EVALUATION OF THE SYSTEM ARCHITECTURE FOR GPS-BASED TRACKING APPLICATIONS

By

PHEBE Y. WANG

B.S. Management Information Technology
Massachusetts Institute of Technology, 2002

SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ENGINEERING IN CIVIL AND ENVIRONMENTAL ENGINEERING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2003

AUTHOR..
Department of Civil and Environmental Engineering
May 9, 2003

CERTIFIED BY..
John R. Williams
Associate Professor of Civil and Environmental Engineering
Thesis Supervisor

ACCEPTED BY..
Oral Buyukozturk
Chairman, Departmental Committee on Graduate Studies

EVALUATION OF THE SYSTEM ARCHITECTURE FOR GPS-BASED TRACKING APPLICATIONS

by

PHEBE Y. WANG

Submitted to the Department of Civil and Environmental Engineering on May 9, 2003 in Partial Fulfillment of the requirements for the Degree of Master of Engineering in Civil and Environmental Engineering

ABSTRACT

The Global Positioning System (GPS) technology was designed primarily for the U.S. military. It uses satellites to triangulate signals and track the position of any object on the Earth. One new market for GPS technology is the increasing demand for personal locators. With over 725,000 missing children a year, there is a rising concern for child safety in the U.S. Using advances in GPS and web services technology, these issues can now be addressed with an amazing technological solution: GPS-based web applications. Project iTrack will be used as a case study of a child tracking system and user interface, which is compatible with many operating systems and hardware due to its web capabilities. This thesis will investigate 1) the problem of child kidnappings and propose a solution, 2) provide the reader with an introduction to GPS technology, 3) evaluate the system architecture of GPS-based web applications, 4) discuss the implementation of project iTrack, and finally 5) consider the potential market for iTrack and personal locators.

Thesis Supervisor: John R. Williams

Title: Associate Professor of Civil and Environmental Engineering

ACKNOWLEDGEMENTS

I would like to sincerely thank:

Professor John Williams for his expertise and support throughout this year.

Professor George Kocur for his advice and guidance.

Dr. Eric Adams for his belief in Project iTrack.

My teammates, Kwang Liang Yeo and Charles Assaf, for their hard work.

My friends and family who have been here for me during my time at MIT.

I wish all my fellow M.Eng students the best of luck.

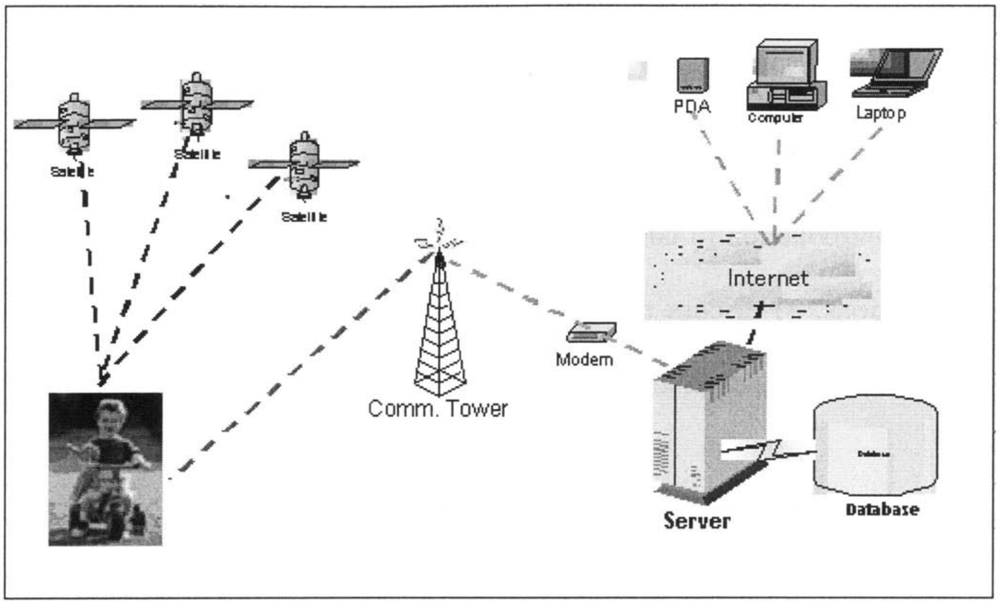
TABLE OF CONTENTS

1. Introduction

The Global Positioning System (GPS) was originally designed by the Department of Defense as a satellite-based radio-navigation system that could locate an object anywhere on Earth. The Global Positioning System consists of three core parts: the space segment, the control segment and the user segment. The user segment consists of the GPS receivers that receive satellite signals containing location information while the control segment consists of five ground stations located around the world. These control stations ensure the proper functioning of the space segment, the satellites. GPS technology uses the triangulation of signals from at least three satellites to locate the position of the user.

GPS provides a substantial military advantage and is now being integrated into virtually every facet of our military operations. It is also rapidly becoming an integral component of the emerging Global Information Infrastructure. GPS technology has applications with recreational uses such as hiking, boating, and everyday driving. However GPS also has more applications ranging from surveying for research to international air traffic management.

Figure 1. System Architecture of Tracking Applications



For a GPS-based web application, the system architecture as shown in Figure 1 is required:

1) A tracking device with a GPS receiver and antenna are needed for the user segment

2) Using GPS technology, the latitude and longitude data from satellites is received on the tracking device.

3) The data must then be transmitted through a wireless service to a server computer where the information is stored for later use.

4) The latitude and longitude is stored in the appropriate format specific to the web application.

5) The user interface can now retrieve the needed data and using web services can render high quality mapping of the location of the desired receiver.

As GPS standards change to allow non-military users access to more accurate GPS signals, new ways to use its capabilities are continually being found for civilians. One new market for GPS technology is the increasing demand for personal locators. With over 725,000 missing children a year, there is a rising concern for child safety in the U.S. It is estimated that the market for location-based services will be worth $16 billion in Western Europe and North America by 2005.

This thesis will 1) investigate the problem of child tracking and propose a solution, 2) provide the reader with an introduction to GPS technology, 3) evaluate the system architecture of GPS-based web applications, 4) discuss the implementation of project iTrack, and 5) consider the potential market for iTrack and personal locators.

2. Project Overview

2.1 Problem Statement

According to the FBI's National Crime Information Center, there are approximately 725,000 cases of missing children in 2001. The issue of child safety has become such a serious concern that it is estimated over 2.37 million households are willing to invest in personal safety products. Due to recent advances in GPS and data transmission technologies, a technological solution is now feasible and can be used to alleviate the problem of child abductions and provide ease of mind to parents worldwide.

2.1 Purpose

Benefiting from the innovation of GPS and web technologies, our group was able to design iTrack to provide a solution to the increasing number of reported missing children cases. iTrack is a child tracking system that consists of a configured GPS tracking device that transmits the latitude/longitude coordinates of the user. This data is stored on a server so it can be accessed by the iTrack web application. iTrack uses Microsoft Map Point .Net Web Services to render quality mapping of the child's location. The user friendly application will also provide extra features such as directions to the child and zooming capabilities. The system architecture will be discussed in further detail in the section 4.

3. GPS Technology

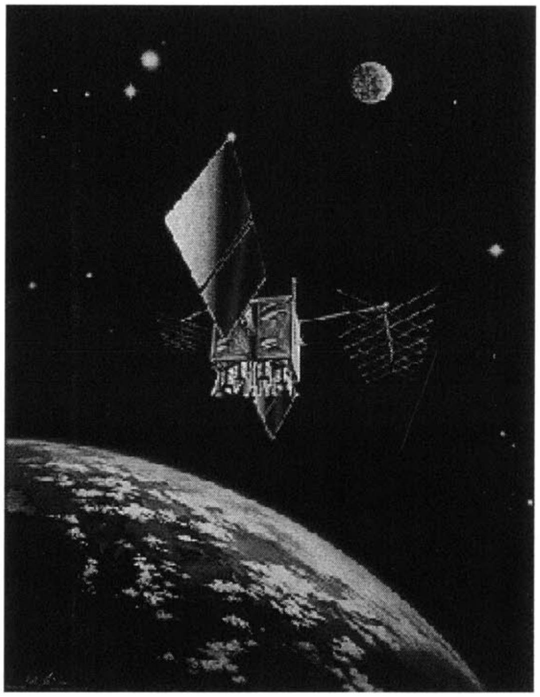
3.1 Background

GPS is funded and controlled by the U. S. Department of Defense (DOD). While there are many thousands of civil users of GPS world-wide, the system was designed for and is operated by the U. S. military. Originally designated the NAVSTAR (Navigation System with Timing And Ranging) Global Positioning System, GPS was developed to provide all-weather round-the-clock navigation capabilities for military ground, sea, and air forces. Since its implementation, GPS has been essential in many civilian applications such as corporate vehicle fleet tracking and mapping.

3.2 GPS Constellation

The first GPS satellite was launched in 1978. The first eleven spacecraft, known as GPS Block I, were used to demonstrate the feasibility of the GPS system. The orbit inclination used for these satellites was 63 degrees, where as the operational system was 55 degrees. Block I satellites are referred to as the original concept validation satellites developed by Rockwell International and reflect various stages of system development.

The first Block II satellite was launched in February 1989 and represents the beginning of the operational system. The Block IIA spacecraft (A = Advanced) were a further improvement over the original Block II satellites. All launches have been successful except for one in 1981.

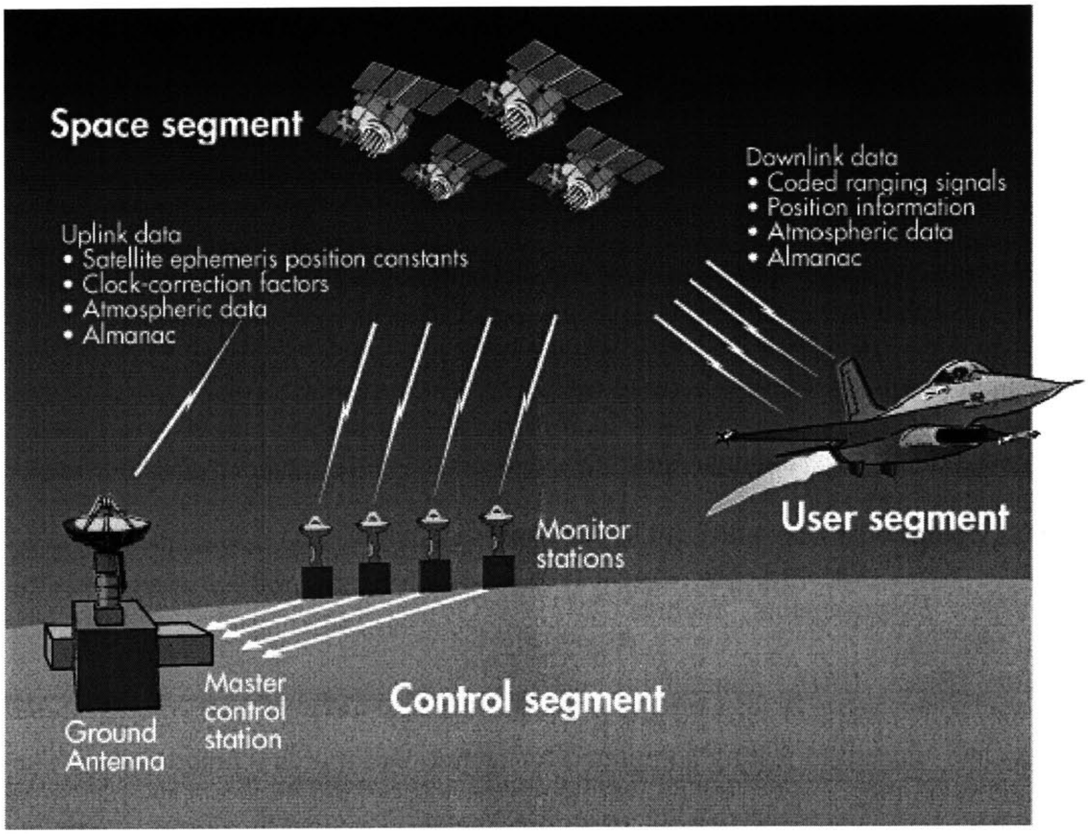


Initial Operational Capability (IOC) was declared on December 8, 1993 when 24 GPS satellites (Block I and Block II/IIA) were operating in their assigned orbits, available for navigation use and providing the Standard Positioning Service levels. The U.S. Air Force Space Command (AFSC) formally declared the GPS satellite constellation as having met the requirement for Full Operational Capability (FOC) as of April 27, 1995. Requirements include 24 operational satellites (Block II/IIA) functioning in their assigned orbits and successful testing completed for operational military functionality. The current GPS constellation consists of 29 Block II/IIA/IIR satellites with the most recent Block IIR satellite launched on January 30, 2001.

3.3 System Elements

The Global Positioning System consists of three major segments: the space segment, the control segment, and the user segment.

Figure 2. GPS Segments



.

3.3.1 Space Segment

The space segment, GPS Operational Constellation, consists of 24 operational satellites which orbit 20,200 km (11,000 nautical miles) above the Earth. Often there are more than 24 as new satellites are launched to replace older satellites. There are six orbital planes with four satellites in each plane. Equipped with accurate clocks, the satellites broadcast radio signals coupled with a precise time message. Each GPS satellite takes 12 hours to orbit the Earth. The satellite orbits repeat almost the same ground track (as the earth turns beneath them) once each day. The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately every 24 hours (4 minutes earlier each day). This GPS Constellation provides the user with between five and eight satellites visible from any point on the earth.

3.3.2 Control Segment

The Control Segment consists of a system of five ground stations located around the world that make sure the satellites are working properly. The Monitor Stations are located at Hawaii, Kwajalein, Ascension Island, Diego Garcia, and Colorado Springs. Only three of the tracking stations have ground antennas: Ascension Island, Diego Garcia, and Kwajalein. The Master Control Station (MCS) is located at Schriever Air Force Base (formerly Falcon AFB) in Colorado. These monitor stations passively track all satellites in view and measure their signals. The ground unit receives the satellite signal, which travels at the speed of light. Even at this speed, the signal takes a measurable amount of time to reach the receiver. The difference between the time the signal is sent and the time it is received, multiplied by the speed of light, enables the receiver to calculate the distance to the satellite. To measure precise latitude, longitude, and altitude, the receiver measures the time it took for the signals from four separate satellites to get to the receiver. This accumulated ranging data is incorporated into orbital models for each of the satellites. The models compute precise orbital data (ephemeris) and satellite clock corrections for each satellite. The Master Control station uploads updated information, ephemeris and clock data, to the satellites via the Ground Antennas. The satellites then send subsets of the orbital ephemeris data to GPS receivers over radio signals. This information is processed at the Master Control Station to determine satellite orbits and to update each satellite's navigation message.

3.3.3 User Segment

The user segment consists of antennas, receiver-processors, and the user community. GPS receivers can be hand-held or placed in aircraft, ships, and ground vehicles. Over 100 different receiver models are in use already. The typical hand-held receiver is the size of a cell phone and getting smaller as we speak. These receivers detect, decode, and process satellite signals which are then converted into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and Time. The three segments of the GPS system can tell you your location anywhere on or above the Earth to within about 300 feet. Even greater accuracy, usually within less than three feet, can be obtained with corrections calculated by a GPS receiver.

3.4 GPS Positioning Services

GPS satellites provide two different signals for different types of users, Coarse-acquisition (C/A) code and the military's Precision (P) code. These codes provide different type of accuracies which led to the Global Positioning System providing two levels of service: Precise Positioning Services (PPS) and Standard Positioning Service (SPS). As operator of GPS, the Department of Defense assesses the changing conditions and updates the limitations of each service as appropriate.

3.4.1 Precise Positioning Service

Precise Positioning Service is an extremely accurate positioning, velocity, and timing service that is available continually around the world. It was designed for U.S. military use. Only authorized users with cryptographic equipment and keys, and specially equipped receivers can use PPS. PPS uses the GPS L1 and L2 frequencies to transmit information. PPS uses anti-spoofing (A-S) to encrypt the P-code to form Y-code to guard against fake transmissions of satellite data. A limited number of people in the United States have access to the Precise Positioning Service. PPS is available to U.S. and Allied military and U.S. Federal Government users.

Selected U.S. Government agency and civil use of PPS will be considered upon request and authorized on a case-by-case basis, provided:

- It is in the U.S. national interest to do so.
- Specific GPS security requirements can be met by the applicant.
- A reasonable alternative to the use of PPS is not available.

Precise Positioning Service is also more accurate than Standard Positioning Service which will be discussed in the following section. P(Y) code capable military user equipment provides the following:

PPS Predictable Accuracy (95%)

- 22 meter Horizontal accuracy
- 27.7 meter vertical accuracy
- 200 nanosecond time (UTC) accuracy

3.4.2 Standard Positioning Service

GPS users worldwide can use the Standard Positioning Service (SPS) which is a positioning and timing service. It is available to all civil users with no direct charge or restrictions. SPS will be provided on the GPS L1 frequency which contains a coarse acquisition (C/A) code and a navigation data message. Unlike the PPS signal, most receivers are capable of receiving and using the SPS signal. The SPS accuracy is intentionally degraded by the Department of Defense by the use of Selective Availability. Selective Availability (SA) is the denial of full accuracy.

This degradation feature is accomplished by manipulating navigation message orbit data (epsilon) and/or satellite clock frequency (dither). SA has been implemented on Block II at the SPS levels when each Block II satellite became operational.

SPS Predictable Accuracy (95%)

- 100 meter horizontal accuracy
- 156 meter vertical accuracy
- 340 nanoseconds time accuracy

3.4.3 Updated Global Positioning System Standard

However in May 2000, an announcement was made that the U.S. Department of Defense would discontinue decreasing the GPS accuracy for civilian use. The Department of Defense finally released a new Global Positioning System performance standard in 2001 that codifies this change. The Selective Availability feature which caused degradation in Coarse-Acquisition (C/A) code will now be discontinued. Users of the Standard Positioning Service can now identify locations up to ten times more precisely than before the new standard was implemented. The previous edition of the GPS standard was published in 1995 and as mentioned in the previous section only provided a horizontal accuracy of 100 meters. The updated GPS standard now provides civil users a horizontal positioning accuracy of 36 meters. Future improvements to the system include new civil codes to correct for distortions such as ionospheric refractions and to assure continuous service for all users. The new services will be deployed with satellite launches scheduled between 2003 and 2012, with full operational capability expected in 2014.

