Usability of GPS Systems for Mobile Robots Navigation

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Abstract: The contribution introduces usability of GPS systems for mobile robots navigation, over medium sized areas. This document include fundamentals of easy implementation with NMEA protocol and available programming tools.

Keywords: GPS systems, mobile robots navigation.

1 Introduction

This document describes and reviews methods for navigating mobile robots, using commercially available GPS systems, over medium sized areas. This will be carried out with a view toward practical mobile robot requirements, such as accuracy and reliability, and implementation constraints. This document includes fundamentals of easy implementation with NMEA protocol and available programming tools.

2 GPS Fundamentals

In 1973 the American Defense Navigation Satellite System was formed, as a joint service between the US Navy and Air Force, along with other departments including the Department of Transport, with the aim of developing a highly precise satellite based navigation system - the *Global Positioning System.* In the 24 years since conception GPS has established itself firmly into many military and civilian uses across the world, here it will be considered in the context of a device for Navigation of mobile robots.

When GPS was released by the US DoD (Department of Defense), it superseded several other systems, however it was designed to have limited accuracy available to nonmilitary users. Several methods of improving the performance, which have been developed as a result of this, will be discussed which greatly increase the usefulness.

The *space segment* of GPS is 24 satellites (or *Space Vehicles* - SVs) in orbit about the planet (Figure 1) at a height of approximately 20 200 km, such that generally at least 4 SVs are viewable from the surface of the Earth at any time. This allows the instantaneous user position to be determined, at any time, by measuring the time delay in a radio signal broadcast from each satellite, and using this and the speed of propagation to calculate the distance to the satellite (the *pseudo-range*).

Position on earth is calculated by triangulation of intersecting radio signals at the GPS receiver. The signals emanate from earth orbiting satellites of the US Defense Department GPS constellation. A typical civilian GPS receiver provides 6-12 meters accuracy, depending on number of satellites available, and the geometry of those satellites.

Actually, geodesists (scientists who study the measurement of the earth), and the global positioning system (GPS) use the earth's centre, and three axes at right angles to describe a position on the earth's surface. This positioning system is based on a linear measurement of meters from the centre along each of the three axes, describing a set of Cartesian coordinates. **Latitude** and **Longitude** is a more practical definition for everyday use, and is a derivative calculated from the axis figures. Typical GPS accuracies in the range of 6-12 meters.

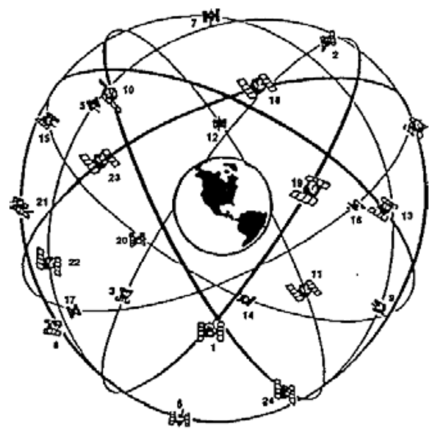


Figure 1
GPS Satellite Constellation

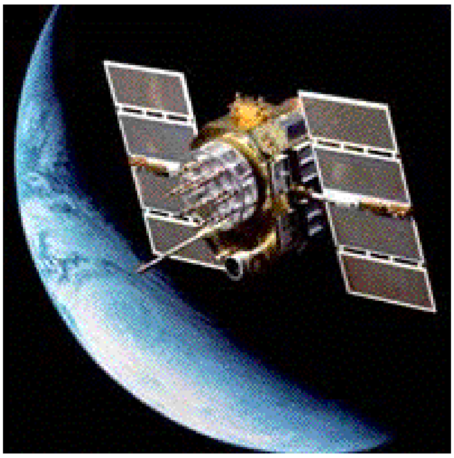


Figure 2
A GPS satellite

DGPS: (Differential GPS) through this process accuracy can be improved to 1 meter. DGPS employs a second receiver at a fixed location to compute corrections to the GPS satellite measurements. How are these corrections provided to your GPS receiver? There are a number of free and subscription services available to provide DGPS corrections. Pay a lot more, and the precision improves but the cost is high in any commercial terms for the mass market.

