest field has limited distance, errors due to the earth arc could be ignored. However, when the robot is in motion, the sampling historical data are taken not for a fixed spot while the robot is moving. This could be fixed by adding shifts of robot over time to the historical data, which could then be used to be processed as if they are sampled at the same spot over a period of time. An efficient algorithm is demonstrated in the following pseudo code:

```
int vX, vY   //velocity of X and Y, global
time  Timer // time variable global
```

Procedure navigateTarget(longitude X, altitude Y, int n)

Input (desired position longitude X, altitude Y)
Output move the car from current position to the desired position (X, Y)
curX: current altitude position
curY: current longitude position
n: number of targets to be hit
Target[1:n] [1:2]Target position altitude and longitude
Tolerance: constant, if the current position fall in the tolerance, go to the next target.
Init: Target[1:n][0:1]=[position[1][0:1], position[2] [0:1],, …position[n] [0:1],)
j=0: the number of the next target to be hit (0<=j<n)

Begin:
While(j<n)
        (curX, curY)=readGPS(timenow) // (curX, curY) is the current position
        diffX=Target[j][0] –curX   // find the difference of longitude
        diffY=Target[j][1]-curY   // find the difference of altitude
        if (sqrt(diffX^2+diffY^2)>Tolerance // if current position is off its tolerance
            vX=vX+0.01*diffX // change X speed
            vY=vY+0.01*diffY// change Y speed
        else
            stopCar();   // if current position is within its tolerance, stop the car
            j=j+1   // go to the next target
        end if
end while
End navigateTarget

Function readGPS (time now)
input : time
output: GPS positions longitude and altitude
n: const, number of historical data to be used for sampling
histData [0:n-1][0:1]: stores historical data.
k: //int, a counter
longitude X, altitude Y, temporary variable
time lastTime // last sample time
time DiffTime // difference between two sampling

Begin
        DiffTime=now-lastTime // find the time difference between two sampling time.
        LastTime=now;

        for k=0 to n-2
            histData[k][0:1]=histData[k+1][0:1] +[vX*diffTime, vY*diffTime]]
                //this will update the historical data as if it is reading from current spot
            sumData[0:1]=sumData[0:1]+histData[k][0:1]; // summary of historical data
        end for

        histData[n-1][0:1]=getData(time) // read data from the GPS receiver
        sumData[0:1]=sumData[0:1]+histData[n:1][0:1]
        [X, Y]=sumData[0:1]/n   // find the average
        return [X, Y] // this will return the averaged position reading
end readGPS

5. CONCLUSIONS AND RECOMMENDATIONS

The GPS is a convenient positioning system. The attempt to use GPS on the mobile robot has a good prospective. In regard of the great benefits that GPS has brought to the performance of Bearcat II, the GPS has enhanced the robot's navigation ability. Compare to other methods, GPS featured with greater accuracy, boundless on earth, weather-proof and simplicity. The biggest obstacle in this application now is the accuracy. However, this could be improved if we use two ground-based receivers. One monitors variations in the GPS signal and communicates those variations to the other receiver. The second receiver can then correct its calculations for better accuracy. In the future, we can combine the GPS signal with the existing vision and laser scanner signal, which is expected to allow the robot moving from one point to the next and at the same time avoid obstacles on the course. The success of this integration of GPS in the mobile robot will soon make possible the robot having long distance travel.

6. REFERENCES

1. H.R. Everett, **Sensors for Mobile Robots**,, Naval Command, Control and Ocean Surveillance Center, A K Peters Ltd, 1995.
2. Peter H. Dana, "Global Positioning System Overview," http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
3. Elliott D. Kaplan, Ed., **Understanding GPS: Principles and Application**, Artech House Publishers, Boston, 1996.
4. http://www.trimble.com/gps/diffgps/gpsfram1.htm
5. Alfred Leick, **GPS Satellite Surveying,** 2nd. ed., John Wiley & Sons, New York. 1995.
6. National Imagery and Mapping Agency. 1997. Department of Defense World Geodetic System 1984: Its Definition and Relationship with Local Geodetic Systems. NIMA TR8350.2 Third Edition. 4 July 1997. Bethesda, MD: National Imagery and Mapping Agency.
7. Chris Wood and Owen Mace, "Vehicle Positioning in Urban Environments," http://www.gpsworld.com/0601/0601wood.html
8. Motorola M12 GPS Oncore User's Guide Supplement, Revision 1.0 01/25/2000
9. GPS World Buyers Guide, http://www.gpsworld.com/gpsbuyers/bgmain.htm