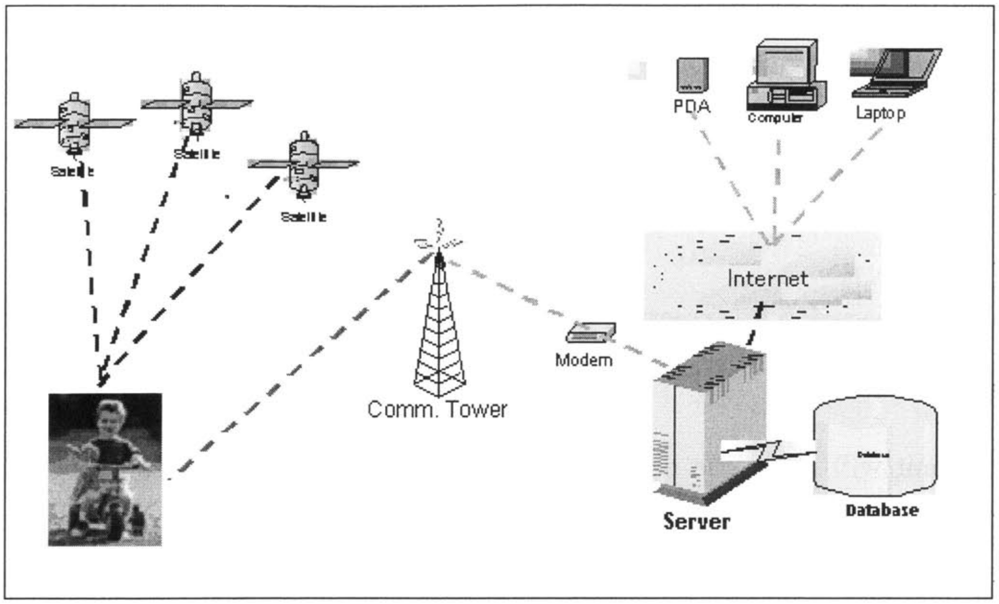
4. System Architecture

4.1 Essential Components

GPS-based tracking systems can be designed and implemented in a multitude of ways for an amazing number of applications yet they must all have the following essential components:

1. GPS Tracking Device
    - Receiver and antenna
    - Data-transmitting machine
    - Independent power supply
    - Mini processor
2. Wireless data transmission medium
3. Server computer
4. Web application

Figure 3. System Architecture of a GPS-based Web Application



4.2 How it works

Stage 1 – Transmission of location information from satellites to tracking unit

In this initial stage, GPS technology is used to determine the location of the child. Using the GPS antenna and GPS receiver that is embedded in the tracking unit, information about the child's locality is transmitted from the satellites to the tracking unit. The child must be outdoors for GPS to function and signals from a minimum of three satellites are needed to calculate the child's location.

Stage 2 – Transmission of collected data from tracking unit to server computer

GPRS cellular technology is used as the medium of transmission. Using existing transmission towers and GSM cellular networks, the GPRS-enabled modem that is contained in the tracking unit will feed the location information back to the central server at a predetermined frequency.

This information will be stored in a SQL database in the server computer. Since GPRS is a cellular technology, the signal strength of the modem is as good as common cellular phones. Data transmission will work indoors. However, coupled with the limitations of GPS, updated tracking information will not be available when the child moves indoors.

Stage 3 – Display location information in a graphical map display on the World Wide Web

The tracking unit will allow the parents to monitor the movement of their children over the Internet from any web-enabled device anytime of the day. Information about the child's location is retrieved from the database of the company's central server. When a parent logs on to the website of our company to make location queries, a web service that can transform latitude and longitude information into a graphical display is used to generate a map of the child's location. Microsoft MapPoint.Net is used to generate this graphical display.

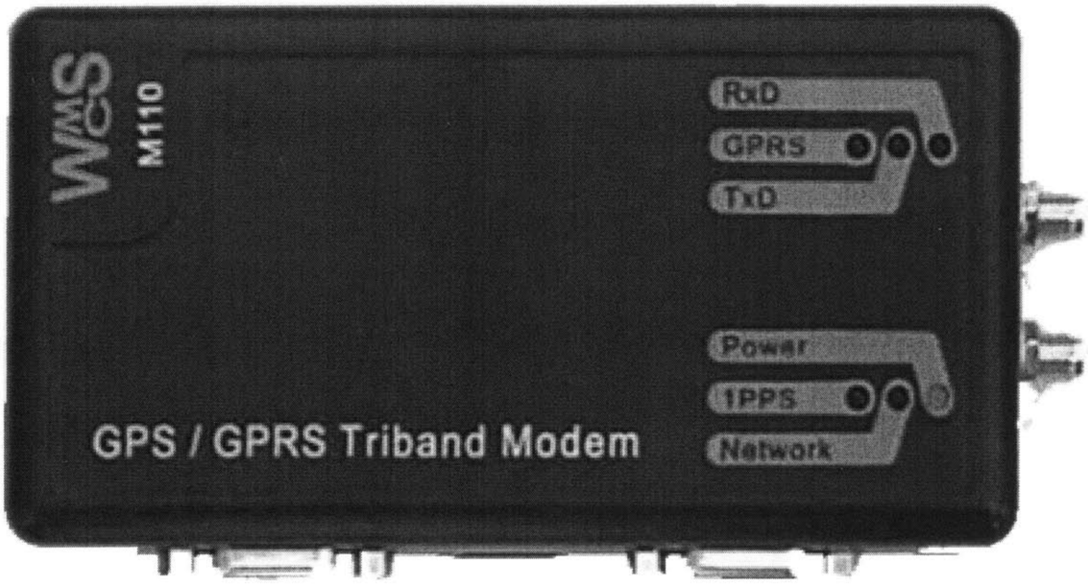
5. System Components

5.1 Tracking Device - M110

In order to consistently follow the movements of a child, a tracking device must be worn or carried by the child. In the case of a child tracking application, an added feature must be considered. As much as technically possible, the tracking device must be miniaturized so as to prevent detection of the device by potential abductors. Camouflaging the tracking device is a possibility. A popular choice among child tracking applications is to integrate the tracking device with a watch, a common adornment that is unlikely to attract excessive attention.

In the child tracking application, the M110 was used as the tracking unit. The GPS sensor had to be portable and easy to configure since our focus was on the software implementation. The M110 manufactured by WMCS, Belgium, is a GPRS modem capable of using UDP or TCP/IP connections for data transfer. It can either function as a stand-alone unit or be connected at a terminal with other equipment that has no TCP/IP stack3. Seven I/O pins can be used to control or monitor external events. This configuration serves any standalone applications where fast data transfer, global positioning, or event control is needed.

Figure 4. M110

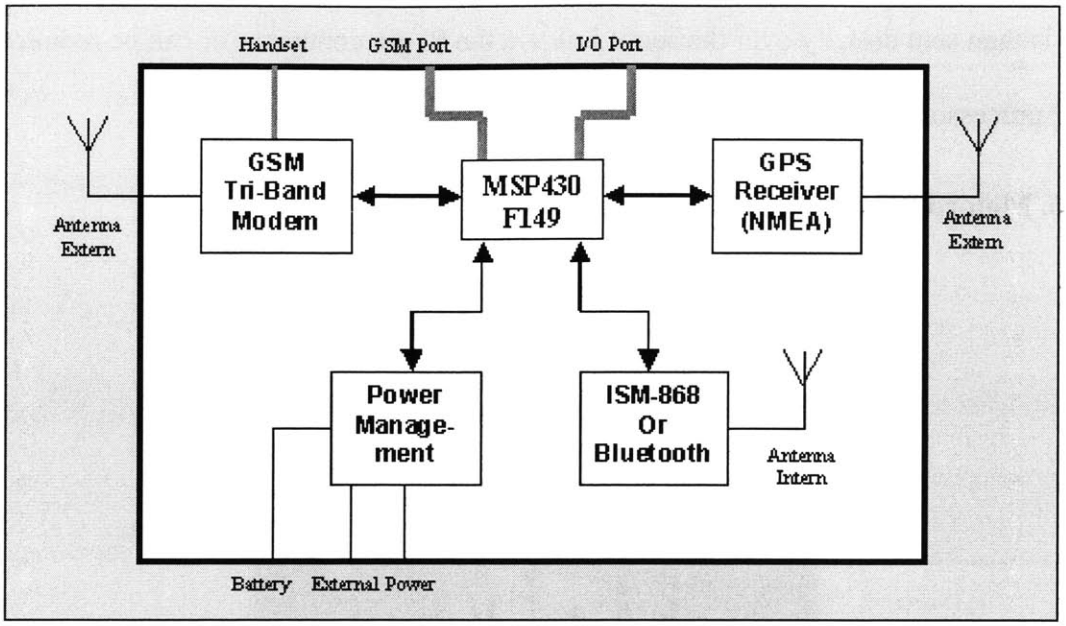


A key feature of the M110 tri-band modem is that it supports the three main GSM frequencies (GSM-900, DCS-1800, and PCS-1900) and could therefore be used in the United States, Europe, Asia-Pacific, Canada and South America. Data can be sent to the server over the Internet, GPRS network or by SMS. This compact and complete product includes an integrated GPS module and an on-board processor. The M110 unit is a flexible device that suits many different types of applications. Typical applications include global positioning, telemetry, security systems, data logging, and remote equipment monitoring.

The standard M110 unit consists of the following components.

- Motorola GSM/GPRS tri-band G18 modem
- Motorola OnCore M12 GPS unit
- Ultra low power processor

Figure 5. Block diagram of the principal components of the M110



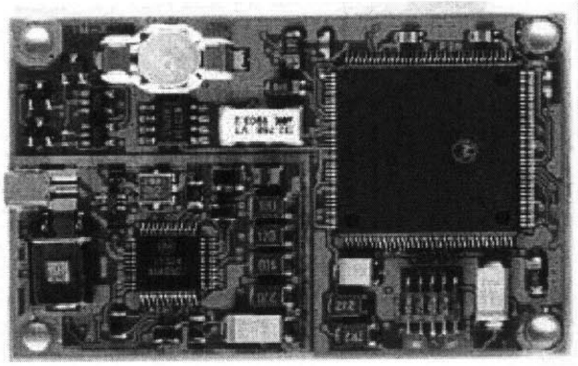
5.1.1 Motorola GSM/GPRS tri-band G18 modem

The GSM/GPRS tri-band G18 modem supports data, fax and SMS transfer in GSM networks. Once the GSM tri-band modem connects to the service provider's network, the device behaves like a standard modem or a fax modem. The modem is configurable using the V.24 serial port. Standard AT commands according to ETSI standards are used to program the unit. The modem supports GPRS data transfer and is dedicated to applications utilizing GSM 900, 1800 and 1900 MHz networks. GSM 1900 MHz is used only in the United States.

5.1.2 Motorola OnCore M12 GPS unit

The OnCore M12 unit is a highly integrated single board GPS receiver module optimized specifically for tracking applications. The GPS receiver tracks the NAVSTAR GPS constellation of satellites. The satellite signals received by an active antenna are tracked with 12 parallel channels of L1, C/A code. They are 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 directly over the serial link via the 9- pin connector or can be redirected over the MSP processor to the GSM port and the GPRS network.

Figure 6. Motorola OnCore M12 GPS Unit



5.1.3 Ultra low power processor

A 6-MHz clocked MSP processor, with 60kB Flash Memory and 2kB RAM, controls both the GSM and GPS modules. This way, actual GPS coordinates can be provided at a distance by using the GSM unit as an intermediary to transmit the information. The processor is equipped with standard software that supports all basic operations. The advantage of using the MSP processor is that, together with a tailored hardware design, low-power performance can be reached. When running in the lowest power mode, with all modules either switch off, or in the sleep or stand-by mode, the power consumption can go as low as 90μAh. This enables applications where no external power supply is available.

5.1.4 Software Configuration

The M110 has a Control Console which allows the user to reprogram the settings for the tracking device. Please see the appendix for the specific software settings used for the iTrack project and more about the M110.

Figure 7. M110 Control Console

```
<00>
@M110_Init
@MDM_Init
@NET_Search.
@MDM_Ready
@IOP_Ready
@GPS_Ready
@M110_Ready
```

5.2 Backup System

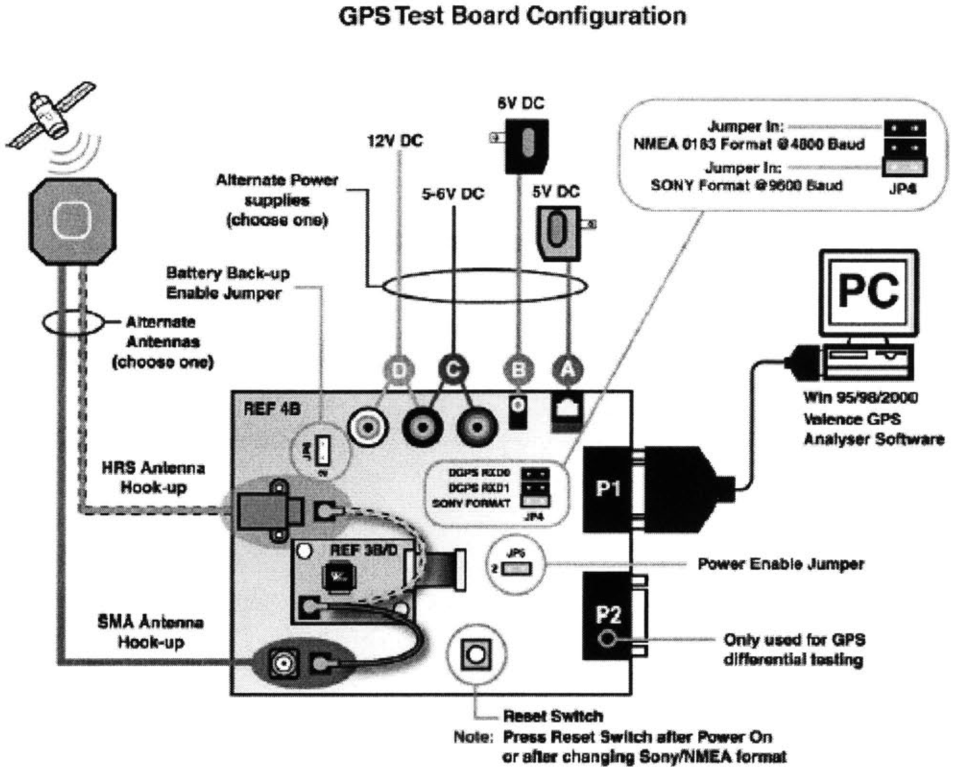
In anticipation of problems configuring the main system, iTrack planned a backup system. The backup system used the UV40 GPS receiver as its hardware component. The UV40 was not a standalone model but directly connected to desktop PC or laptop. Thus it is not as advanced as the M110 but had the key advantage of a higher success rate of implementation because it was easier to configure for data transmission. It was meant to allow concurrent software development and testing in view of project deadline.

5.2.1 System Description

We chose the UV40 distributed by Laipac Tech for a backup system because of the following features:

- 16-Channel GPS Receiver
- All-in-View Navigation
- Differential Corrections Supported
- Supports Passive and Active Antenna
- Compact Size: only 35 x 25 x 7mm
- Low power consumption
- Wide operating temperature range
- Using the Valence VS7001 Pure CMOS Front End and Sony CXD2931R Baseband Chip
- TF-Star II Development Board

Figure 8. UV40



5.2.2 GPS Diagnostic Software Description

The GPS Diagnostic Software for the UV40 displays the following information:

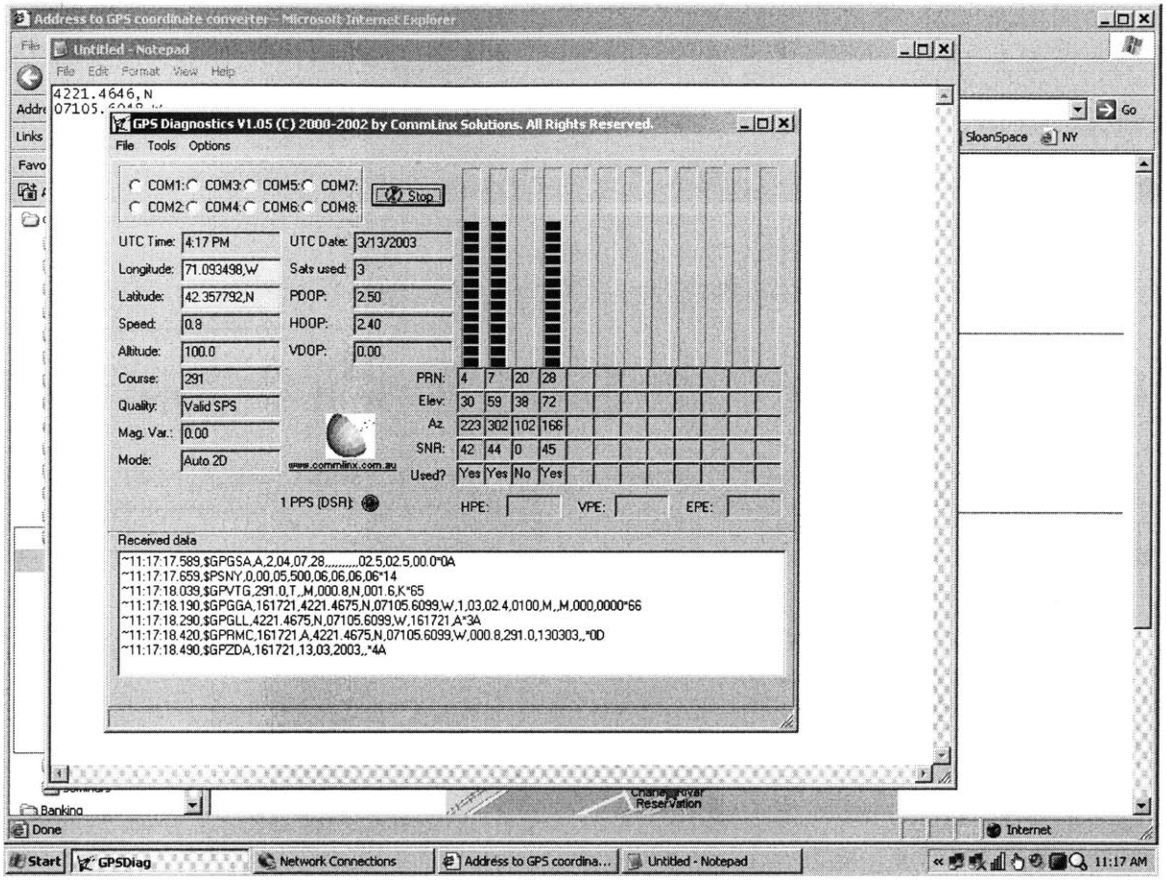
- UTC Time
- Longitude
- Latitude
- Speed
- Altitude
- Course
- Quality (Valid, Invalid)