WAAS: (Wide Area Augmentation System) is an extremely accurate navigation system developed for civil aviation. Before WAAS, the U.S. National Airspace System (NAS) did not have the ability to provide horizontal and vertical navigation for precision approach operations for all users at all locations. With WAAS, this capability is becoming a reality. WAAS provides service for all classes of aircraft in all flight operations - including en route navigation, airport departures, and airport arrivals. This includes precision landing approaches in all weather conditions at all locations throughout the NAS. It is possible to "augment" these signals from other satellites or ground transmitters of known position, thereby increasing either reliability, or accuracy, or both. WAAS is currently available over US, some northern Pacific areas, and Europe (EGNOS). This system is available only from 2001, in limited parts of the world. Accuracy to 3m.

INS: By adding INS capability to a GPS navigation system, considerable improvements have been observed. In this situation the GPS provides short term accuracy, while the INS provides long term stability - complementing each other well to produce a sustainable navigational position. The outputs of both systems are compared and suitably filtered, and corrections made to either or both systems accordingly. One widely quoted filter for doing this is the *Kalman* filter, which combines two estimates and provides a weighted mean, using factors chosen to yield the most probable estimate.

The introduction of the **Galileo1** Europe system will improve the efficacy and usefulness of this method as we move from 24 to 30 satellites. Will be available in 2008. System will be compatible with GPS-System.

2.1 Errors which are given by GPS Technology

If we want use GPS systems for robotics navigation we must know all influences to precision.

Ionosphere and troposphere delays – The satellite signal slows as it passes through the atmosphere. The system uses a built-in model that calculates an average, but most an exact, amount of delay.

Signal multi-path – Occurs when the GPS signal is reflected off object such as tall buildings or large surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.

Orbital errors – Also known as ephemeris errors, these are inaccuracies of the satellite’s reported location.

Number of satellites visible – The more satellites the receiver can see, the better the accuracy. Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. The clearer the view, the better the reception. GPS units will work indoors (typically), underwater, or underground.

Satellite geometry/shading – This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in tight grouping.

Intentional degradation of the satellite signal – The U.S. military's intentional degradation of the signal is known as "Selective Availability" (SA) and is intended to prevent military adversaries from using the highly accurate GPS signals. SA accounts for the majority of the error in the range. SA was turned off May 2, 2000, and is currently not active. This means you can expect typical GPS accuracies in the range of 6-12 meters.

Time-To-First-Fix (TTFF) is a measure of the elapsed time required for a receiver to acquire the satellite signals and navigation data, and calculate the first position solution. This process does it take about 5-15 minutes. Usually are last possitions of satellites stored to internal memory and next time is GPS active immediately.

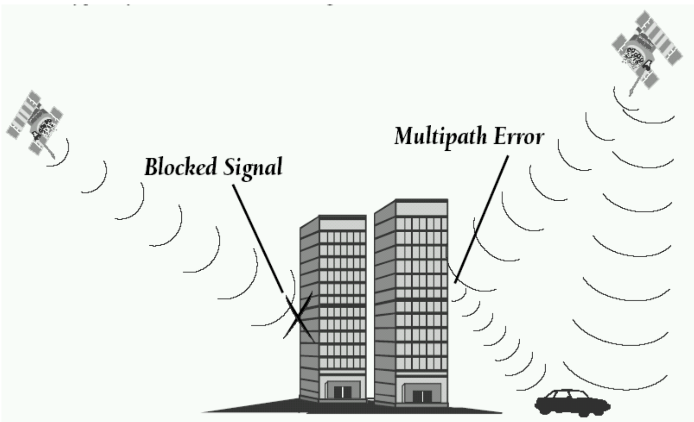


Figure 3

Example of blocked signal and multipath error

3 Description of Usability

3.1 Generic Accuracy of Single Receiver

There are several major manufacturers of OEM GPS receivers that are all characterized in producing much the same type of data extracted from satellite transmission. Calculations based on a low cost receiver are normally made available every second and posted out from the receiver at an unpredictable time delay after real-time fixing has taken place. If the fix is valid at time kT, where k is the kth iteration of the universal clock and T is normally an interval of one second, the result will not be offered till kT + ~0.5 seconds. Further to this delay, the internal processing of the receiver will occasionally interrupt the continuity of the output, to permit real time internal machinations such as signal input, such that transmission is begun at say kT + ~0.5s, then may stop for a few hundred milliseconds and then resume to completion. The time delay is incurred by the receiver performing the transformations on the pseudo range data to arrive at an absolute position. The accuracy is of order a few meters with occasional excursions to greater than 10 meters. The error in the elevation (heading) will be more like 20-30 meters. It is usable when we want use navigation in 3D maps. GPS receivers can also be categorized according to their number of tracking channels, which varies from 1 to 12 channels. A good GPS receiver would be multichannel, with each channel dedicated to continuously tracking a particular satellite. Presently, most GPS receivers have 9 to 12 independent (or parallel) channels.

