Handheld GPS –Today and Tomorrow

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ABSTRACT

Magellan introduced the NAV 1000, the first handheld GPS receiver for positioning and navigation, in 1988. By today's standards the NAV 1000 was a large unit (19x8.9x5.3 centimetres) weighing 850 grams. It was a single channel receiver, could only track four satellites and only supported Latitude/Longitude coordinates. It supported 100 waypoints and 1 route of 10 waypoints, but no raw data was stored. The price was in the order of US$2,500 per unit.

It has been more than a decade since this first handheld GPS came on the market. With the ongoing development of the underlying GPS technology and infrastructure, wireless communication, and information management, the handheld GPS has evolved a great deal technically as well as physically. Today, the handheld GPS is a unit that fully integrates GPS receiver, antenna, data collector, interface, navigation capabilities, map display, and more into one mobile-phone-like unit. It can be comfortably held in the hand and is convenient for one hand operation. For users' convenience, models are designed to be able to mount on a vehicle, an airplane, or a boat. Typically 2 or 4 AA rechargeable batteries last one working day or more. The handheld GPS has become a versatile navigation and mapping tool that typically offers graphical-based, multi-functionality with advanced operational features, at a relatively low price. Most models are 12-channel, weigh only a few ounces and achieve a consistent accuracy of about 15m in most conditions. Models with WAAS/EGNOS capabilities can acquire an accuracy as high as 1~3m. Most recent units allow data and/or map to be exchanged between the unit and desktop computer, and manipulated using increasingly sophisticated firmware.

Handheld GPS are often integrated with wireless technology. For example, the Garmin NavTalk and NavTalk Pilot are not only full-featured GPS receivers, but also high-performance cellular phones with exceptional features. Trimble's GeoExplorer 3 enabled the handheld GPS with the capability of mapping and GIS data collection and maintenance. The recently released Ashtech ProMark2 delivers a combination of post-processed, centimetre-level static survey capabilities with stand-alone, real-time, 3~5m reconnaissance, navigation and mapping capabilities.

Because of it's unique features, characteristics, mobility, physical design and relatively low price, the handheld GPS has been widely used in the air, on land and at sea. Many successful applications have been reported in such areas as aviation, land vehicle tracking, rescue

missions and wildlife studies. Applications integrated with other systems are also under development worldwide, encouraged by a rapidly growing market.

It can be expected that handheld/micro GPS will continue to flourish in the coming decade. For increasingly mobile consumers and enterprises, "where" and "how to" are quickly becoming as important as "what" and "how much". Handheld and imbedded GPS will contribute significantly to these demands. To meet the challenges of diverse applications and a broadening market, the handheld GPS must continue to evolve. Likely innovations will include:
Process weak GPS signals: Handheld GPS needs to function reliably at home, the office, shopping malls, multi-story car parks, and urban canyons.
Integrate with other systems: These will include GSM (GPRS, UMTS), ORBCOMM, Internet and other wireless systems.
Combine functionality: Single units will provide the existing functionality of a cellphone, PDA, personal navigation assistant, and Internet browser.
Reduce power consumption: Lower power consumption to facilitate further miniaturisation and greater flexibility.
Reduce size and weight: Units will progress quickly from handheld to wearable.
Reduce price: With increased markets, mass production of GPS chipsets could result in cost structures approaching those of digital time displays.

This paper presents a synopsis of the development of handheld GPS technology. A comprehensive summary of the handheld GPS genre, including classification, major technical and physical specifications, advanced features and accuracies is presented. Several innovative applications are described to illustrate the expanding market for this technology. Finally, further developments and trends are identified.

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1. INTRODUCTION

Magellan introduced the NAV 1000, the first handheld GPS receiver for positioning and navigation, in 1988 (Langley, 2000). By today's standards the NAV 1000 was a large unit (19x8.9x5.3cm) weighing 850 grams. It was a single channel receiver, could only track four satellites and only supported Latitude/Longitude coordinates. It supported 100 waypoints and 1 route of 10 waypoints, but no raw data was stored. The price was in the order of US$2,500 per unit.