- Magnetic variation
- Fix mode (2D, 3D)
- UTC Date
- Satellites used
- PDOP, HDOP & VDOP (dilution of precision)

And for each satellite in view (but not necessarily being used) the following information is provided:

- PRN
- Elevation
- Azimuth
- SNR (signal to noise ratio)
- Satellite used in fix

Figure 9. Diagnostic Software Settings



```
4221.4646,N
07105.
```

○ COM1: ○ COM3: ○ COM5: ○ COM7:
○ COM2: ○ COM4: ○ COM6: ○ COM8:

UTC Time: 4:17 PM
UTC Date: 3/13/2003
Longitude: 71.093498,W
Sats used: 3
Latitude: 42.357792,N
PDOP: 2.50
Speed: 0.8
HDOP: 2.40
Altitude: 100.0
VDOP: 0.00
Course: 291
Quality: Valid SPS
Mag. Var.: 0.00
Mode: Auto 2D

PRN:	4	7	20	28
Elev:	30	59	38	72
Az:	223	302	102	166
SNR:	42	44	0	45
Used?	Yes	Yes	No	Yes

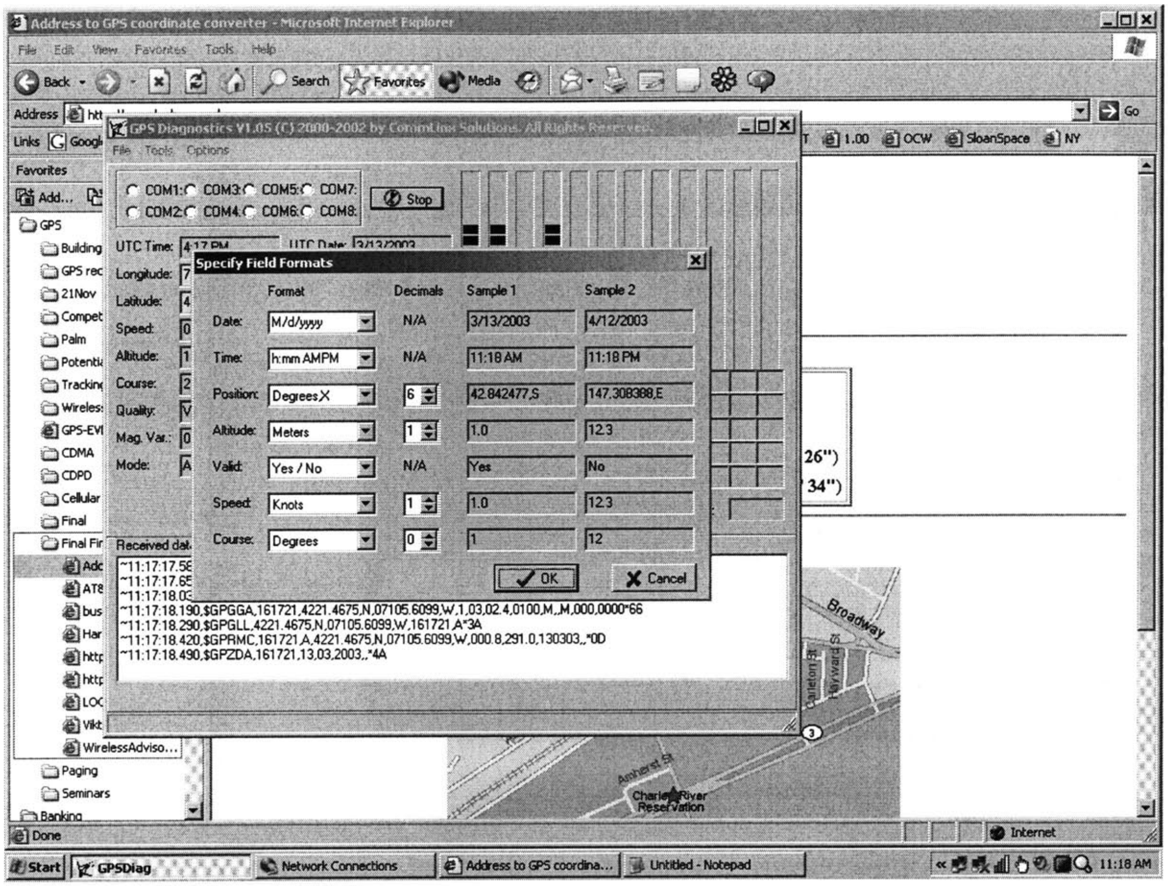
1 PPS (DSR):
HPE:
VPE:
EPE:

Received data

```
~11:17:17.589,$GPGSA,A,2,04,07,28,,,,,,,,,,02.5,02.5,00.0*0A
~11:17:17.659,$PSNY,0,00,05,500,06,06,06,06*14
~11:17:18.039,$GPVTG,291.0,T,,M,000.8,N,001.6,K*65
~11:17:18.190,$GPGGA,161721,4221.4675,N,07105.6099,W,1,03,02.4,0100,M,,M,000,0000*66
~11:17:18.290,$GPGLL,4221.4675,N,07105.6099,W,161721,A*3A
~11:17:18.420,$GPRMC,161721,A,4221.4675,N,07105.6099,W,000.8,291.0,130303,,*0D
~11:17:18.490,$GPZDA,161721,13,03,2003,,*4A
```

The Diagnostic Software also allows the user to specify the field formats as shown in Figure 9. Figure 10 shows how the resulting data from the UV40 is shown on the screen and the data generated from the backup system is also placed in a text file on the connecting laptop.

Figure 10. UV40 Diagnostic Software



UTC Time: 4:17 PM
UTC Date: 3/13/2003

	Format	Decimals	Sample 1	Sample 2
Date:	M/d/yyyy	N/A	3/13/2003	4/12/2003
Time:	h:mm AMPM	N/A	11:18 AM	11:18 PM
Position:	Degrees,X	6	42.842477,S	147.308388,E
Altitude:	Meters	1	1.0	12.3
Valid:	Yes / No	N/A	Yes	No
Speed:	Knots	1	1.0	12.3
Course:	Degrees	0	1	12

```
~11:17:17.58
~11:17:17.65
~11:17:18.03
~11:17:18.190,$GPGGA,161721,4221.4675,N,07105.6099,W,1,03,02.4,0100,M,,M,000,0000*66
~11:17:18.290,$GPGLL,4221.4675,N,07105.6099,W,161721,A*3A
~11:17:18.420,$GPRMC,161721,A,4221.4675,N,07105.6099,W,000.8,291.0,130303,,*0D
~11:17:18.490,$GPZDA,161721,13,03,2003,,*4A
```

Figure 11 is an excerpt of the text file showing that the UV40 is at the location with longitude 3537.8333 N and latitude 13944.6667 E.

Figure 11. Text File Output

```
~14:51:52.088,$GPGGA,001112,3537.8333,N,13944.6667,E,0,00,99.9,0100,M,,M,000,0000*7B

~14:51:52.168,$GPGLL,3537.8333,N,13944.6667,E,001112,V*3D

~14:51:52.308,$GPRMC,001112,V,3537.8333,N,13944.6667,E,000.0,000.0,010497,,*01

~14:51:52.368,$GPZDA,001112,01,04,1997,,*48

~14:51:52.459,$GPGSA,A,1,,,,,,,,,,,,,99.9,99.9,99.9*09

~14:51:52.519,$PSNY,0,00,05,500,06,06,06,06*14

~14:51:52.889,$GPVTG,000.0,T,,M,000.0,N,000.0,K*60
```

```
~14:51:53.049,$GPGGA,001113,3537.8333,N,13944.6667,E,0,00,99.9,0100,M,,M,000,0000*7A
~14:51:53.139,$GPGLL,3537.8333,N,13944.6667,E,001113,V*3C
~14:51:53.280,$GPRMC,001113,V,3537.8333,N,13944.6667,E,000.0,000.0,010497,,*00
~14:51:53.340,$GPZDA,001113,01,04,1997,,*49
~14:51:53.420,$GPGSV,1,1,00,,,,,,,,,,,,,,,,*79
~14:51:53.921,$GPVTG,000.0,T,,M,000.0,N,000.0,K*60
```

5.2.3 Testing

While the iTrack software was being developed, many tests were conducted with the backup system. A tester would take the UV40 receiver and drive around Boston while another group member would watch the GPS Diagnostic Software for changes in signal and check if they were accurate. During testing, problems such as inaccurate latitude/longitude signals were received and the signals would freeze after correctly tracking the hardware sensor for a few minutes.

The following reasons were predicted for these errors:

- It was felt that the antenna was insufficiently placed in the open even though the device was placed outside the car window.
- Buildings were reflecting signals and deteriorating the connection between the GPS sensor and satellites.

5.3 Data Transmission

To send the relevant data from the M110 to the server computer, a wireless service is needed. iTrack chose to use provider T-Mobile's data services on their GSM/GPRS network to test our prototype.

5.3.1 GSM Network

GSM, which stands for Global System for Mobile communications, is an open, non-proprietary system that is constantly evolving. GSM was first introduced in 1991 and was available in more than 100 countries by the end of 1997. GSM is the current de facto radiotelephone standard in Europe, Asia, and many other countries except Japan and the United States. However, GSM's benefits are undeniable and companies in the U.S. such as AT&T and T-Mobile are expanding their services into this area.

GSM differs from first generation wireless systems because it uses digital technology and narrowband TDMA transmission methods. TDMA, time division multiple access, allows eight simultaneous calls on the same radio frequency and voice is digitally encoded via a unique encoder, which emulates the characteristics of human speech. These methods of transmission permit efficient data rate/information content ratio which allows GSM to be one of the leading digital cellular systems.

5.2.2 GPRS

The GPRS (General Packet Radio Service) is an extension of the GSM network, a standard for wireless communications. GPRS enables the transmission of data "packets" at high speeds across a mobile telephone network. It supplements today's Circuit Switched Data and Short Message Service. GPRS, which supports a wide range of bandwidths, is an efficient use of limited bandwidth and is particularly suited for sending and receiving small bursts of data, such as e-mail and Web browsing, as well as large volumes of data. With speeds up to ten times higher than GSM, the network provides virtually instant and permanent connections. (1) iTrack chose to use GPRS for data transmission for because of its speed and immediacy.

Speed:

- Theoretical maximum speeds of up to 171.2 kilobits per second (kbps) using all eight timeslots at the same time.
- This is about three times as fast as the data transmission speeds possible over today's fixed telecommunications networks and ten times as fast as current Circuit Switched Data services on GSM networks.
- By allowing information to be transmitted more quickly, immediately and efficiently across the mobile network, GPRS may well be a relatively less costly mobile data service compared to SMS and Circuit Switched Data.

Immediacy:

- Facilitates instant connections whereby information can be sent or received immediately as the need arises
- No dial-up modem connection is necessary
- "Always on, always available " service
- Immediacy is one of the advantages of GPRS (and SMS) when compared to Circuit Switched Data.
- High immediacy is a very important feature for time critical applications such personal tracking where you want updated information

To use GPRS, users specifically need:

- A mobile phone or terminal that supports
- A subscription to a mobile telephone network that supports GPRS
- Use of GPRS must be enabled for that user. Automatic access to the GPRS may be Allowed by some mobile network operators, others will require a specific opt-in
- Knowledge of how to send and/ or receive GPRS information
- A destination to send or receive information through GPRS, it is likely to be an Internet address, since GPRS is designed to make the Internet fully available to mobile users for the first time.

5.2.3 T-Mobile Packet Data Service

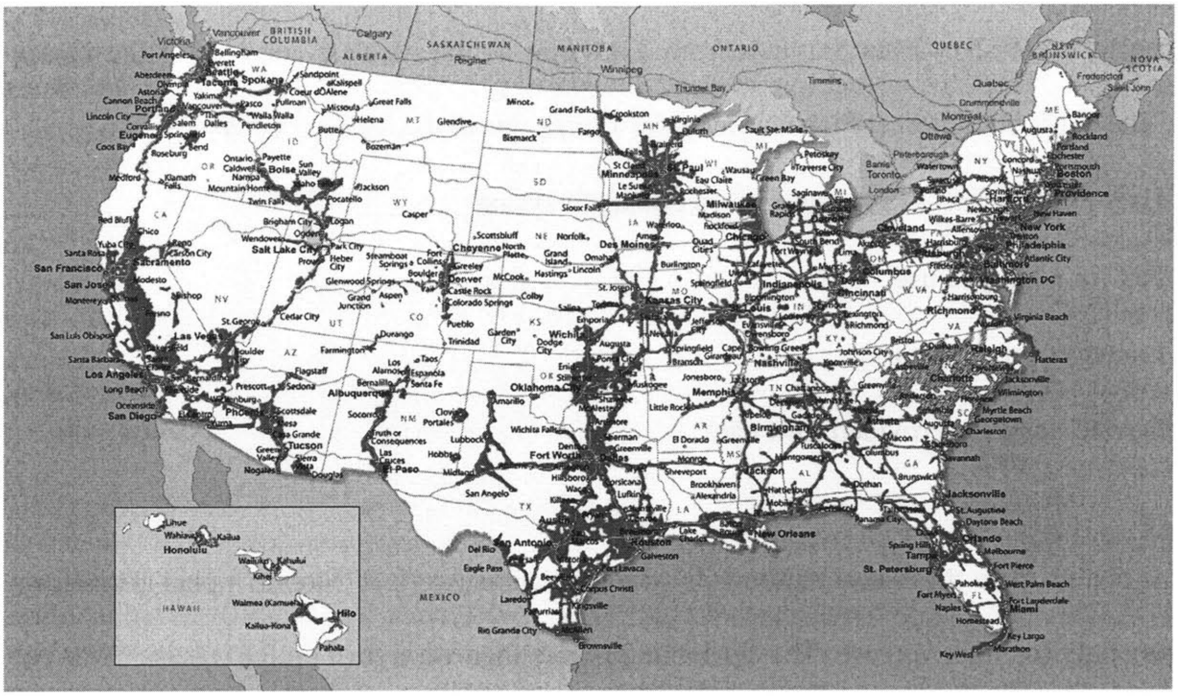
We chose to use Packet Data Services from T-Mobile as the wireless service for the iTrack system. The T-Mobile Internet Plan was ideal for iTrack due to the following reasons:

- Uses GSM/GPRS - fast instant connection, always on
- Pay for what you use
- Larger coverage area
- Device-agnostic/Provided SIM card

T-Mobile claims to be the fastest nationwide wireless data network. T-Mobile's plan also allows you to pay only for what you use. The T-Mobile Internet Plan we signed up for was the 5MB per month for $19.99. iTrack can transfer up to 5MB of information between a wireless device, the tracking device, and the network. For example, if you send 3 emails you are charged for the emails and not the time it took you to write them.

iTrack also chose T-Mobile to be the service provider because of its coverage area. Our wireless internet connection is available across the entire T-Mobile network. It is desirable to be able to track a child outside the city of Boston and throughout as much of the United States as possible. Looking at Figure 12, T-Mobile's coverage area may seem limited but is actually larger its competitors in the U.S. However, GPS/GPRS is a new emerging technology in the United States and new areas are constantly being added.

Figure 12. T-Mobile Coverage Area



In order to take advantage of t-zones and T-Mobile Internet, customers must have GPRS capable subscriber equipment (GPRS phone, PC Card modem, or GPRS integrated device) which has been properly configured for t-zones and T-Mobile Internet service. The M110 is GPRS-compatible but requires a SIM card that T-Mobile provided. T-Mobile wireless internet is device-agnostic, working with all different devices such as phones, laptops, handhelds, and GPS tracking devices. Not all service providers have this feature and may only allow service with their own brand equipment. Choosing a service provider with an interoperable SIM card was essential since our tracking device, the M110, is custom made.

5.4 Server

The tracking device uses T-Mobile Data Services to transmit the text file containing location coordinates to the server. A server computer was needed to 1) retrieve the file 2) extract the relevant data, 3) store information to be accessed by tracking application and 4) host iTrack website.

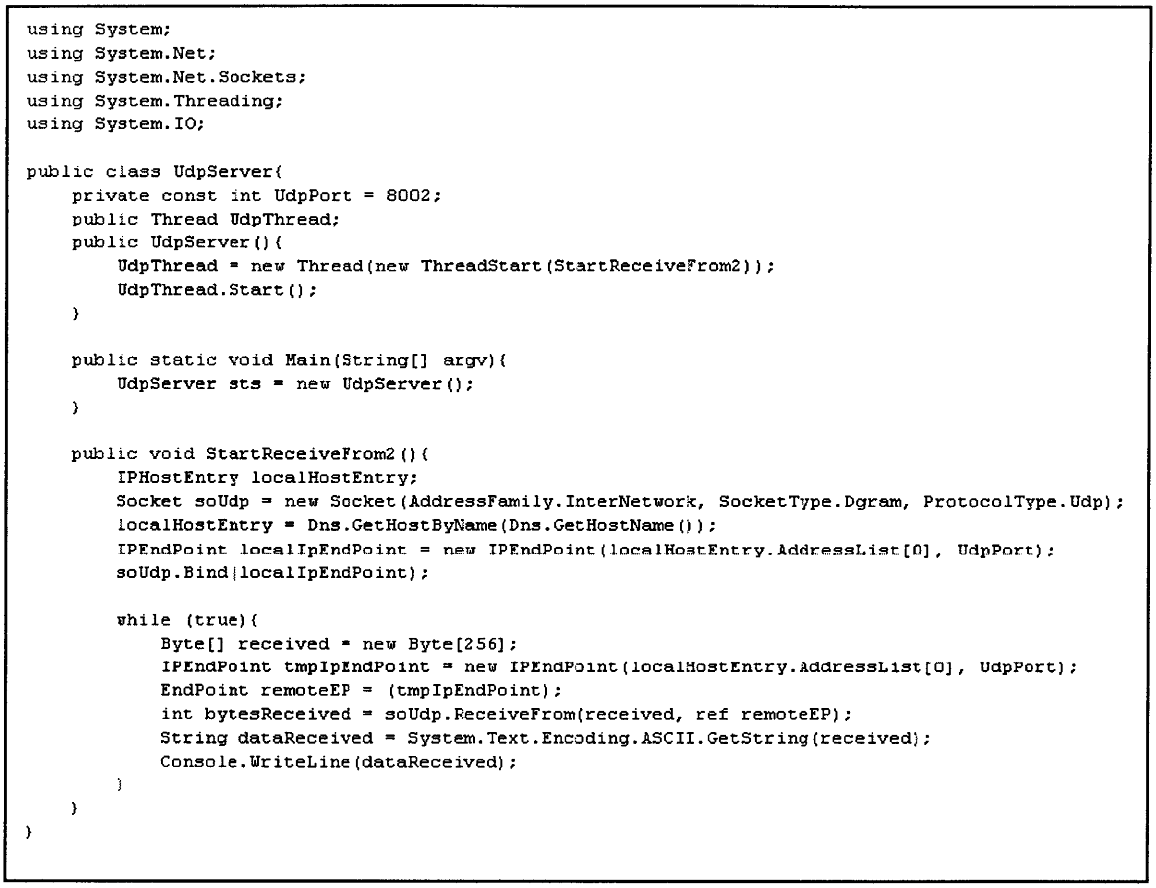
5.4.1 Server Program

A program on the server computer is needed to

- accept the incoming information
- extract the latitude, longitude, and timestamp
- store it on the server

To handle these actions, a program was written in C# in the Visual Studio .NET development environment. The server program first listens for network activity on the server. The connection is established on port 8002 on the server's computer using UDP protocol.