Which type of GPS is the best for us?

So what's the best GPS receiver for mobile robots navigation? I believe you can answer that, only when you understand some of the things a GPS can do for you. I will attempt here to show you some. But first, just think of the GPS as a calculator - it calculates distances and directions from your current location.

We can divide GPS to two groups:

1 Expensive GPS (map GPS) receiver: have graphical display (color or B/W) and embedded controller for storing and manipulating data inside of device. Some model have interface for uploading maps and external communication.

2 Low cost GPS receiver: without display only with communication port. Non-map GPS cannot be upgraded to a map GPS. Usually send calculated data though MNEA Protocol.

Both of this GPS types do basic calculation of **Longitude**, **Latitude**, Heading and Velocity. For autonomous mobile robots navigation we don't need graphical display only information about actual position which can provide Low cost GPS receiver. Most of mobile robotics applications are satisfied by accuracies of order

2 to 10 meters. This can be achieved by DGPS or WAAS system, but it is possible use other method, combination of low cost GPS system and other sensors, for example with compass, gyros or ultrasonic sensors. There are many articles with high precision GPS-guided movement based on the use of readily available low-cost receivers.

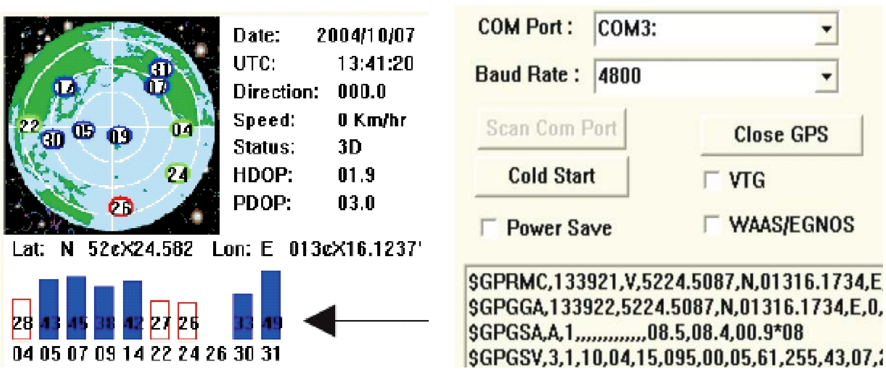
4 NMEA Protocol

Easy implementation of GPS systems provide generally known protocol NMEA0183 currently in version 3.01.

Example of Low cost GPS reciever.

Navilock NL-208P:

- Baud rate 4,800 bps, TTL/RS232, Protocol NMEA0183 V2.2, GGA, GSA, GSV, RMC, GLL
- Position Horizontal 10 Meter 2D RMS and 5 Meter 2D RMS with Waas/Egnos.
- Velocity 0.1m/sec 95%
- Measure 41 x 41 x 18mm, 5V DC, cca. 90mA



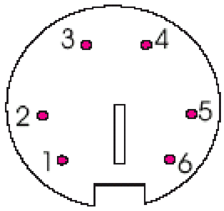


Figure 4
NL-208P

Figure 5
PS2 Connector

1 - TTL TX, 2 - RS232 RX, 3 - 5V, 4 – GND, 5 - TTL RX, 6 - RS232 TX

As we can see on Fig. 5 output connector provide data in TTL and RS232 format. GPS can be easy connected to Serial Port or to embedded microcontroller through UART. This gps receiver provide calculated position data transformed to latitude and longitude which are detailed described in NMEA Protocol. We show how these data simple are stored in RMC (String).