It has been more than a decade since the first handheld GPS receiver came on to the market. With the development of the underlying GPS technology, wireless communication and information management since that time, the handheld GPS has evolved dramatically. It has progressed from simple, single channel, limited functionality to a versatile navigation and mapping tool that typically offers graphical-based, multi-functionality with advanced operational features, at relatively low prices.

New development in electronic and computer technology has resulted in sufficient built-in memory and firmware for handheld GPS to accommodate digital maps/databases of national or even worldwide areas of interest and upload/download capabilities. Standard interfaces and protocols make it easy to communicate with a PC, GSM/GPRS mobile phone, Internet and other optional accessories. Manufacturers are taking advantage of the above advanced functionalities and excellent worldwide satellite coverage to appeal to a broad international market.

With WAAS/EGNOS/MSAS capability, the accuracy of the typical handheld GPS can be of the order of 1 to 3 meters. This level of positional accuracy is more than sufficient for the usual outdoor recreational activities, and allows the application of handheld GPS to general information collection, emergency rescue, prospecting, rapid mapping down to a scale of 1:10,000 and many other higher order tasks.

This paper presents a synthesis of the development of handheld GPS technology. A comprehensive summary of the handheld GPS genre, including classification, major technical and physical specifications, advanced features and accuracies is presented. Several innovative applications are described to illustrate the expanding market for this technology. Finally, further developments and trends are identified.

2. CURRENT DEVELOPMENT OF HANDHELD GPS TECHNOLOGY

GPS Performance

There are many GPS manufacturers, with several specialising in handheld GPS technology, such as Garmin, Magellan and Lowrance (Garmin, 2001, Magellan, 2001, Lowrance, 2001). The product offerings of these companies are a good illustration of the current state of handheld GPS development. The 18 Garmin models summarised in Tab. 1 are a case in point.

Table 1. Typical characteristics of Garmin GPS units

<table>
<tr><td rowspan="2">Model</td><td rowspan="2">Approx. Price (US$**)</td><td colspan="4">Performance</td></tr>
<tr><td>DGPS capability</td><td>WAAS capability</td><td>Antenna</td><td>Interface (besides NMEA0183)</td></tr>
<tr><td>GPS V</td><td>449.00</td><td rowspan="6">YES
Accuracy: 3-5m</td><td rowspan="4">YES
Accuracy: < 3m</td><td>Built in with External antenna capability</td><td rowspan="4">RS232, RTCM 104 DGPS data format and proprietary GARMIN</td></tr>
<tr><td>GPS 76*</td><td>219.00</td></tr>
<tr><td>GPSMAP 76*</td><td>325.00</td></tr>
<tr><td>Etrex Legend*</td><td>225.00</td><td>Built in</td></tr>
<tr><td>Etrex Venture*</td><td>169.00</td><td rowspan="5">NO</td><td rowspan="5">Built in
Built in
Built in
Built in</td></tr>
<tr><td>ETrex Vista*</td><td>315.00</td></tr>
<tr><td>Etrex Camo*</td><td>129.00</td></tr>
<tr><td>StreetPilot III*</td><td>999.00</td><td rowspan="3">Built in with External antenna capability</td><td rowspan="2">RS232</td></tr>
<tr><td>StreetPilot</td><td>399.99</td><td rowspan="10">YES

Accuracy: 1-5m</td></tr>
<tr><td>StreetPilot GPS –ColourMap</td><td>579.99</td><td rowspan="3">RTCM104</td></tr>
<tr><td>GPS III Plus</td><td>289.95</td></tr>
<tr><td>GPS 48</td><td>183.00</td><td rowspan="4">Built in with External antenna capability</td></tr>
<tr><td>GPS 12CX</td><td>244. 95</td></tr>
<tr><td>NavTalk</td><td>399.99</td><td>RTCM and RS232</td></tr>
<tr><td>GPSMAP 175</td><td>399.00</td><td rowspan="2">NMEA 0180/182/ and RTCM 104</td></tr>
<tr><td>GPS 12XL</td><td>194.95</td></tr>
<tr><td>GPS 12MAP</td><td>364.00</td><td>Built in</td><td rowspan="2">RTCM 104</td></tr>
<tr><td>GPS 12</td><td>144.95</td><td>Built in</td></tr>
</table>