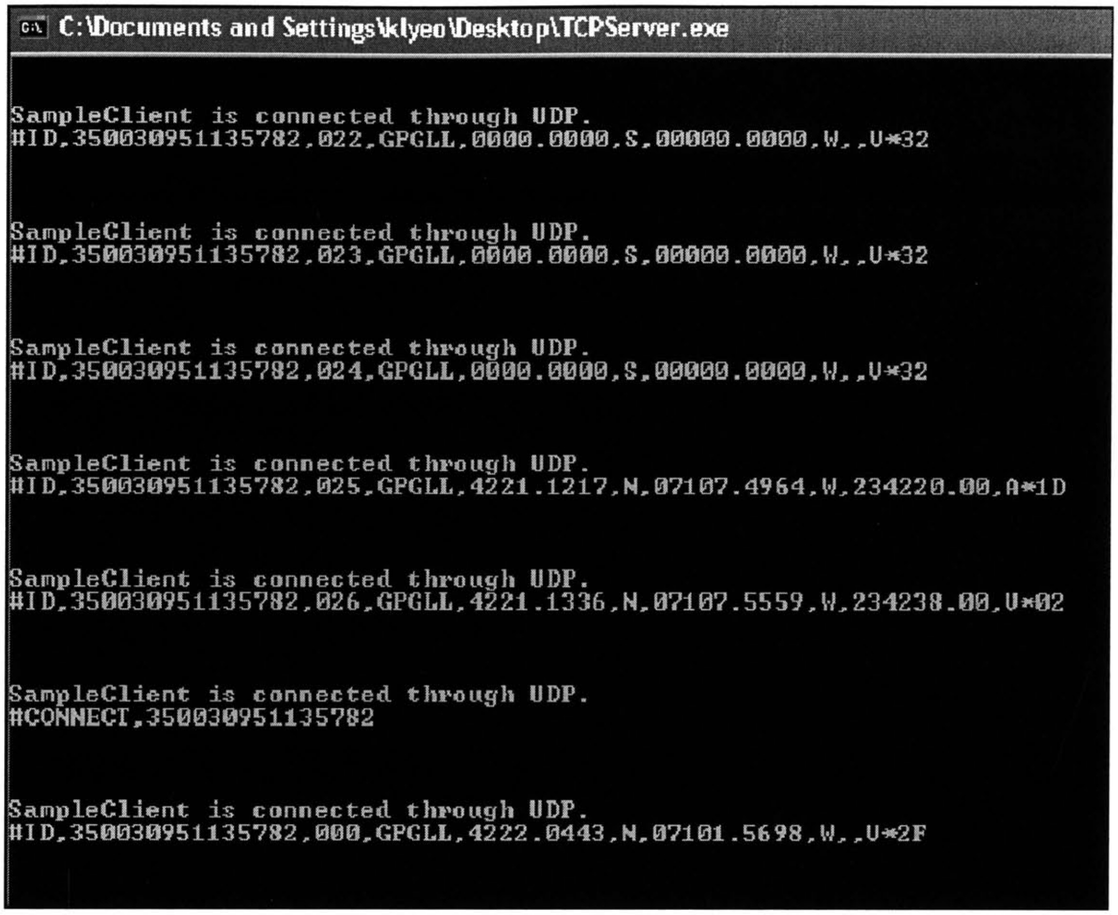
Figure 13. Server Program: check for activity on server



```
using System;
using System.Net;
using System.Net.Sockets;
using System.Threading;
using System.IO;

public class UdpServer{
    private const int UdpPort = 8002;
    public Thread UdpThread;
    public UdpServer(){
        UdpThread = new Thread(new ThreadStart(StartReceiveFrom2));
        UdpThread.Start();
    }

    public static void Main(String[] argv){
        UdpServer sts = new UdpServer();
    }

    public void StartReceiveFrom2(){
        IPHostEntry localHostEntry;
        Socket soUdp = new Socket(AddressFamily.InterNetwork, SocketType.Dgram, ProtocolType.Udp);
        localHostEntry = Dns.GetHostByName(Dns.GetHostName());
        IPEndPoint localIpEndPoint = new IPEndPoint(localHostEntry.AddressList[0], UdpPort);
        soUdp.Bind(localIpEndPoint);

        while (true){
            Byte[] received = new Byte[256];
            IPEndPoint tmpIpEndPoint = new IPEndPoint(localHostEntry.AddressList[0], UdpPort);
            EndPoint remoteEP = (tmpIpEndPoint);
            int bytesReceived = soUdp.ReceiveFrom(received, ref remoteEP);
            String dataReceived = System.Text.Encoding.ASCII.GetString(received);
            Console.WriteLine(dataReceived);
        }
    }
}
```

Output from the server program is shown in Figure 14. The program prints to the console window if the client is connected and the selects the line from the transmitted file that contains the latitude and longitude of the tracking device. The program checks for network activity every 15 seconds but the timer is adjustable.

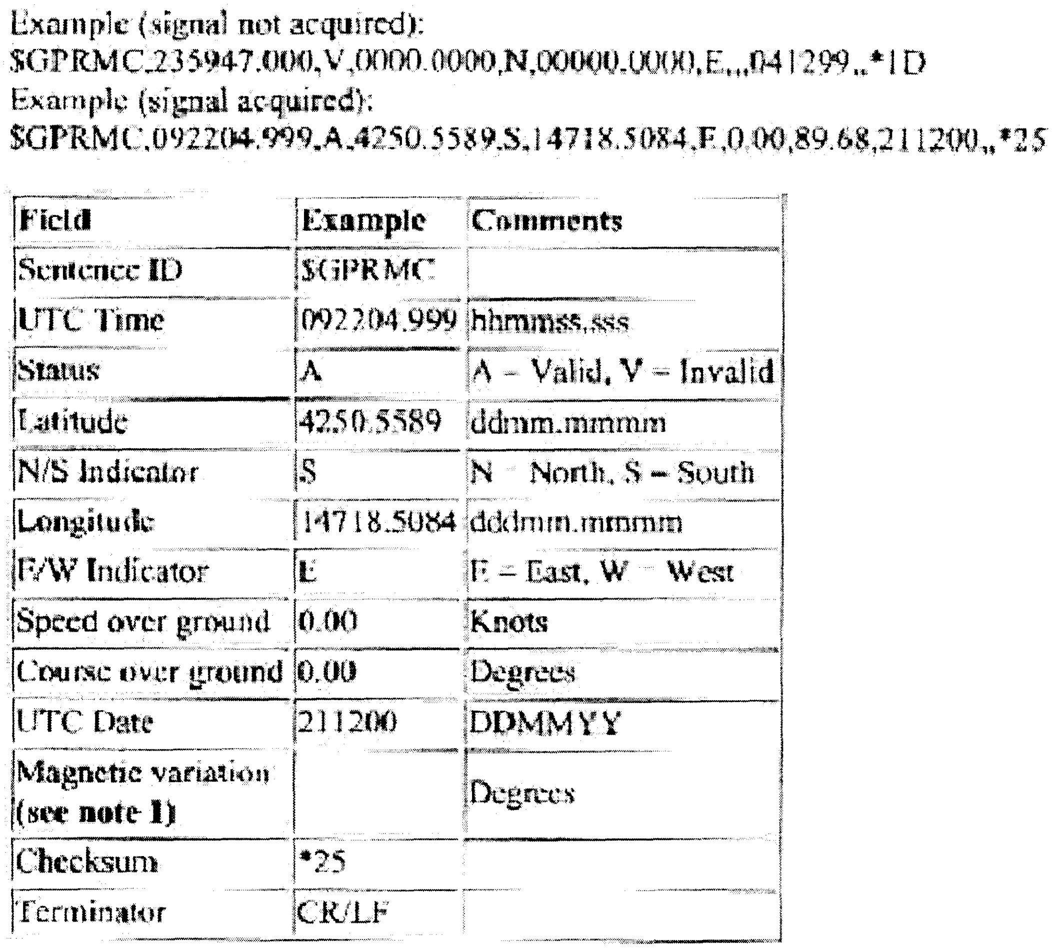
Figure 14. Server Program Output



```
SampleClient is connected through UDP.
#ID,350030951135782,022,GPGLL,0000.0000,S,00000.0000,W,,V*32


SampleClient is connected through UDP.
#ID,350030951135782,023,GPGLL,0000.0000,S,00000.0000,W,,V*32


SampleClient is connected through UDP.
#ID,350030951135782,024,GPGLL,0000.0000,S,00000.0000,W,,V*32


SampleClient is connected through UDP.
#ID,350030951135782,025,GPGLL,4221.1217,N,07107.4964,W,234220.00,A*1D


SampleClient is connected through UDP.
#ID,350030951135782,026,GPGLL,4221.1336,N,07107.5559,W,234238.00,V*02


SampleClient is connected through UDP.
#CONNECT,350030951135782


SampleClient is connected through UDP.
#ID,350030951135782,000,GPGLL,4222.0443,N,07101.5698,W,,V*2F
```

After the server program proceeds to read the transmitted text file, the code's next step was to extract only the relevant latitude and longitude information and make it easily accessible for the iTrack user interface. According to Figure 15, it is known that the desired latitude and longitude data always follow the lines in the text file that begin with "GPGLL" by a specified amount. The code in the server program parses through the text file looking for these specific lines and selects only the latitude, longitude, and timestamp information within that line to be stored.

Figure 15. GPS RMC Sentence Definition

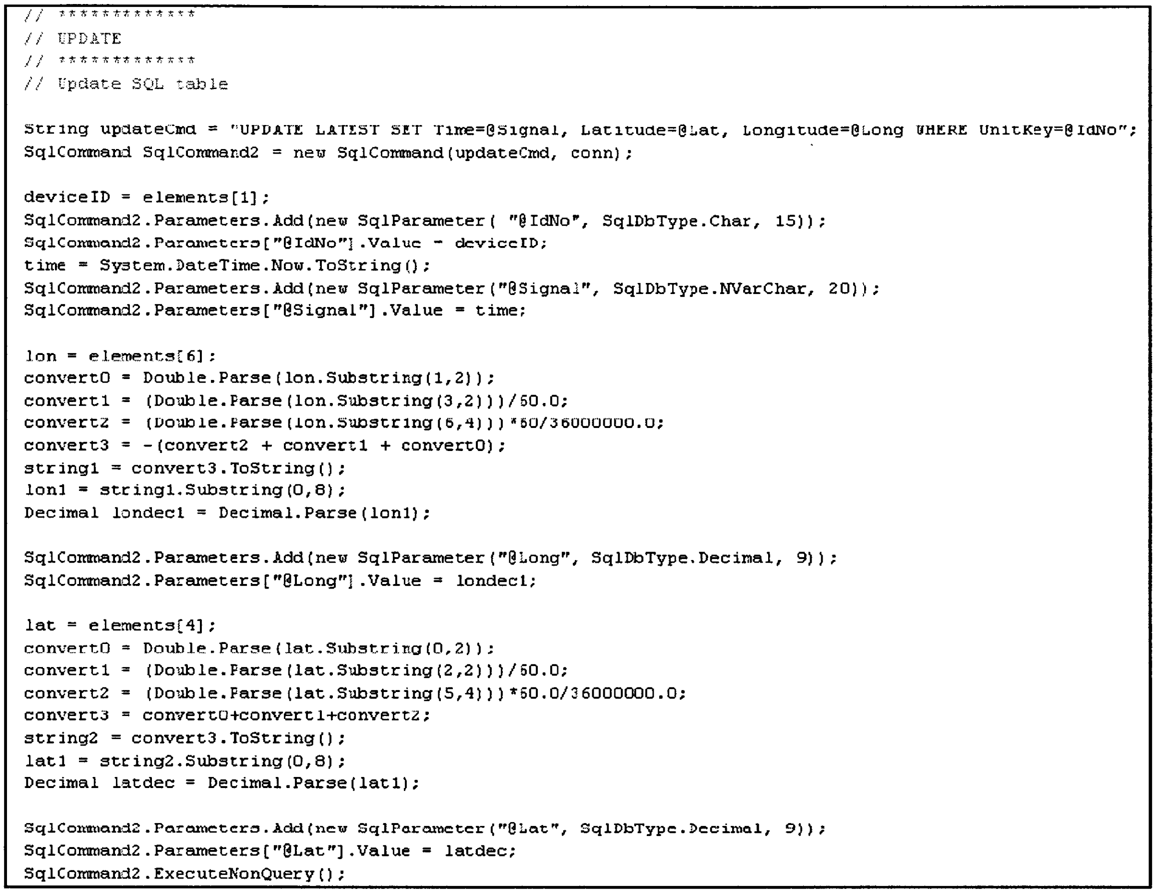


Example (signal not acquired):
$GPRMC,235947.000,V,0000.0000,N,00000.0000,E,,,041299,,*1D
Example (signal acquired):
$GPRMC,092204.999,A,4250.5589,S,14718.5084,E,0.00,89.68,211200,,*25

Field	Example	Comments
Sentence ID	$GPRMC	
UTC Time	092204.999	hhmmss.sss
Status	A	A - Valid, V - Invalid
Latitude	4250.5589	ddmm.mmmm
N/S Indicator	S	N - North, S - South
Longitude	14718.5084	dddmm.mmmm
E/W Indicator	E	E = East, W - West
Speed over ground	0.00	Knots
Course over ground	0.00	Degrees
UTC Date	211200	DDMMYY
Magnetic variation **(see note 1)**		Degrees
Checksum	*25	
Terminator	CR/LF	

The last part of the server code as shown in Figure 16 stores the extracted data on a table in SQL Server. This makes the position coordinates of the tracking device easily accessible by the iTrack user interface for a variety of applications.

Figure 16. SQL Database code



```
// *************
// UPDATE
// *************
// Update SQL table

String updateCmd = "UPDATE LATEST SET Time=@Signal, Latitude=@Lat, Longitude=@Long WHERE UnitKey=@IdNo";
SqlCommand SqlCommand2 = new SqlCommand(updateCmd, conn);

deviceID = elements[1];
SqlCommand2.Parameters.Add(new SqlParameter( "@IdNo", SqlDbType.Char, 15));
SqlCommand2.Parameters["@IdNo"].Value = deviceID;
time = System.DateTime.Now.ToString();
SqlCommand2.Parameters.Add(new SqlParameter("@Signal", SqlDbType.NVarChar, 20));
SqlCommand2.Parameters["@Signal"].Value = time;

lon = elements[6];
convert0 = Double.Parse(lon.Substring(1,2));
convert1 = (Double.Parse(lon.Substring(3,2)))/60.0;
convert2 = (Double.Parse(lon.Substring(6,4)))*60/36000000.0;
convert3 = -(convert2 + convert1 + convert0);
string1 = convert3.ToString();
lon1 = string1.Substring(0,8);
Decimal londec1 = Decimal.Parse(lon1);

SqlCommand2.Parameters.Add(new SqlParameter("@Long", SqlDbType.Decimal, 9));
SqlCommand2.Parameters["@Long"].Value = londec1;

lat = elements[4];
convert0 = Double.Parse(lat.Substring(0,2));
convert1 = (Double.Parse(lat.Substring(2,2)))/60.0;
convert2 = (Double.Parse(lat.Substring(5,4)))*60.0/36000000.0;
convert3 = convert0+convert1+convert2;
string2 = convert3.ToString();
lat1 = string2.Substring(0,8);
Decimal latdec = Decimal.Parse(lat1);

SqlCommand2.Parameters.Add(new SqlParameter("@Lat", SqlDbType.Decimal, 9));
SqlCommand2.Parameters["@Lat"].Value = latdec;
SqlCommand2.ExecuteNonQuery();
```

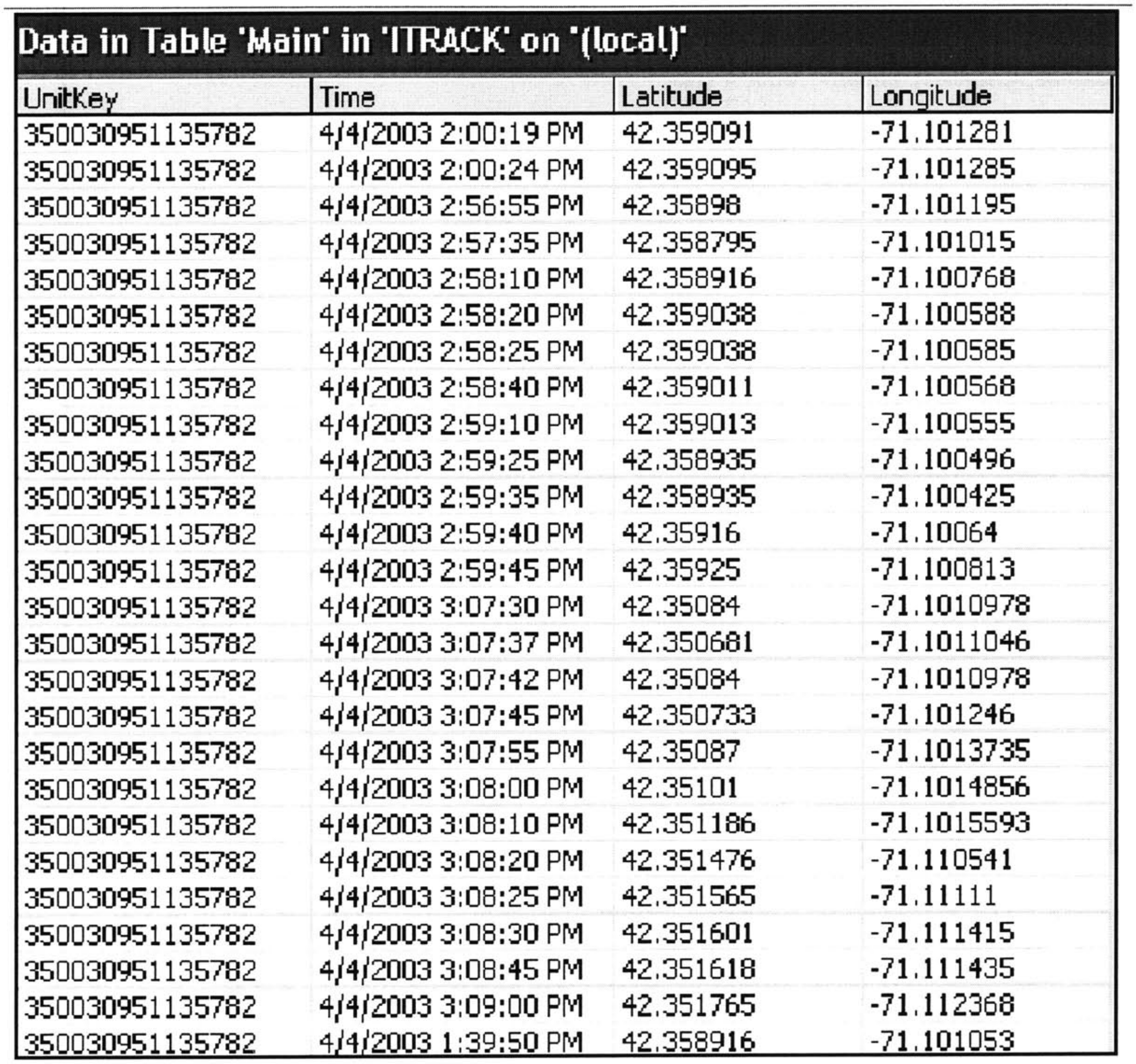
5.4.2 SQL Database

The server program then stores the extracted details into two tables: Main and Latest, on the SQL server database. The server code is written so that it dynamically updates the SQL database with new incoming data from the tracking device. Each table had the following fields:

- UnitKey
- Time
- Latitude
- Longitude

The Main table contains all tracking details while the Latest table contains only the record in the Main table with the latest timestamp. The iTrack application will use the coordinates in the Latest table to display the most up-to-date location of the child.