RMC - NMEA has its own version of essential gps pvt (position, velocity, time) data. It is called RMC, The Recommended Minimum, which will look similar to:

$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A
Where:

RMC	Recommended Minimum sentence C
123519	Fix taken at 12:35:19 UTC
A	Status A=active or V=Void.
4807.038,N	Latitude 48 deg 07.038' N
01131.000, E	Longitude 11 deg 31.000' E
022.4	Speed over the ground in knots
084.4	Track angle in degrees True
230394	Date - 23rd of March 1994
003.1,W	Magnetic Variation
*6A	The checksum data, always begins with *

We can easy extract from this data string usable information for mobile robot navigation.

General data which we can acquire from GPS receiver:

Latitude (X position), Longitude (Y position), Heading GPS (Z position), Velocity GPS, Datum

Analogical data coding is for **GGA**, **GSV** and **RMC.**

Usually we need GPS data stored or manipulated in upper level of control. We must use wireless solution. Usable are all systems which are able send data by speed 4800 bps. There exist many low priced solutions from Aerial, Atmel, Motorola.

5 Maps for Navigation

We can use raster (bitmap) or vector map for navigation. This map must be calibrated for gps navigating. If we use own aerial map or scanned bitmap maps we can use tool for this for example Ozie explorer. Bitmap map can be stored in jpg, bmp and tiff format calibration will be stored in same named file with extension .map. Vector maps are usually stored in Garmin .img format. Open source description of this format is available on internet.

If you intend to relate GPS position to a scanned map, you should at least be aware of different datum positions. Coordinates on the maps can be stored in various formats nowadays the most used is WGS84. **WGS 84** (Would Geodetic System 1984) is a state-of-the-art global geodetic reference system based on the use of data, techniques, and technology available within DMA through early 1984 and replaces its predecessor WGS 72. The WGS 84 reference frame, EGM, geoid, and datum transformation parameters (with local datums) are more accurate and relate more datums (83 compared to 27 for WGS 72). These improvements can be translated into more accurate maps and charts, geodetic positioning, geoidal heights, improved satellite orbits, and the capability to relate more local datums worldwide to a unified system.

Figure 6

Example of vector maps

Figure 7

Example of raster maps

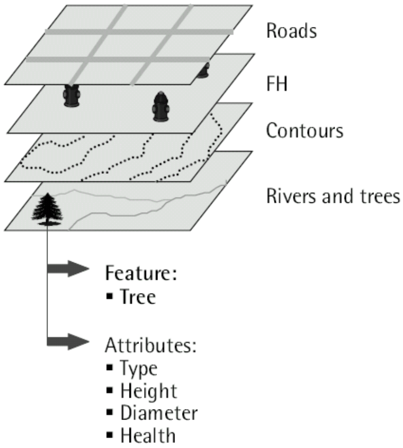


Figure 8
Vector maps consist of many shapes

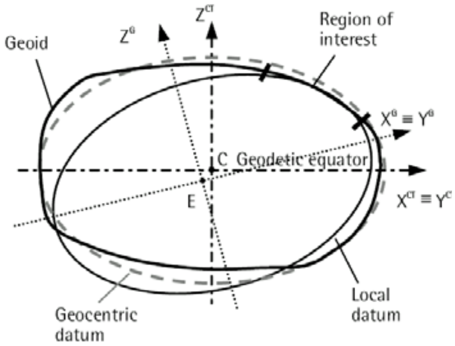


Figure 9
WGS84 Geocentric and local datums

6 Implementation GPS to you Navigation Software

For developer purposes are bitmap maps easier to implement. Google released Google API and developer can now use their aerial maps in our own application. Many open source solutions exist on Linux platform for example **GPS Manager (GPSMan)** is a graphical manager of GPS data that makes possible the preparation, inspection and edition of GPS data in a friendly environment, supports communication and real-time logging with both Garmin, Lowrance and Magellan receivers and accepts real-time logging information in NMEA 0183 from any GPS receiver. **GpsDrive** is a car (bike, ship, plane) navigation system. GpsDrive displays your position provided from your NMEA capable GPS receiver on a zoomable map, the map file is auto selected depending of the position and preferred scale. The maps are auto selected for best resolution depending of your position and can be downloaded from Internet. All Garmin GPS receiver with a serial output should be usable, also other GPS receiver which supports NMEA protocol. In article from Jon Person, Writing Your Own GPS Applications: Part 1, Part 2, and A. Riazi, Add GPS support to your desktop, is described decoding of MNEA protocol by programming in C++, C# and VB.NET (include free source).