*: with Autolocate acquisition time approximately 2 minutes.
** source: The GPSStore (2001) and Navtech (2001)

All of the models in Tab. 1 are 12 parallel channel GPS receivers and can therefore continuously track and use up to 12 satellites to simultaneously compute and update position at one-second intervals if needed. The acquisition times can be as short as 15 seconds (warm) or 45 seconds (cold). The acquisition time with "Autolocate" is approximately 2 minutes (as shown in Tab. 1 with "*") or 5 minutes with Ezinit (easy initialisation) which is 45 seconds (categories without "*" in Tab. 1).

Most recent handheld GPS are differential-ready receivers. With this feature, the positional accuracy of the handheld GPS can be improved from 15m to within 5m when DGPS (Differential GPS) corrections are applied. Of these, those that are WAAS-capable can obtain improved accuracy of less than 3m vertically and horizontally.

Magellan has released its new Meridian series (including Meridian GPS, Meridian Gold, Meridian Marine and Meridian Platinum) and MAP 330 series (including MAP 330, MAP 330M and MAP 330X) with WAAS capabilities. These receivers provide higher accuracy, not only from WAAS signals, but also when receiving correction signals from the EGNOS, which covers Europe. Furthermore, projected specifications for the coming Multi-transport Satellite-based Augmentation System (MSAS) for Asia suggest that upgraded Magellan receivers will work with this system as well (Magellan, 2001)

Navigation Features

Based on navigation features, currently available handheld GPS can be classified roughly into the following four categories:

1. Basic navigation capabilities with a low price.
2. Necessary navigation capabilities with internal database.
3. Enhanced navigation capabilities with internal database and additional information downloading options.
4. Advanced navigation capabilities with built-in maps and additional map downloading options.

2.1.1. Category 1: Basic Navigation Capability at a Low Price

The navigation features in this category include a number of saved favourite locations (called waypoints) and a number of reversible routes with a small number of legs (waypoints) per route (Tab. 2). Typical products of this category include Garmin eTrex, Garmin GPS 12 and Magellan's GPS 310. The distance, bearing, heading, average and maximum speed, trip time, time to destination, elevation, XTE (cross-track error), and even satellite elevations can also be displayed. With these capabilities, the user will know where they are, where they have been, and how to get to where they want to go. Location can be expressed according to an extensive range of coordinate systems compatible with commonly used map products (see Tab. 2). Interesting additional capabilities include sunrise/sunset time (eTrex) and proximity alarms (GPS 12).

Table 2: Comparison of the typical category 1 products

Units	# of waypoints	# of route/ # of waypoints	Max bat. life/# of batteries	PC interface capability	Plotter type	Speed limitation	Co-ord. systems (besides Latitude/ Longitude/UTM)	Price* (US$)
GPS 310	100	1 Reversible /10	20Hrs/ 2 AA	YES	None	951 MPH	OSGB,Swiss,Irish, Swedish,Finnish, French,German	99.95
ETrex	500	1/50	22Hrs/2AA	YES	Track plotter	999 MPH	Maidenhead, MGRS	114.95
GPS 12	500	20 Reversible /30	24Hrs/ 4AA	YES	Track plotter	999 MPH	UPS, MGRS, Loran TDs, Maidenhead & UTM	144.95

* source: The GPS Store at www.thegpsstore.com

2.1.2. Category 2: Basic Navigation Capability with Internal Database

Typical products of this category include Garmin's GPS II Plus, GPS48. GPS12XL, GPS12CX. They feature a database of major cities and/or marine navigation aids regionally or worldwide. For example, the Garmin products contain a database of cities of population more than 200,000 throughout the world, with North American coverage of all cities. City names and locations can simply be displayed on the screen or the user can employ the "spell and find" feature to locate the city from the database, and then navigate to the selected city using the "go to" feature. In addition to city locations, some models can also provide regional navaids (for example, GPS 48 provides navaids within North America) including buoys, racons, fog horns, radiobeacons and daybeacons. Some other innovations such as color screen, different language selections, messages and icons compiling abilities, "zoom in" and "zoom out" capabilities make data management easier and the display more attractive for some models in this category.