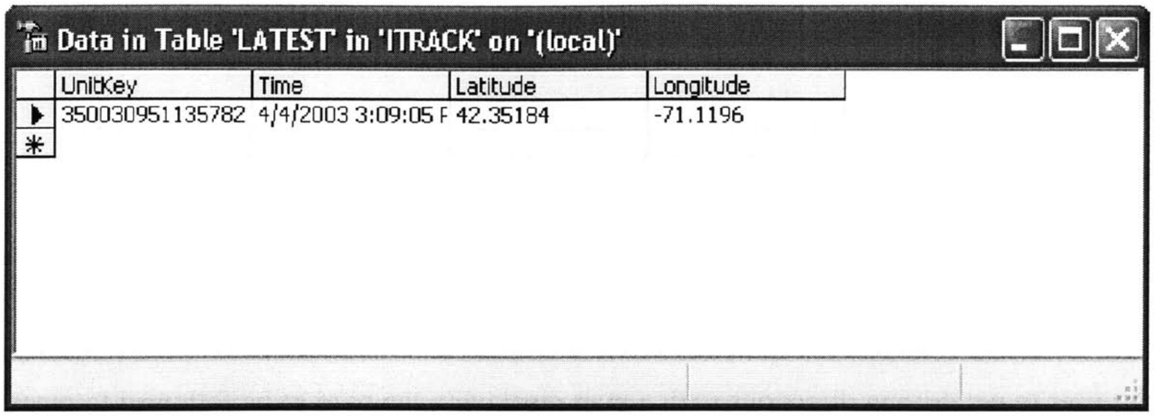
Figure 17. 'Main' Table



Data in Table 'Main' in 'ITRACK' on '(local)'

UnitKey	Time	Latitude	Longitude
350030951135782	4/4/2003 2:00:19 PM	42.359091	-71.101281
350030951135782	4/4/2003 2:00:24 PM	42.359095	-71.101285
350030951135782	4/4/2003 2:56:55 PM	42.35898	-71.101195
350030951135782	4/4/2003 2:57:35 PM	42.358795	-71.101015
350030951135782	4/4/2003 2:58:10 PM	42.358916	-71.100768
350030951135782	4/4/2003 2:58:20 PM	42.359038	-71.100588
350030951135782	4/4/2003 2:58:25 PM	42.359038	-71.100585
350030951135782	4/4/2003 2:58:40 PM	42.359011	-71.100568
350030951135782	4/4/2003 2:59:10 PM	42.359013	-71.100555
350030951135782	4/4/2003 2:59:25 PM	42.358935	-71.100496
350030951135782	4/4/2003 2:59:35 PM	42.358935	-71.100425
350030951135782	4/4/2003 2:59:40 PM	42.35916	-71.10064
350030951135782	4/4/2003 2:59:45 PM	42.35925	-71.100813
350030951135782	4/4/2003 3:07:30 PM	42.35084	-71.1010978
350030951135782	4/4/2003 3:07:37 PM	42.350681	-71.1011046
350030951135782	4/4/2003 3:07:42 PM	42.35084	-71.1010978
350030951135782	4/4/2003 3:07:45 PM	42.350733	-71.101246
350030951135782	4/4/2003 3:07:55 PM	42.35087	-71.1013735
350030951135782	4/4/2003 3:08:00 PM	42.35101	-71.1014856
350030951135782	4/4/2003 3:08:10 PM	42.351186	-71.1015593
350030951135782	4/4/2003 3:08:20 PM	42.351476	-71.110541
350030951135782	4/4/2003 3:08:25 PM	42.351565	-71.11111
350030951135782	4/4/2003 3:08:30 PM	42.351601	-71.111415
350030951135782	4/4/2003 3:08:45 PM	42.351618	-71.111435
350030951135782	4/4/2003 3:09:00 PM	42.351765	-71.112368
350030951135782	4/4/2003 1:39:50 PM	42.358916	-71.101053

Figure 18. 'Latest' Table



	UnitKey	Time	Latitude	Longitude
▶	350030951135782	4/4/2003 3:09:05 F	42.35184	-71.1196
*				

5.4 User Interface

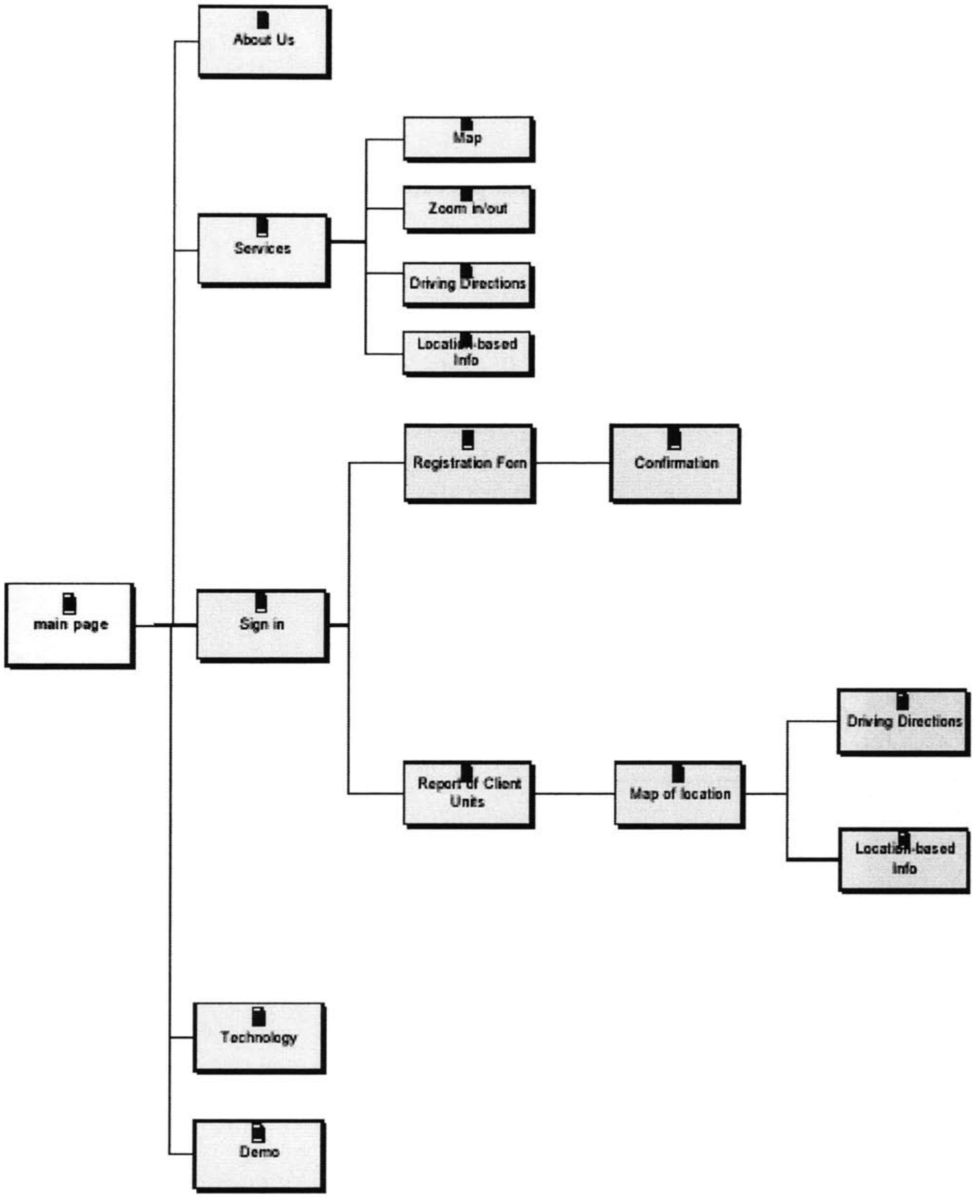
The final system component of iTrack is the user friendly web application. Parents will log on to a website to retrieve information about his or her child's location. The iTrack application will contact the main server to request the latitude and longitude coordinates for the specified unique ID. After the server has sent back the desired information, the iTrack website uses Microsoft Map Point .Net Web Services' map rendering functionality to focus on the child's specified position.

Other functionalities are also provided on the website:

- Access general information about our company: this includes a description of the company and its products, the services it offers and their pricing.
- Login to the website in order to locate the position of a unit by inputting the unit product key.
- Give the user a report containing all his units (in the case where the user will possess more than one unit) along with a description of each unit and a locate feature for each one of them.

- Give our users zoom in/out capabilities as well as the ability to navigate through the map that displays the unit's location.
- Provide the user with the nearest address relative to the unit position.
- Allow the user to refresh the map for a continuous monitoring of the unit.
- Provide the user with the option of displaying the unit's position corresponding to a certain time range. This would allow the user to have an idea of the movement for a certain unit.
- Allow the user to get driving directions with a map displaying the road to be followed to reach the unit's location along with a report on the distance and the time required to get to the final destination.
- Provide the user with the option of choosing between the shortest or the quickest way to get driving directions to the location of the unit.
- Access location based information relevant to the unit's position.
- Find particular point of interest in a specified range from the position of the unit.
- Provide the user with capability of updating his personal information.
- Allow the customer to create an account and send feedback.

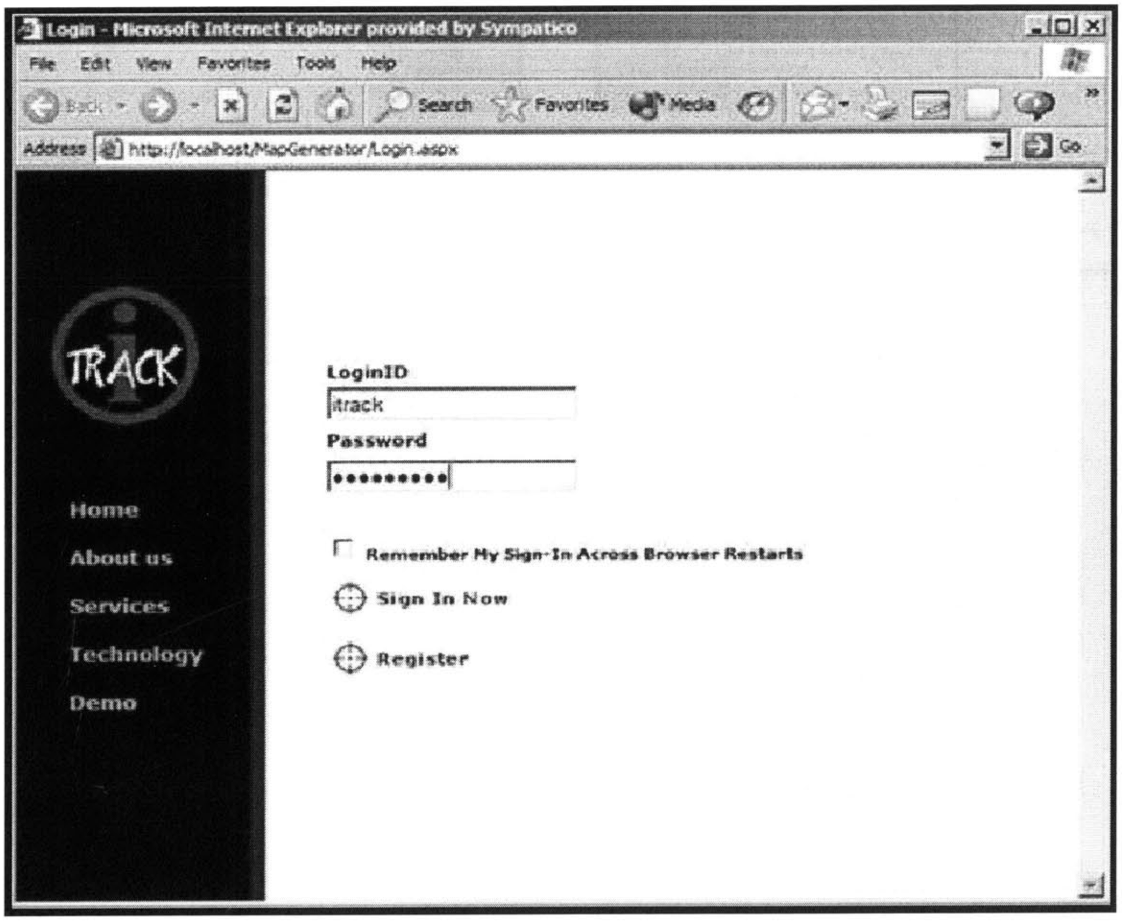
Figure 19. Web System Structure



The diagram above shows how the tracking system is structured on the website. A parent can sign in either as a client, which implies that he or she already knows the product key of the unit or as a potential client. Other pages accessible by the user from home page are also shown in the diagram. It should be noted that in the case when the client has more than one product key, the client would be directed to a page where he or she would be prompted to choose which units he or she would like to locate and obtain location-based information. In total, there are 16 web pages in this web-based system.

The following section contains a number of snapshots pertaining to the user interface of the web-based system.

Figure 20. Login Page



LoginID

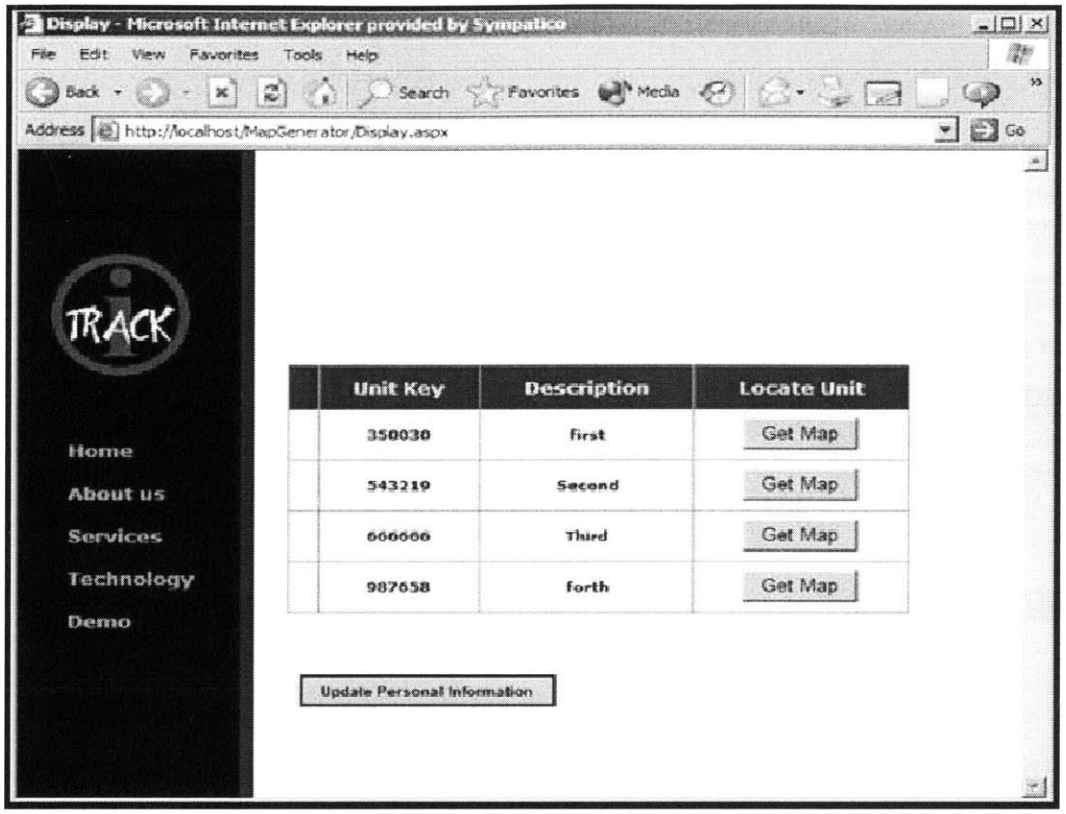
itrack

Password

●●●●●●●●●●

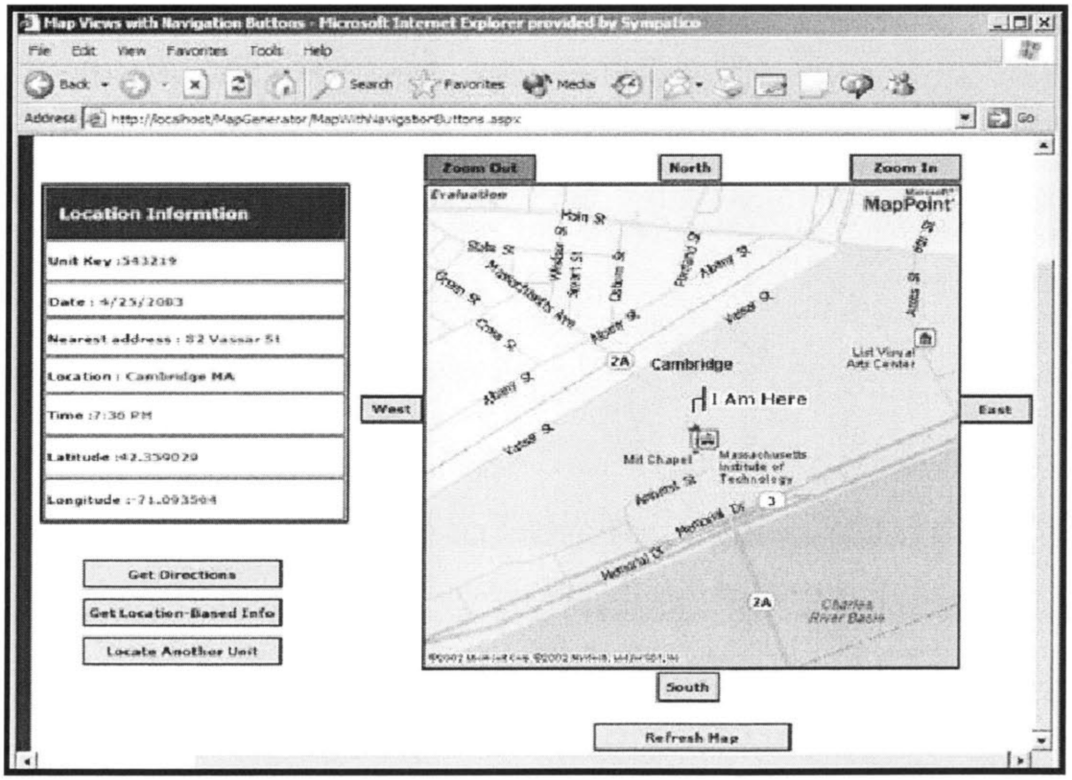
☐ Remember My Sign-In Across Browser Restarts