Commercial program for viewing maps is the **MapE Library**, which consists of about 100 classes in 130.000 lines of C++ code, including map core classes, user interface classes and other. Other commercials solution are **GIS NET 1.0**, **GPS.net 1.0** or **GPS.net 2.0.**, GPS **ToolKit Pro v1.01 (ActiveX_Object)**. Some of this solution includes handling with maps and some only decoding NMEA Protocol.

For blending path and filtering noise we must use some mathematical model usually Kalman filtering, we can found many mathematical models of Kalman Filtering as free mathlab library. For example inexpensive waypoint navigation system developed on *Kalman Filter* is the Man Portable Robotic System (MPRS) Urban Robot (URBOT). The package uses inexpensive sensors and a combination of standard *Kalman Filter* and waypoint following techniques along with some novel approaches to compensate for the deficiencies of the GPS and gyroscope sensors. The algorithms run on a low-cost embedded processor. A control unit was also developed that allows the operator to specify path waypoints on ortho-rectified aerial photographs.

Example informations from other sensors for improving accuracies and blending path with Kalman filter.

Heading (Compass), Pitch (Compass), Roll (Compass), Velocity (Encoders), Turn rate (Gyro)

The purpose of a Kalman filter is to estimate the state of a system from measurements which contain random errors. An example is estimating the position and velocity of a satellite from radar data. Let's look at an example. Figure 10 shows how well the Kalman Filter was able to estimate the position, in spite of the large measurement noise.

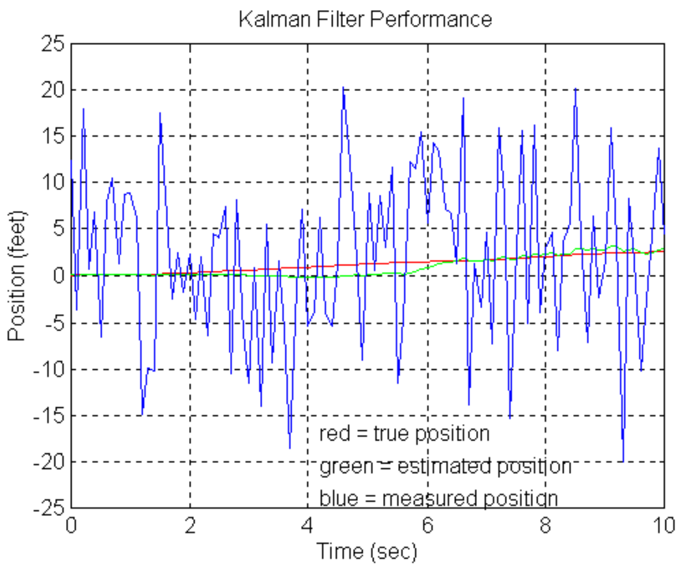


Figure 10

How to improve Kalman filter GPS data for navigation

Kalman filters can be used for another combination of GPS systems for example INS/GPS. For better understanding exist Kalman Filter Toolbox for Mathlab. This toolbox supports filtering, smoothing and parameter estimation (using EM) for Linear Dynamical Systems.

Conclusions

GPS on its own does not currently offer a sufficient navigation resolution to allow it to be used as a standalone global navigation method for mobile robots. A robot would typically work on a scale of 2 m. This only allows GPS to act as a coarse position fixing aid, and then some other more localized method has to be used, with reference to landmarks or otherwise, to get an adequate position fix. When considering positioning systems for mobile robots, there are a large number of variables that must be considered, including, size of mobile transceiver, power requirements of mobile transceiver, positioning accuracy, cost of mobile units, cost of total implementation, number of units supported within range area, inclusion of integrated data communications for other purposes, time to first position fix (from a "cold" start), update rate with movement, standardization/ availability of equipment, portability / time to set up. GPS navigation is suitable only for outdoor application and accuracy do down in forests and big cities.

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Other WWW Sites

- http://www.gpsdotnet.com/download/ (commercial library for gps)
- http://www.cs.unc.edu/~welch/kalman/kftool/KalmanFilterApplet.html
- http://www.wgs84.com/wgs84/downloads.htm (WGS84)
- http://www.mapesoft.com/source.htm (C++ maps implementation)
- http://www.mapesoft.com/MapELibrary.htm (Map view support)
- http://www.nmea.org/ (MNEA Standard)