2.1.3. Category 3: Enhanced Navigation Capability with Internal Database and Additional Data Downloading Options

Typical products of this category include Garmin' s eTrex Venture, GPS 76 and Magellan's GPS 315 and GPS 320. For example, the eTrex Venture features a built-in Worldwide city point database and can accept up to 1 megabyte of uploadable data from Garmin's optional MapSource "Point of Interest" CD-ROM. With the optional points of interest loaded, the user can make a selection from restaurants, hotels, shopping, entertainment venues, and obtain telephone, address, direction and heading information for the site. Marine data such as buoys, lights, wrecks and obstructions are also included. In addition, some models like Garmin GPS 76, Magellan GPS 315/320 provide tide data for the US, celestial tables for best times to fish and hunt, and sunrise/sunset data.

2.1.4. Category 4: Advanced Navigation Capability with Built-in Maps and Additional Map Download Options

Typical products of this category include Garmin's GPSMAP 76, GPS Plus, GPS 12MAP, eTrex Vista, eTrex Legend, StreetPilot, StreetPilot ColorMap, StreetPilot, NavTalk, GPSMAP 176/176C; Garmin's aviation products like GPSMAP 295/195,GPS III Pilot, NavTalk Pilot; Magellan's MAP 330 series, Meridian series; and Lowrance's GlobalMap 100, Ifinder. These products have a built-in basemap and additional map download capabilities. The built-in basemap typically contains information such as highways, railways, national parks, lakes, rivers, streams, airports/runways, coastlines, U.S. cities, worldwide political boundaries, US Navaids such as buoys, channel markers, lighthouses, wrecks and obstructions. Information can be displayed on customizable graphic navigation screens. The download capabilities enable these products to accept 64 MB or more of map data from MapSource CDs (Garmin), MapSend Streets (Magellan) and MapCreate (Lowrance). Different manufacturers have different software for their products. The coverage of the maps has been extended from the US to North and South America and many countries in Europe and Australia (eg. MapSend Streets Australia CD-ROM for MAP 330). The data includes a

wide variety of information such as street level detail, topographic information, and points of interest. The inbuilt software is increasingly sophisticated with extensive find and display capabilities.

For communication enhancement, units like NavTalk incorporate a fully featured cellular phone. Table 3 presents a comprehensive summary of the navigation features, physical specifications and indicative price of several typical products.

Table 3: Comparison of different products

	GPS 310	GPS-Plus	eTrex Venture	GPS 330	eTrex Vista	GPS V
Company	Magellan	Garmin	Garmin	Magellan	Garmin	Garmin
Price US$	100	195	170	250	350	450
# of waypoints	100	500	500	500	500	500
Routes/legs	1/10	20/30	20/50	20/30	20/50	20/50
Trackpoints	N/A	1024	2048	2000	3000	10 saved tracks (Auto track log)
Basemap	N/A	Database (details)	Worldwide city datsbase	8 MB	US Basemap (detail)	North and south America
Additional map options	N/A	N/A	MapSource Pts of Interest CD (1 MB)	MapSend Streets CD-ROM (8 MB)	MapSource CD-ROMs (24 MB)	MapSource CD-ROMs (19 MB)
Dimensions (cm)	15.7×5.1×3.3	12.7×5.9×4.1	11.1×5.1×3	15.2×5.1×3.3	11.1×5.1×3	12.7×5.8×4.1
Weight with battery	192.7g	255g	150g	198.8g	150g	255g
Battery life	20hrs/2AA	22hrs/4AA	20hrs/2AA	10hrs/2AA	12hrs/2AA	25hrs/4AA
compass & barometer	N/A	N/A	N/A	N/A	Built-in	N/A
Alarm	N/A	N/A	N/A	Yes	N/A	Yes
Celestial info	N/A	N/A	N/A	Yes	Yes	Yes
Hunting & Fishing cal.	N/A	N/A	Yes	Yes	Yes	Yes
Water resistance	Weatherproof /Floats	IPX7	IPX7	IEC-529, IPX2, /Floats	IEC 529 IPX7	IEC 529 IPX7
Coordinate systems (besides: Lat/ Lon, UTM)	OSGB, Irish, Swiss, Swedish, Finnish, French and German	UPS, OSGB, German, Swiss, Swedish, Irish, Taiwan Maidenhead & user defined	Loran TDs, MGRS, and other grids.	OSGB,Irish, MGRS,Swiss, German Swedish, French & User Grid	UPS, Maidenhead, MGRS, Loran TDs, and other grids	UPS, Maidenhead, MGRS, Loran TDs & user grid