Figure 21. Unit Display Page



Unit Key	Description	Locate Unit
350030	first	Get Map
543219	Second	Get Map
666666	Third	Get Map
987658	forth	Get Map

Figure 22. Display Child Location Page



Location Informtion

Unit Key :543219

Date : 4/25/2003

Nearest address : 82 Vassar St

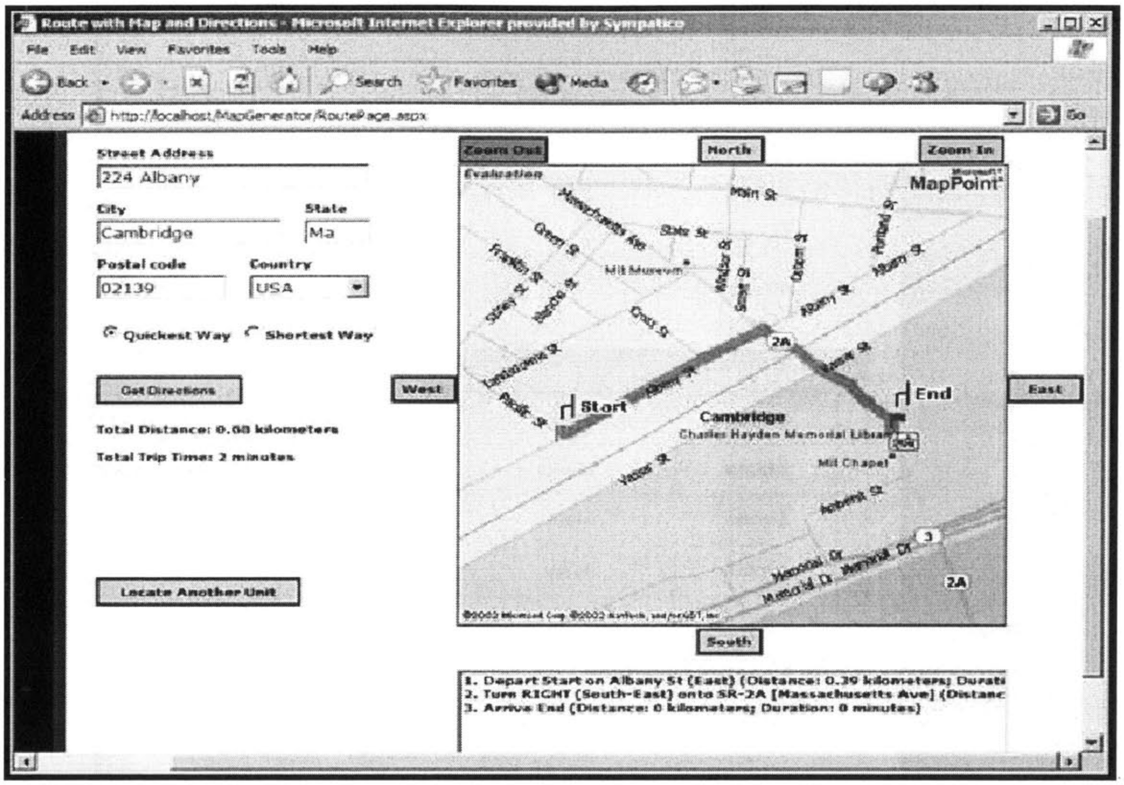
Location : Cambridge MA

Time :7:30 PM

Latitude :42.359029

Longitude :-71.093564

Figure 23. Driving Directions Page



Address: http://localhost/MapGenerator/RoutePage.aspx

Street Address: 224 Albany

City: Cambridge

State: Ma

Postal code: 02139

Country: USA

● Quickest Way ○ Shortest Way

Total Distance: 0.68 kilometers

Total Trip Time: 2 minutes

1. Depart Start on Albany St (East) (Distance: 0.39 kilometers; Durati
2. Turn RIGHT (South-East) onto SR-2A [Massachusetts Ave] (Distanc
3. Arrive End (Distance: 0 kilometers; Duration: 0 minutes)

6. Market Value

6.1 Incentive

The incentive for the creation of iTrack was the rising concern with child safety. FBI's National Crime Information Center reported approximately 725,000 children were reported missing in 2001.

Missing children reports are filed as a result of

- Non-family abductions
- Family Abductions
- Runaway/Throwaway
- Missing/lost/injured
- Missing benign explanation

The disappearance of 2,000 children per day is serious enough that a parent calls the police. So a child is missing every 43 seconds! The iTrack focuses on monitoring children because 85 – 90% of missing persons in 2001 are juveniles. The FBI also states that over 350,000 minors get taken each year by a family member, usually in custody situations. Many of these missing children cases could have been prevented or solved more easily if a personal tracking system had been involved.

6.2 Target Audience

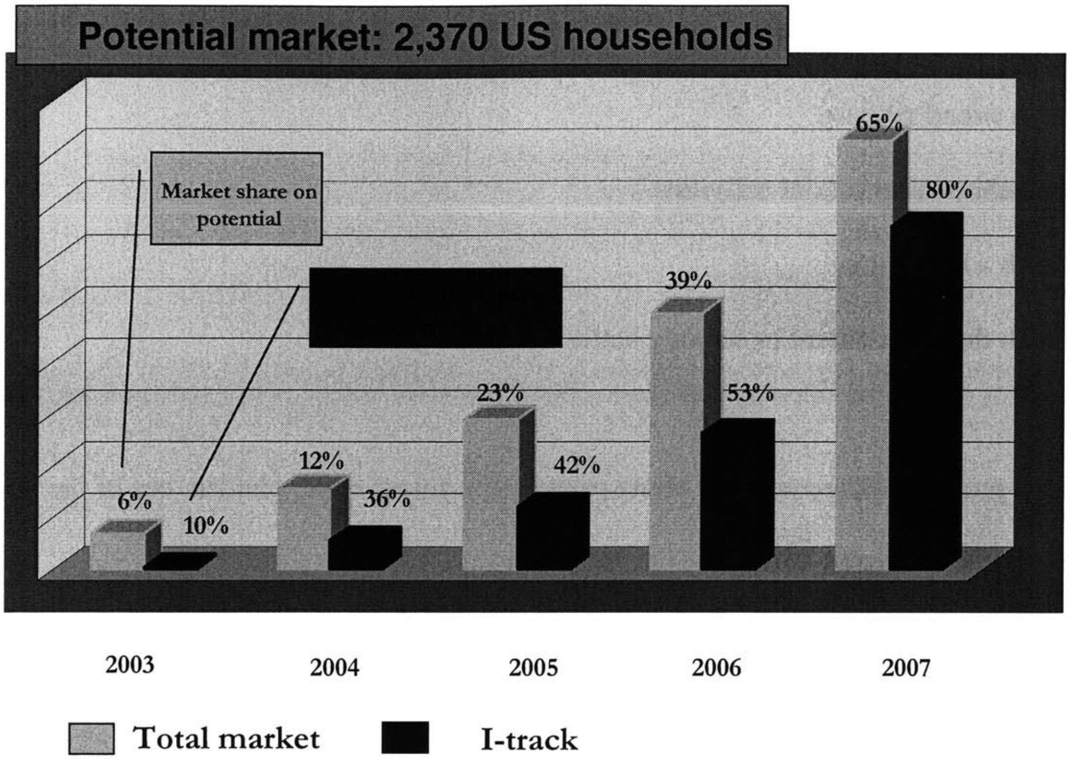
The target market for iTrack is parents with children the ages of 4 to 12 years old. The iTrack focuses on children old enough to be active on their own and young enough not to have privacy issues yet. Survey figures show that 2.37 million urban households are anticipated to be concerned with personal safety and willing to purchase related products for their children.

Figure 24. Market Potential

	(in thousands)	Assumptions	Source
Families w/ one or more children in the US (0-17 yrs)	38,427		*US census 2002*
...w/children 4-12 yrs old	9,607	0,25	*US census 2002*
...w/income over 60,000$	4,227	0,44	*US census 2002*
...living in metropolitan areas	3,386	80%	*US census 2002*
...with Internet connection	3,386	100%	*US census 2002*
...concerned with personal safety *(market of home safety products taken as a proxy)*	**2,370**	70%	*SDM/Interlogix survey 2001*

We project a market penetration for GPS-based tracking systems for children to be 12% of this potential market and with more consumer awareness of GPS, an increase to 65% by 2007. Because of its easy-to-use yet enhanced features, it is anticipated iTrack will be welcomed warmly by parents and capture 36% of the personal locator market in 2004.

Figure 25. Market Potential



6. 3 Customer Needs

Parents will no longer fear losing their children in high risk situations and unfamiliar environments.

- Vacations
- Crowded concerts
- Class field trips
- Camping trips
- Theme parks

Customers will have peace of mind leaving their children with others.

- At a friend's house
- At school/after school activities
- With a baby sitter
- With the other parent in custody battle

iTrack also provides awareness and alerts parents if a young child wanders out of the house into the street or into restricted areas.

6.4 Competition

Since the Clinton administration's 1996 decision to open Pentagons 24 satellite global Position System satellite to the general public, a few companies have created personal tracking systems:

- Wherify Wireless, Inc.
- Digital Solutions' Digital Angel
- eWorldTrack.com

Wherify, one of the leaders in the market, created a child-friendly watch that acts as both a tracker and pager. It has a patented SafetyLock to prevent unwanted removal and a 911 call button. Digital Angel has just released a prototype for a microchip transmitter implanted under the skin. The third company, eWorldTrack.com has focused their product on children in high risk situations such as custody battles or autistic kids. Their tracking device is placed in an athletic shoe or backpack.

6. 5 Vector of Differentiation

iTrack sets itself from its competitors by its focus on software and an enhanced user-friendly application. This mindset makes the iTrack compatible with many different tracking devices and lets the customer chose customized hardware suited to their needs. iTrack differs from other products because of its design and utilization of web services. These features enable customers using different operating platforms and devices to access tracking information easily. The design also allows the integration of new web applications such as notification systems without hindrance to the current iTrack tracking system. GPS technology allows tracking over any part of the world and our partnership with Microsoft allows detailed map rendering for many countries. Therefore iTrack can be used on family vacations and is not limited to the United States.

Tragically, only 2% of the missing children reported had current and proper identification to aid law enforcement agencies and FBI in their recovery efforts. iTrack will not only prevent incidents but also improve the likeliness solving missing children cases.

7. Conclusion

Using GPS and web technology, we were able to create a potential solution for the issue of child safety by designing the iTrack. However, during the implementation of iTrack we encountered challenges that all web-based tracking applications will face.

- Current limited GMS/GPRS network in the United States
- Size of standalone GPS hardware
- Unreliable signals

But the future of GPS and tracking applications looks bright and solutions to the previously stated challenges loom near. Due to the increasing popularity of 3rd generation services, mobile telephone companies are constantly enlarging their GMS/GPRS service areas. The Department of Defense has reevaluated the Standard Positioning Service and improved the service for civilians nationwide the last few years. These two changes should improve the signal reliability which is important when trying to display the precise location of a child. Though the tracking device used for the iTrack was not the ideal size, new better, smaller standalone GPS sensors that were not available when the iTrack project began have come into the market. Some miniaturized tracking hardware are now the size of a postage stamp, though meant to be integrated into other mobile devices.

One of the benefits of a web-based GPS tracking system is that the iTrack can be easily integrated into many different operating systems. In the future, it is anticipated that applications such as iTrack will be compatible with not only all operating systems but also all devices.

Other additional features we would like the iTrack to have include:

- Device compatible – web display of map on PDA, cell phone, pager
- Geo Fencing capabilities
- Notification System – through email or phone that child has wandered outside designated, taken off device, or other options
- E911

New applications will continue to be created as the technology evolves. Tracking systems such as the iTrack can be expanded to involve applications such as tracking pets, medical patients with memory problems, and even assets. The future of GPS is as unlimited as your imagination.

References

1999 Federal Radionavigation Plan. February 2000. Washington, DC: U.S. Department of Transportation and Department of Defense.

The Aerospace Corporation . "GPS Primer". July 6, 1999. (http://www.aero.org/publications/GPSPRIMER)

Assaf, C., P. Wang and K.L. Yeo. A GPS GPRS-based Child Tracking System. MIT, 2003.

Business Communication Robberechts (BCR). "M110 Triband Modem". April 21st 2003. (http://www.bcr.be/)

Dana, Peter H. Global Positioning System Overview, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder. May 1, 2000. (http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html)

Hofmann-Wellenhof, B., H. Lichtenegger, and J. Collins. Global Positioning System Theory and Practice. Fourth Ed. New York: Springer-Verlag Wien, 1997.

Trimble Navigation Limited. "About GPS Technology". (http://www.trimble.com/gps/)

Tsui, James Bao-Yen. Fundamentals of Global Positioning System Receivers: A Software Approach. New York: John Wiley & Sons, Inc., 2000.

Appendix 1

Figure 1.Layout of M110

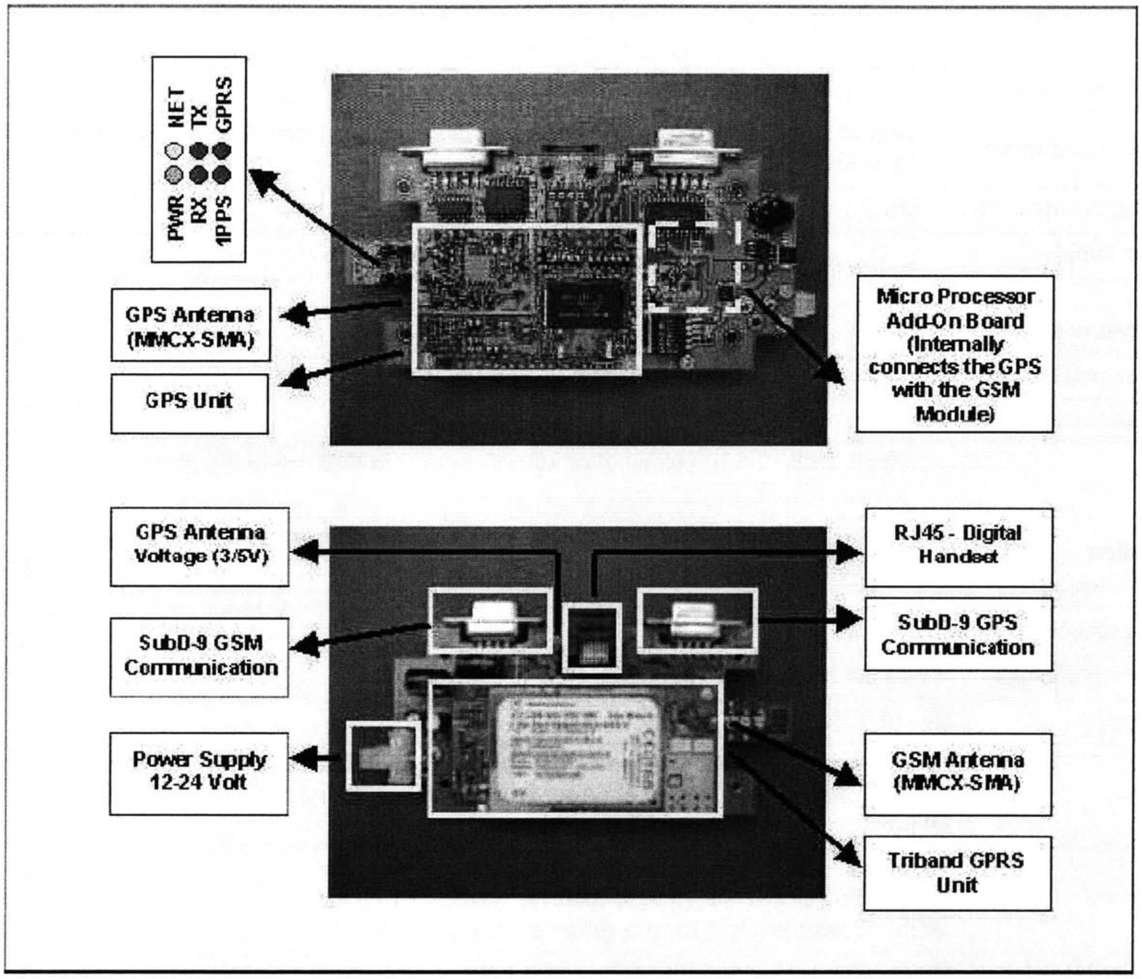


Table 1. M110 Technical Specifications

Physical	
Size:	65x130x25 mm
Weight:	200g
Volume	
Housing material:	Plastic housing PC/ABS – IP54 (Flame Retardant) / Black or Grey
Interface connector:	Sub-D female 9-pins, ± 15kV ESD-protected, RS232 Serial Asynchronous full flow DCE control
RF output connector	FME (Male) matching 50 Ω GSM antenna
Power Supply connector:	8-14V/300mA DC Power Connector (Male) 2.1 mm
Environmental	
Operational temperature	-30 to +60 degrees C
Storage temperature	-40 to +85 degrees C
Shock:	20 g's with 11 millisecond duration, 20 impacts in three mutually perpendicular planes
Vibration:	S-19: 1.5g acceleration, 5 to 500 Hz @ 0.1 octave/minute in three mutually perpendicular planes