2.3 Mapping and GIS Data Collection/Maintenance

The Trimble GeoExplorer 3 illustrates the capabilities of integrated handheld GPS mapping and GIS data collection/maintenance system (Trimble, 2001). It is a high performance 12-channel GPS receiver with an antenna in a compact handheld. It offers portability (20.6 cm ×9.4cm×5.1cm, 0.64 kg with battery) and powerful mapping capabilities.

The GeoExplorer 3 allows the user to map points, lines and areas quickly and easily. Customized attribute data about these features can also be recorded. When combined with Trimble's Beacon-on-belt (BoB) differential correction receiver, the GeoExplorer 3 system becomes a precise differential GPS tool for real-time mapping and maintenance of GIS data without the need for differential post processing. The Trimble GPS Pathfinder Office

software completes the mapping system with data dictionary creation, data processing, and GIS data export and import. It works with the MediaMapper software to link geo-referenced digital photographs to users' GIS and support Shapefile (SHP), MapInfo(MIF), dBase(DBF), and Microsoft Access(MDB). Upload capabilities facilitate efficient data verification and maintenance in the field.

The GeoExplorer 3 is a good solution for mapping and managing spatial data in many applications such as natural resource mapping, environmental studies, and creating and maintaining utility and urban asset databases.

2.4 Combination of Navigation and Survey Applications

In July 2001, Thales Navigation announced the release of the new Ashtech ProMark2 Survey System (Ashtech, 2002). The ProMark2 receiver weighs 0.14kg only with a palm size (15.8cm 5.1cm 3.3cm). It costs US$4,000 for a 2-receiver configuration with software. With 10 independent channels and L1 C/A code and carrier data storing, the ProMark2 delivers a combination of post-processed, centimeter-level static survey capabilities with stand-alone, real-time, sub-3-meter (by the use of correction signals from WAAS/EGNOS) reconnaissance, navigation and mapping capabilities, all in a single system. With ProMark2, the user can operate in dual modes: navigation and survey applications, at a high accuracy (Static Survey: 0.005m+1~2ppm, Azimuth: < 1 arc second; Real-Time with WAAS: 1 second position fix ~3 m with Ashtech ProAntenna and 5 m with internal antenna).

In navigation mode, the built-in map database includes United States' city streets, roads, highways, waterways, railways and more. Other parts of the world are represented with maps of coastlines, country borders and major international cities. Additional U.S. street detail is available by downloading data from Magellan MapSend Streets software. In survey mode, using the new Ashtech ProAntenna and Ashtech Solution L1 Processor, the ProMark2 can be used as a precise survey system utilizing three or more receivers for added productivity.

3. MAIN APPLICATION AREAS

Handheld GPS have been used for a variety of applications on land, at sea and in the air. Figure 1 summarizes the main application fields of handheld GPS.