Performance1 [1]	
Operating systems	GSM 900MHz, DCS 1800MHz, PCS 1900MHz
Voltage:	8 - 14 V dc
Current:	7.2 +/- 0.5mA @ DRX 2 Stand by (sleep) ; 3.5 +/- 0.5mA @ DRX 9 Stand by (sleep); 300mA avg. in call at power level 5 (max. 350mA); 1.2 A peak @ 217 Hz at power level 5 (max. 1.8A)
Power out	GSM – Power levels #19 to 5, 5dBm to 33dBm per ETSI; DCS – Power levels # 15 to 0, 0dBm to 30dBm per ETSI PCS – Power levels # 15 to 0, 0dBm to 30dBm per FCC.
SIM Card Reader:	Internal on G18 - chip SIM CR 3/5V SIM
Host Protocol:	CSD mode: AT commands including GSM 07.07,GSM 07. 05 GRRS mode: AT commands per standard for GSM 07.60 and 07.07 ver 7.5.0
Data CSD mode	9.6, 19.2 and 57.6 kbps (over the air rate depending on network, 1.14 kbps max) RS232 user data: 57.6 kbps (over-the- air data rate depends on schemes used SC1-CS4)
Data GPRS mode	GPRS packet data (SMG31), multi slot class 1, 2 and 4, coding schemes CS1 to CS4. 1X (uplink)/2X (downlink) or 1X (uplink)/3X (downlink)
PC FAX:	Class 1 using Winfax, alternate between fax and voice (TS61)
SMS:	Send and receive (PDU and block mode per GSM 07.05)
Optional GPS:	*Independent GPS receiver (GPS model only)*

Table 2. Performance of GPS Modem

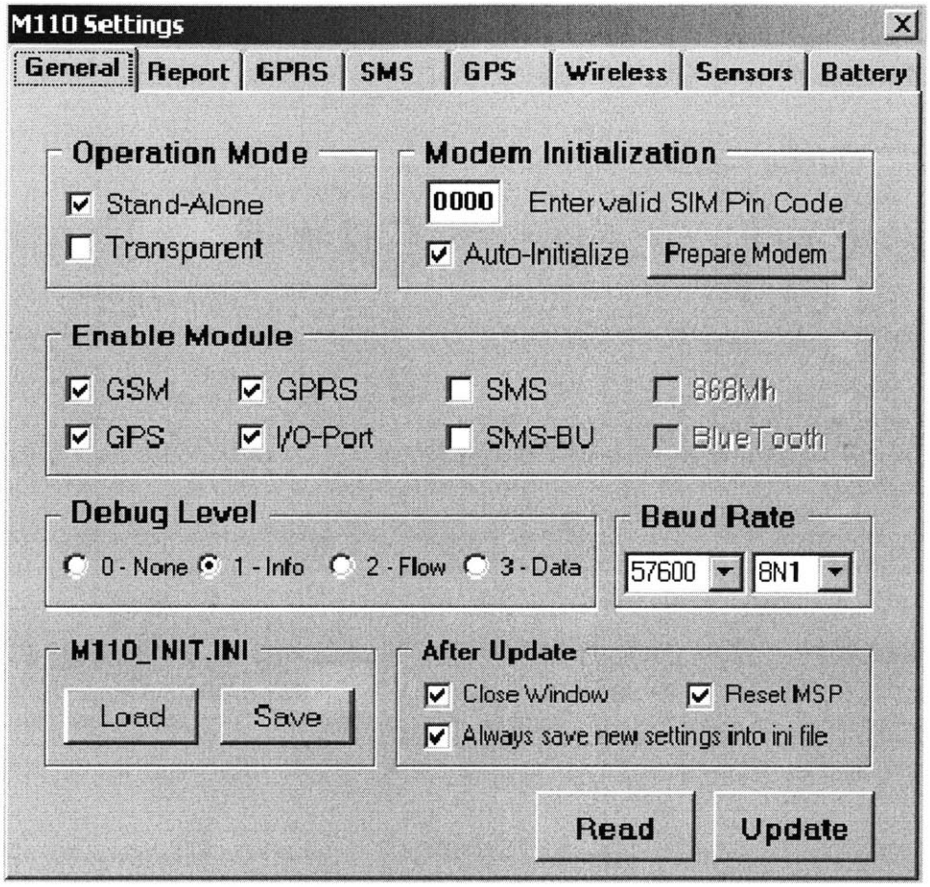
Operating systems		GSM 900MHz, DCS 1800MHz, PCS 1900MHz.
Voltage:		3.0 to 6V measured at the I/O connector during the transmit slot (576us out of 4.6ms)
Current:		=7.2 +/- 0.5 mA @ DRX 2 Stand by (sleep) =3.5 +/- 0.5 mA @ DRX 9 Stand by (sleep) < 150uA off current 300mA avg. in call at power level 5 (max. 350 mA) 1.2 A peak @ 217 Hz at power level 5 (max. 1.8A)
Host Protocol:	CSD	AT commands including GSM 07.07,GSM 07. 05 (Chapter 4)
	GRRS	AT commands per standard for GSM 07.60 and 07.07 ver 7.5.0. (Chapter 4)
Data:	CSD GPRS	1. at 9.6, 19.2 and 57.6 kbps (over the air rate depending on network, 1.14 kbps max) 2. Circuit Switched Data RS232 user data: 57.6 kbps (over-the- air data rate depends on schemes used SC1-CS4) GPRS packet data (SMG31) Class B (only when a handset is used), multi slot class 1, 2 and 4, coding schemes CS1 to CS4. 1X (uplink)/2X (downlink) or 1X (uplink)/3X (downlink)
PC FAX:		Class 1 using Winfax, alternate between fax and voice (TS61)
SMS:		Send and receive (PDU and block mode per GSM 07.05)
Voice Call:		Supported I/O with external H/SET
Audio:		Analog - Full duplex I/O on interface connector Digital - Motorola Proprietary DSC Bus Echo canceling activated by AT for Hands Free Audio applications (analog only)

Table 3. Product Specification M110 – GPS Module

General Characteristics	Receiver Architecture	• 12 parallel channels • L1 1575.42 MHz • C/A code (1.023 MHz chip rate) • Code plus carrier tracking (carrier aided tracking)
	Tracking Capability	• 12 simultaneous satellites
Performance Characteristics	Dynamics	• Velocity: 515 m/s (1000 knots); >515 m/s at altitudes < 18,000 m • Acceleration: 4 g • Jerk: 5 m/s • Vibration: 7.7G per Military Standard 810E
	Acquisition Time (Time To First Fix, TTFF)	• <15 s typical TTFF - Hot (current almanac, position, time, ephemeris) • <45 s typical TTFF - Warm (current almanac, position and time) • <70 s typical TTFF - Cold (No stored information) • <1.0 s internal reacquisition
	Positioning Accuracy	• 100 meters 2dRMS with SA as per DoD specification • Less than 25 meters, SEP without SA

	Timing Accuracy (1PPS) Date	• < 500 ns with SA on • WGS-84 • One user definable date
SerialCommunication	I/O Messages	• Latitude, longitude, height, velocity, heading, time • Motorola binary protocol at 9600 baud • NMEA 0183 at 4800 baud (GGA, GLL, GSA, GSV, RMC, VTG, ZDA) • Software selectable output rate (continuous or poll) • 3 V digital logic interface • Integrated pin on COM port for RTCM input
	Power Requirements	• 2.8 to 3.2 Vdc; 50 mVp-p ripple (max)
	"Keep-Alive" BATT Power	• External 1.8 Vdc to 3.2 Vdc, 5μA (typical @2.7 Vdc @ +25°C)
	Power Consumption	• <0.225 W @ 3 V without antenna
Electrical Characteristics	Dimensions	• 40.0 x 60.0 x 10.0 mm [1.57 x 2.36 x 0.39 in.]
	Weight	• Receiver 25 g (0.9 oz.)
	Connectors	• Power/Data: 10 pin (2x5) unshrouded male header on 0.050 inch centers (available in right angle or straight configuration) • RF: right angle MMCX female (subminiature snap-on)
Environmental Characteristics	Operating Temperature	• -40°C to +85°C
	Storage Temperature	• -40° to 105°C
	Humidity	• 95% over dry bulb range of +38°C to+85°C
	Altitude	• 18,000 m (60,000 ft.) maximum • > 18,000 m (60,000 ft.) for velocities < 515m/s (1000 knots)
Miscellaneous	Standard Features	• Motorola DGPS corrections at 9600 baud on COM port one • RTCM SC-104 input Type 1 and Type 9 messages for DGPS at 2400, 4800 or 9600 baud extra pin COM port One • NMEA 0183 output • Inverse DGPS support

Figure 2. M110 General Settings



Operation Mode
☑ Stand-Alone
☐ Transparent

Modem Initialization
0000 Enter valid SIM Pin Code
☑ Auto-Initialize

Enable Module
☑ GSM ☑ GPRS ☐ SMS ☐ 868Mh
☑ GPS ☑ I/O-Port ☐ SMS-BU ☐ BlueTooth

Debug Level
○ 0 - None ● 1 - Info ○ 2 - Flow ○ 3 - Data

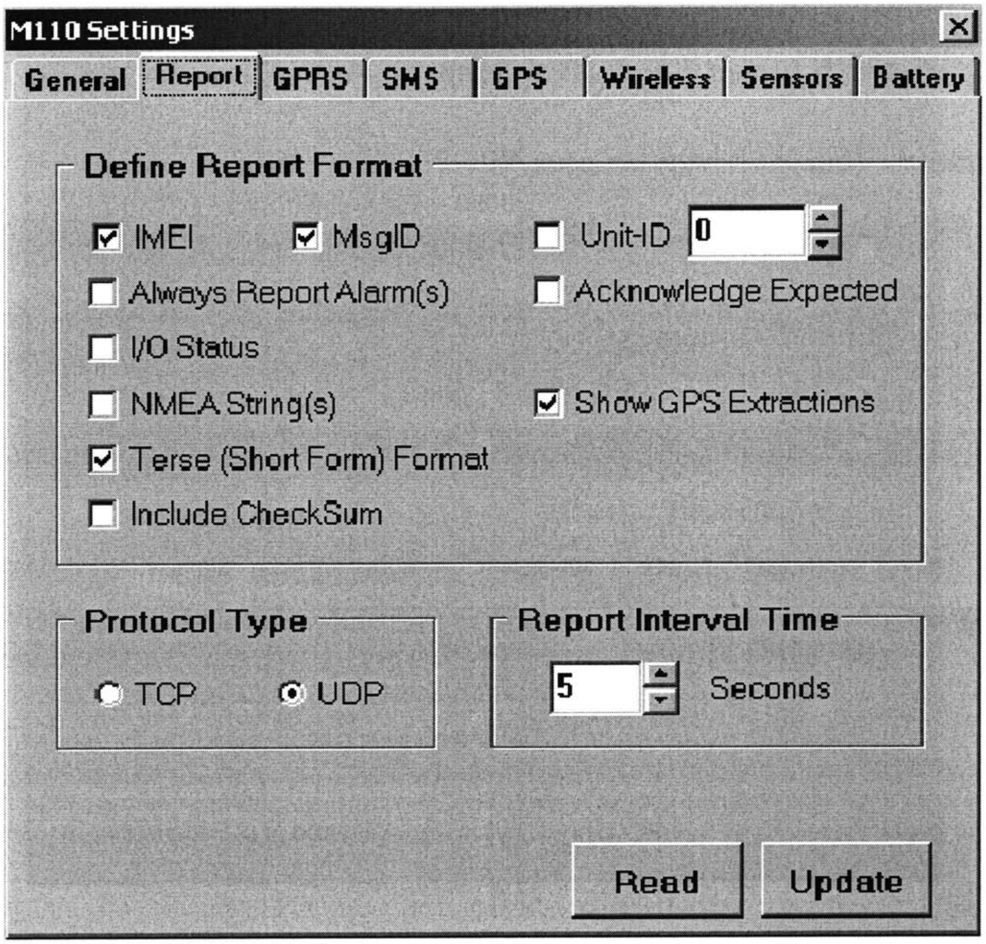
Baud Rate
57600 8N1

M110_INIT.INI

After Update
☑ Close Window ☑ Reset MSP
☑ Always save new settings into ini file

The process parameters are set and defined by the user in the M110 general settings. In the child tracking application, the settings displayed in Figure 2 are selected. The selected settings are stored into flash memory when updated.

Figure 3. M110 Report Settings



Define Report Format

☑ IMEI ☑ MsgID ☐ Unit-ID 0
☐ Always Report Alarm(s) ☐ Acknowledge Expected
☐ I/O Status
☐ NMEA String(s) ☑ Show GPS Extractions
☑ Terse (Short Form) Format
☐ Include CheckSum

Protocol Type

○ TCP ● UDP

Report Interval Time

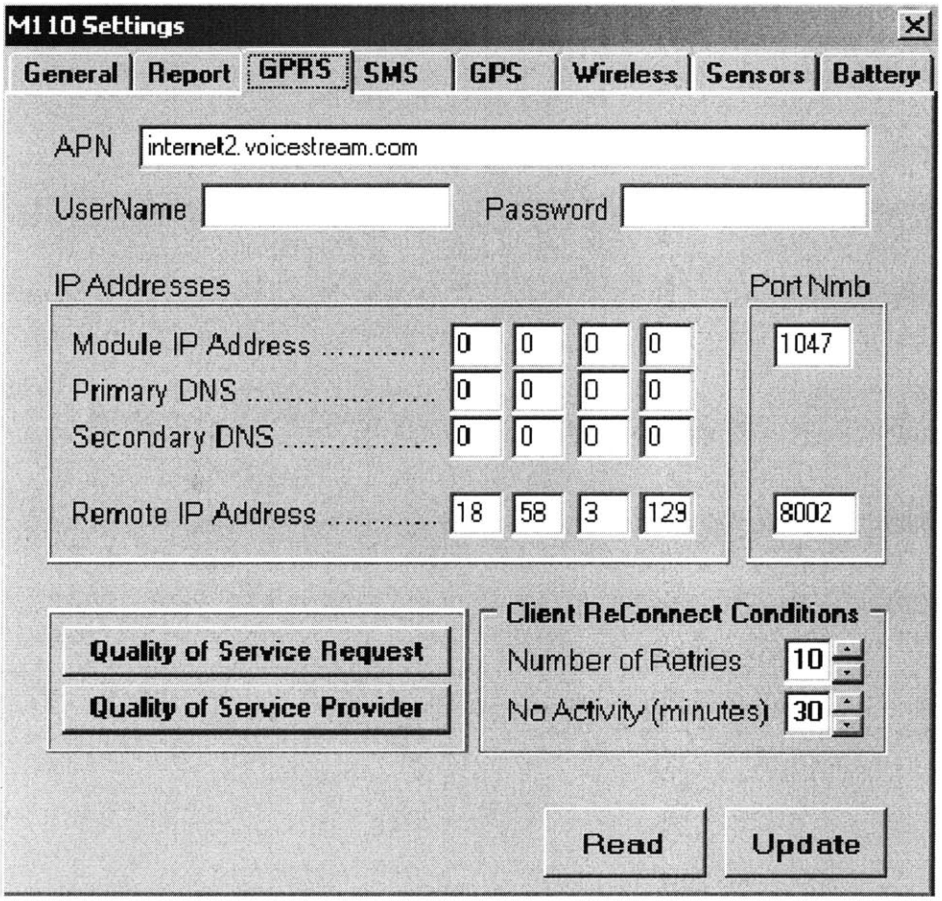
5 Seconds

An explanation of the key report settings is provided below:

- IMEI: The IMEI number (International Mobile Subscriber Identity) is a 15-digit number that uniquely identifies a piece of telecommunication equipment. It can be used as a primary key in a table in any relational databases and should be sent along with any message to the central server machine.
- Terse (Short Form) Format: The report produced by the M110 will be as short as possible, given the user-defined report options. This is recommended in any application since the cost of telecommunication service is often dependent on the amount of data that is sent.

- Protocol Type: A choice of either using TCP or UDP. The UDP protocol is used in the child tracking application.
- Interval: The frequency in which the report is being sent to the central server can be adjusted. In a tracking application, the balance between the cost of data transmission and the effectiveness of tracking should be reflected here.