The following brief descriptions illustrate the diversity of region, type of application, and level of integration supported by handheld GPS:

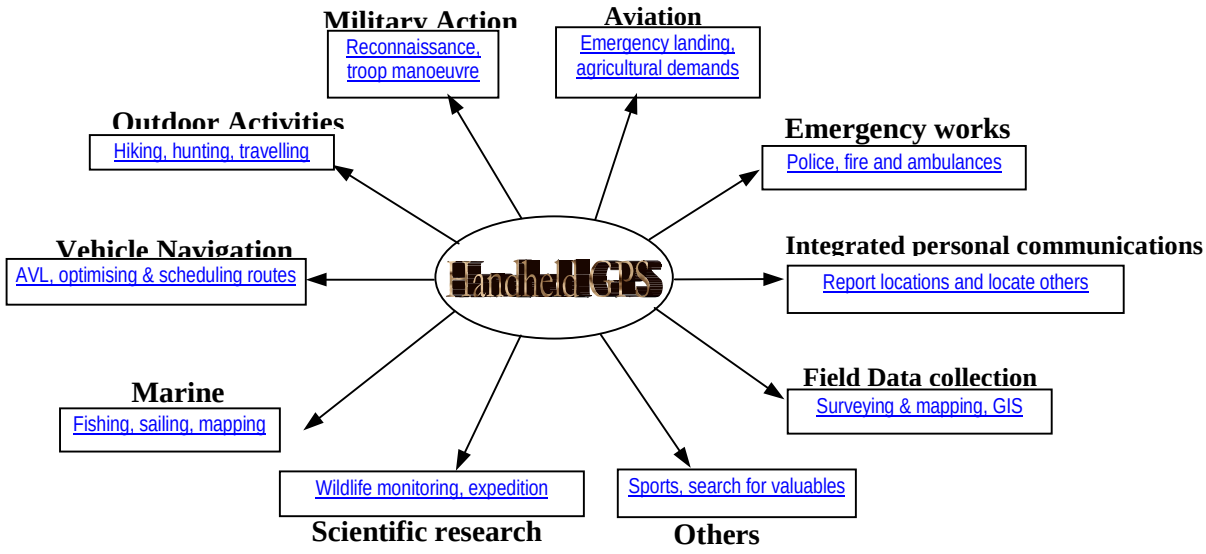

Figure 1 Main application areas of the handheld GPS receivers

Wildlife Monitoring

As early as 1993, a team of wildlife research scientists used the Garmin GPS 100 to conduct snow leopard research in Mongolia (Garmin, 2002). It is impossible to track the snow leopards with traditional techniques since the snow leopards have a territorial range of approximately 600 miles. Little concrete information on snow leopards, present status, range, and abundance was known, and knowledge regarding their social behavior remained incomplete. The scientists used the handheld GPS to track snow leopards, survey their territories, calculate movement and interaction with their surroundings, and evaluate areas to establish additional reserves. The handheld GPS became an indispensable tool for them working in poorly mapped regions such as deep, narrow valleys, and gorges in temperatures as cold as -25°.

The commercial development of GPS-based telemetry systems for tracking animals began in 1991 (Rodgers, 2001). Since then a variety of configurations have been designed for use by researchers in different environment. The newest version of the GPS-Collar has a revolutionary modular concept combining both GPS receiver technology and data communication. Handheld GPS receivers is used as a ground station in the latest high performance GPS collars developed by the VECTRONIC Aerospace GmbH and Environmental Studies, (Schulte and Fielitz, 2001). The handheld ground station can receive the last computed GPS position of the collar and calculate the direction and distance to the collar with its own GPS receiver. The combination of the GPS collar and the handheld GPS make the animal tracking more efficient especially in remote areas with abominable weather conditions and forbidding environment.

Scientific Exploration

A team of scientists reportedly used Magellan ProMark X-CP hand-held GPS receivers to find meteorites in Antarctica (Magellan, 2002).

Antarctica is one of the most abominable places. For searching for widely scattered meteorites as small as a quarter of an inch on a featureless ice sheet over areas of high meteorite concentration as large as 100 miles, the Antarctic Search for Meteorites Project (ANSMET) team members had to work in temperatures as low as -25°, and storms with winds in excess of 200 knots that can last six to seven days. The team fulfilled most of its surveying work with the help of the all-weather navigation and location capability function. They stored in the receivers the locations of each finding. Then maps of the area were produced for the team to study meteorite occurrence patterns and return to those locations for future exploration. Furthermore, the ProMARK X-CP receivers can also enable the team members to find their way back to camp during a blizzard or determine their position in case an emergency rescue was required.