Figure 4. M110 GPRS Settings



APN internet2.voicestream.com

UserName

Password

IP Addresses

Port Nmb

Module IP Address 0 0 0 0 1047

Primary DNS 0 0 0 0

Secondary DNS 0 0 0 0

Remote IP Address 18 58 3 129 8002

Client ReConnect Conditions

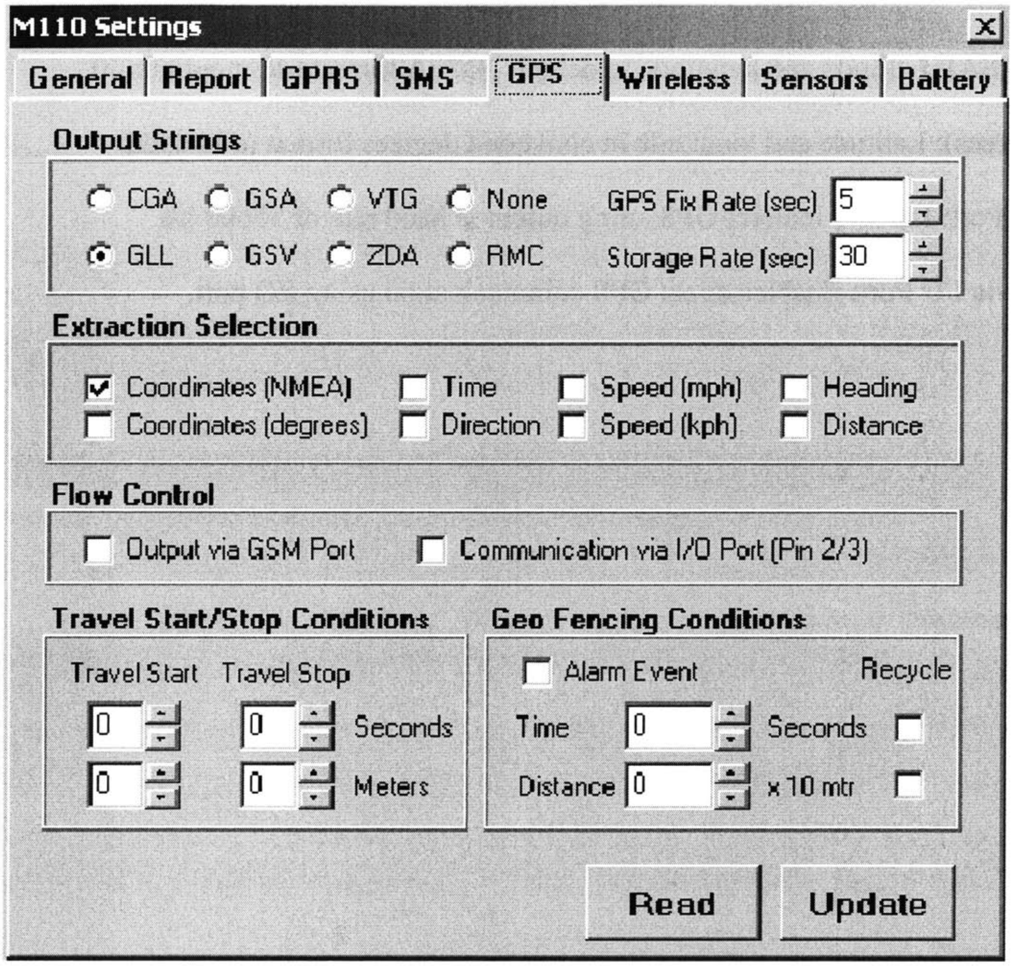
Number of Retries 10

No Activity (minutes) 30

An explanation of the key GPRS settings is provided below:

- APN: Access Point Name of the GPRS network provider. With T-Mobile, the APN is 'internet2.voicestream.com' and the username and password fields should be left empty.
- Module IP: The service provider could assign an IP address to the M110 unit.
- Primary DNS: Primary Domain Name Server IP Address
- Secondary DNS: Secondary Domain Name Server IP Address
- Remote IP Address: This defines the IP address of the server that the information is going to be sent to. Along with the port number, a client server connection could be setup.

Figure 5. M110 GPS Settings



Output Strings

○ CGA ○ GSA ○ VTG ○ None GPS Fix Rate (sec) 5

● GLL ○ GSV ○ ZDA ○ RMC Storage Rate (sec) 30

Extraction Selection

☑ Coordinates (NMEA) ☐ Time ☐ Speed (mph) ☐ Heading

☐ Coordinates (degrees) ☐ Direction ☐ Speed (kph) ☐ Distance

Flow Control

☐ Output via GSM Port ☐ Communication via I/O Port (Pin 2/3)

Travel Start/Stop Conditions

Travel Start Travel Stop

0 0 Seconds

0 0 Meters

Geo Fencing Conditions

☐ Alarm Event Recycle

Time 0 Seconds ☐

Distance 0 x 10 mtr ☐

An explanation of the key GPS settings is provided below:

- GPS Fix Rate: This shows that rate (0 to 60 seconds) at which GPS data is extracted from the satellites.
- CGA: GPS Fixed Data
- GLL: Geographic Position-Latitude/Longitude
- GSA: GPS DOP and Active Satellites
- GSV: Satellites in View
- VTG: Track Made Good and Ground Speed

- ZDA: Time and Date information
- RMC: Recommended Minimum Specific GPS /Transit Data
- Coordinates (NMEA): Latitude and longitude in default NMEA format (dd.mmmmmm)
- Coordinates (degrees): Latitude and longitude in converted degrees format (ddd.dddd)
- Output via GSM Port: Enables indirect GPS string output at baud rate of 57600 b/s.
- Communication via I/O Port: Enables direct GPS communication using I/O port.

Appendix 2

Server Program

```
namespace sampleTcpUdpServer2

{

        using System;

        using System.Net;

        using System.Net.Sockets;

        using System.Threading;

        using System.IO;

        using System.Data;

        using System.Data.SqlClient;


public class SampleTcpUdpServer2

{

        private const int sampleTcpPort = 8001;

        private const int sampleUdpPort = 8002;

        public Thread sampleTcpThread, sampleUdpThread;


        string[] elements;

        char[] delimiters=new char[]{',','\r','\n'};

        string lat="";

        string lon="";

        string time="";

        string deviceID="";

        string temp="";


        double convert0;
```

```
        int result0;
        string string0="";
        double convert1;
        int result1;
        string string1 ="";
        double convert2;
        int result2;
        string string2 ="";
        double convert3;
        int result3;
        string string3 ="";
        string lon1 ="";
        string lat1="";

    public SampleTcpUdpServer2()
    {
        Console.WriteLine("***************************************");
        Console.WriteLine("iTrack Data Logging Program Version 1.03");
        Console.WriteLine("***************************************");
        Console.WriteLine("");
        try
        {
            //Starting the TCP Listener thread.
            sampleTcpThread = new Thread(new ThreadStart(StartListen2));
            sampleTcpThread.Start();
            Console.WriteLine("Started TcpUdpServer's TCP Listener Thread!\n");
        }
```

```
        catch (Exception e)
        {
                Console.WriteLine("An TCP Exception has occurred!" + e.ToString());
                sampleTcpThread.Abort();
        }
        try
        {
        //Starting the UDP Server thread.
                sampleUdpThread = new Thread(new ThreadStart(StartReceiveFrom2));
                sampleUdpThread.Start();
                Console.WriteLine("Started TcpUdpServer's UDP Receiver Thread!\n");
        }
        catch (Exception e)
        {
                Console.WriteLine("An UDP Exception has occurred!" + e.ToString());
                sampleUdpThread.Abort();
        }
}

public static void Main(String[] argv)
{
        SampleTcpUdpServer2 sts = new SampleTcpUdpServer2();
}
```

```
public void StartListen2()
{
//Create an instance of TcpListener to listen for TCP connection.
        TcpListener tcpListener = new TcpListener(sampleTcpPort);
        try
        {
                tcpListener.Start();
                while (true)
                {
                //Program blocks on Accept() until a client connects.
                        Socket soTcp = tcpListener.AcceptSocket();
                        Console.WriteLine("Client is connected through TCP.");
                        Byte[] received = new Byte[512];
                        int bytesReceived = soTcp.Receive(received, received.Length, 0);
                        FileStream f = new FileStream("test.txt", FileMode.Append);
                        StreamWriter sw = new StreamWriter(f);
                        String dataReceived = System.Text.Encoding.ASCII.GetString(received);
                        Console.WriteLine(dataReceived);
                        sw.WriteLine(dataReceived);
                        String returningString = "The Server got your message through TCP: " + dataReceived;

                        Byte[] returningByte = System.Text.Encoding.ASCII.GetBytes
                        (returningString.ToCharArray());
                        //Returning a confirmation string back to the client.
                        sw.Close();
                        f.Close();
                }
                tcpListener.Stop();
```

```
          }
          catch (SocketException se)
          {
                    Console.WriteLine("A Socket Exception has occurred!" + se.ToString());
          }
}

public void StartReceiveFrom2()
{
          IPHostEntry localHostEntry;
          try
          {
          //Create a UDP socket.
                    Socket    soUdp    =    new    Socket(AddressFamily.InterNetwork,    SocketType.Dgram,
                    ProtocolType.Udp);
                    try
                    {
                              localHostEntry = Dns.GetHostByName(Dns.GetHostName());
                    }



                    catch(Exception)
                    {
                              Console.WriteLine("Local Host not found"); // fail
                              return ;
                    }
                    IPEndPoint localIpEndPoint = new IPEndPoint(localHostEntry.AddressList[0], sampleUdpPort);
```

```
    soUdp.Bind(localIpEndPoint);
    while (true)
    {
        FileStream f = new FileStream("test.txt", FileMode.Append);
        StreamWriter sw = new StreamWriter(f);
Byte[] received = new Byte[256];
        IPEndPoint tmpIpEndPoint = new IPEndPoint
        (localHostEntry.AddressList[0], sampleUdpPort);
        EndPoint remoteEP = (tmpIpEndPoint);
        int bytesReceived = soUdp.ReceiveFrom(received, ref remoteEP);
        String dataReceived = System.Text.Encoding.ASCII.GetString(received);
        Console.WriteLine("Client is connected through UDP.");
        Console.WriteLine(dataReceived);
        sw.WriteLine(dataReceived);
        temp = dataReceived;
        elements = temp.Split(delimiters);
        for(int j=0; j <(elements.Length); j++)
        {
        if(elements[j].Equals("GPGLL"))
        {
        //Open Connection
        SqlConnection conn = new
        SqlConnection("DataSource=localhost; Integrated Security=SSPI; Initial
        Catalog=ITRACK");
        conn.Open();
        // *************
        // UPDATE
        // *************
```

```
                        // Update SQL table
                        String  updateCmd  =  "UPDATE  LATEST  SET  Time=@Signal,  Latitude=@Lat,
                        Longitude=@Long WHERE UnitKey=@IdNo";
                        SqlCommand SqlCommand2 = new SqlCommand(updateCmd, conn);
                        deviceID = elements[1];
                        SqlCommand2.Parameters.Add(new SqlParameter( "@IdNo", SqlDbType.Char, 15));
                        SqlCommand2.Parameters["@IdNo"].Value = deviceID;                    time    =
System.DateTime.Now.ToString();
                        SqlCommand2.Parameters.Add(new   SqlParameter("@Signal",   SqlDbType.NVarChar,
                        20));
                        SqlCommand2.Parameters["@Signal"].Value = time;                      lon     =
elements[6];
                        convert0 = Double.Parse(lon.Substring(1,2));
                        convert1 = (Double.Parse(lon.Substring(3,2)))/60.0;
                        convert2 = Double.Parse(lon.Substring(6,4)))
                        *60/36000000.0;
                        convert3 = -(convert2 + convert1 + convert0);
                        string1 = convert3.ToString();

                        lon1 = string1.Substring(0,8);
        Decimal londec1 = Decimal.Parse(lon1);
                        SqlCommand2.Parameters.Add(new SqlParameter("@Long", SqlDbType.Decimal, 9));
                        SqlCommand2.Parameters["@Long"].Value = londec1
                lat = elements[4];
        convert0 = Double.Parse(lat.Substring(0,2));
                        convert1 = (Double.Parse(lat.Substring(2,2)))/60.0;
                        convert2 = (Double.Parse(lat.Substring(5,4)))*60.0/36000000.0;
                        convert3 = convert0+convert1+convert2;
```

```
string2 = convert3.ToString();
lat1 = string2.Substring(0,8);
Decimal latdec = Decimal.Parse(lat1);
SqlCommand2.Parameters.Add(new SqlParameter("@Lat", SqlDbType.Decimal, 9));
SqlCommand2.Parameters["@Lat"].Value = latdec;
SqlCommand2.ExecuteNonQuery();

// *************
// INSERT
// **************
//Add to SQL table
String insertCmd = "INSERT INTO Main(UnitKey, Time, Latitude, Longitude) values
(@IdNo, @Signal, @Lat, @Long)";
SqlCommand SqlCommand1 = new SqlCommand(insertCmd, conn);
deviceID = elements[1];
SqlCommand1.Parameters.Add(new SqlParameter( "@IdNo", SqlDbType.Char, 15));
SqlCommand1.Parameters["@IdNo"].Value = deviceID;
time = System.DateTime.Now.ToString();
SqlCommand1.Parameters.Add(new SqlParameter("@Signal", SqlDbType.NVarChar,
20));

SqlCommand1.Parameters["@Signal"].Value = time;
lon = elements[6];
result0 = -Int32.Parse(lon.Substring(1,2));
string0 = result0.ToString()+".";
convert1 = Double.Parse(lon.Substring(3,2));
result1 = (int)(convert1*100/60);
if (result1 <10)
```

```
{
        string1 = "0"+result1.ToString();
}
        else
{
        string1 = result1.ToString();
}
        convert2 = Double.Parse(lon.Substring(6,4));
        result2 = (int)(convert2*100/60);
if (result2<1000 && result2>99)
{
        string2 = "0" +result2.ToString();
}
else if (result2<=99 && result2>9)
{
        string2 = "00" + result2.ToString();
}
else
{
        string2 = result2.ToString();
}
lon1 = String.Concat(string0, string1, string2);
londec1 = Decimal.Parse(lon1);
SqlCommand1.Parameters.Add(new SqlParameter("@Long", SqlDbType.Decimal, 9));
SqlCommand1.Parameters["@Long"].Value = londec1;
lat = elements[4];
result0 = Int32.Parse(lat.Substring(0,2));
string0 = result0.ToString()+".";
```

```
                    convert1 = Double.Parse(lat.Substring(2,2));

                    result1 = (int)(convert1*100/60);

                    string1 = result1.ToString();

                    convert2 = Double.Parse(lat.Substring(5,4));

                    result2 = (int)(convert2*100/60);

                    if (result2<1000 && result2>99)

                    {

                        string2 = "0" +result2.ToString();

                    }

                    else if (result2<=99 && result2>9)

                    {

                        string2 = "00" + result2.ToString();

                    }

                    else

                    {

                        string2 = result2.ToString();

                    }

                    lat1 = String.Concat(string0, string1, string2);

                    Decimal latdec1 = Decimal.Parse(lat1);

                    SqlCommand1.Parameters.Add(new SqlParameter("@Lat", SqlDbType.Decimal, 9));


                    SqlCommand1.Parameters["@Lat"].Value = latdec1;

SqlCommand1.ExecuteNonQuery();

        }

}

sw.Close();

f.Close();

}
```

```
            }
            catch (SocketException se)
            {
            Console.WriteLine("A Socket Exception has occurred!" + se.ToString());
            }
    }
    }
    }
```

Appendix 3

Glossary of GPS Terminology

Anywhere fix

The ability of a receiver to start position calculations without being given an approximate location and approximate time.

Bandwidth

The range of frequencies in a signal.

C/A code

The standard (Course/Acquisition) GPS code. A sequence of 1023 pseudo-random, binary, biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. Also known as the "civilian code."

Carrier

A signal that can be varied from a known reference by modulation.

Carrier-aided tracking

A signal processing strategy that uses the GPS carrier signal to achieve an exact lock on the pseudo random code.

Carrier frequency

The frequency of the unmodulated fundamental output of a radio transmitter.

Carrier phase GPS

GPS measurements based on the L1 or L2 carrier signal.

Channel

A channel of a GPS receiver consists of the circuitry necessary to receive the signal from a single GPS satellite.

Chip

The transition time for individual bits in the pseudo-random sequence. Also, an integrated circuit. Also a snack food. Also a betting marker.

Clock bias

The difference between the clock's indicated time and true universal time.

Code phase GPS

GPS measurements based on the pseudo random code (C/A or P) as opposed to the carrier of that code.

Control segment

A world-wide network of GPS monitor and control stations that ensure the accuracy of satellite positions and their clocks.

Cycle slip

A discontinuity in the measured carrier beat phase resulting from a temporary loss of lock in the carrier tracking loop of a GPS receiver.

Data message

A message included in the GPS signal which reports the satellite's location, clock corrections and health. Included is rough information on the other satellites in the constellation.

Differential positioning

Accurate measurement of the relative positions of two receivers tracking the same GPS signals.

Dilution of Precision

The multiplicative factor that modifies ranging error. It is caused solely by the geometry between the user and his set of satellites. Known as DOP or GDOP

Dithering

The introduction of digital noise. This is the process the DoD uses to add inaccuracy to GPS signals to induce Selective Availability.

Doppler-aiding

A signal processing strategy that uses a measured doppler shift to help the receiver smoothly track the GPS signal. Allows more precise velocity and position measurement.

Doppler shift

The apparent change in the frequency of a signal caused by the relative motion of the transmitter and receiver.

Ephemeris

The predictions of current satellite position that are transmitted to the user in the data message.

Fast switching channel

A single channel which rapidly samples a number of satellite ranges. "Fast" means that the switching time is sufficiently fast (2 to 5 milliseconds) to recover the data message.

Frequency band

A particular range of frequencies.

Frequency spectrum

The distribution of signal amplitudes as a function of frequency.

Geometric Dilution of Precision (GDOP)

See Dilution of Precision.

Hardover word

The word in the GPS message that contains synchronization information for the transfer of tracking from the C/A to P code.

Ionosphere

The band of charged particles 80 to 120 miles above the Earth's surface.

Ionospheric refraction

The change in the propagation speed of a signal as it passes through the ionosphere.

L-band

The group of radio frequencies extending from 390 MHz to 1550 MHz. The GPS carrier frequencies (1227.6 MHz and 1575.42 MHz) are in the L band.

Multipath error

Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. Usually caused by one path being bounced or reflected.

Multi-channel receiver

A GPS receiver that can simultaneously track more than one satellite signal.

Multiplexing channel

A channel of a GPS receiver that can be sequenced through a number of satellite signals.

P-code

The Precise code. A very long sequence of pseudo random binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz which repeats about every 267 days. Each one week segment of this code is unique to one GPS satellite and is reset each week.

Precise Positioning Service (PPS)

The most accurate dynamic positioning possible with standard GPS, based on the dual frequency P-code and no SA.

Pseudolite

A ground-based differential GPS receiver which transmits a signal like that of an actual GPS satellite, and can be used for ranging.

Pseudo random code

A signal with random noise-like properties. It is a very complicated but repeating pattern of 1's and O's.

Pseudorange

A distance measurement based on the correlation of a satellite transmitted code and the local receiver's reference code, that has not been corrected for errors in synchronization between the transmitter's clock and the receiver's clock.

Satellite constellation

The arrangement in space of a set of satellites.

Selective Availability (SA)

A policy adopted by the Department of Defense to introduce some intentional clock noise into the GPS satellite signals thereby degrading their accuracy for civilian users. This policy was discontinued as of May 1, 2000 and now SA is turned off

Slow switching channel

A sequencing GPS receiver channel that switches too slowly to allow the continuous recovery of the data message.

Space segment

The part of the whole GPS system that is in space, i.e. the satellites.

Spread spectrum

A system in which the transmitted signal is spread over a frequency band much wider than the minimum bandwidth needed to transmit the information being sent. This is done by modulating with a pseudo random code, for GPS.

Standard Positioning Service (SPS)

The normal civilian positioning accuracy obtained by using the single frequency C/A code.

Static positioning

Location determination when the receiver's antenna is presumed to be stationary on the Earth. This allows the use of various averaging techniques that improve accuracy by factors of over 1000.

User interface

The way a receiver conveys information to the person using it. The controls and displays.

User segment

The part of the whole GPS system that includes the receivers of GPS signals.