Synthetic Speech Integration

The visually impaired are using handheld GPS to achieve levels of mobility not previously contemplated, using digital talking map software called GPS-Talk, which allows an electronic map to "talk" through a software speech synthesizer. Before leaving home, the user creates routes using GPS-Talk software on a special computer adapted for the visually impaired. When going out for a walk or heading for a business appointment, a backpack holding a laptop computer is connected to eMap-a Garmin handheld GPS, together with earphones and a numeric keypad. The keypad is used to access information and execute functions on the GPS, and information is relayed through the earphones indicating which way to start walking, how far to proceed and how to come back home. It even announces streets and intersections as they are approached (Garmin, 2002).

Integration with Other Systems

The Trimble' CrossCheck AMPS/GSM/XR is typical products which integrate with other systems into a single, low cost mobile positioning and communications unit (see Fig 2). The CrossCheck AMPS integrates GPS, computing technologies and wireless cellular into a single mobile system. It uses the standard wireless AMPS cellular network to send GPS data and messages from mobile units to base station. While the CrossCheck GSM integrate GPS, computing technology and GSM into a single mobile system. It can send GPS data and messages from mobile units to base stations and also receives messages sent from the base station. Additionally, the CrossCheck RX integrates GPS, computing power and transparent protocol support into a mobile system for fleet management.

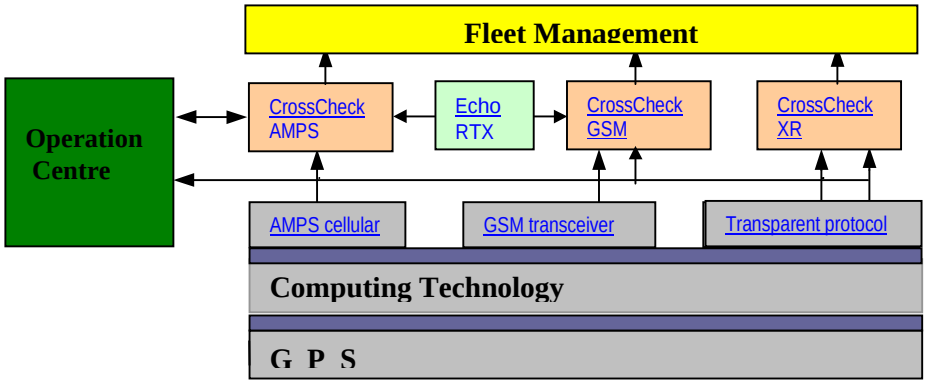

Figure 2 The Trimble's fleet management mobile unit (CrossCheck) systems

With its coming along IQEventEngine the system can provide improved security, efficiency, and lower operating costs through intelligent, configurable event and position reporting and datalogging. Users can easily configure its firmware for most common operating scenarios by using the CrossCheck IQEvenEngine Configuration Toll.

Asset management Asset monitoring and control are enhanced with the systems by using operating events (e.g.: trailer connect, ignition on/off, out of area) and discrete inputs to notify an operations center of abnormal vehicle activity. Driver, vehicle and cargo security are enhanced using security events (e.g.: out of area, motion detection) and discrete inputs to alert an operations center of unauthorized activity. The mobile communicator also provides discrete outputs to activate vehicle security peripherals, for example, ignition lockout or audible alarm.

Route management The systems can continuously record position, events, and vehicle status. The data can be transmitted immediately over-the-air or stored for downloading later for further analysis. That will improve route efficiency and customer service.
Consumer application The systems also provide the foundation for consumer service like roadside assistance, stolen vehicle recovery, remote locksmith and so forth.

4. FURTHER INNOVATION OF HANDHELD GPS

It can be expected that handheld/micro GPS will continue to flourish in the coming decade. For increasingly mobile consumers and enterprises, "where" and "how to" are quickly becoming as important as "what" and "how much". Handheld and imbedded GPS will contribute significantly to these demands.

The 1999 European GPS market is summarized in Figure 3, and the market prediction for 2015 in Figure 4 reflects what is expected with the GNSS (Global Navigation Satellite Services) in the next fifteen years. (DG-TREN, 2001). These analyses indicate that GPS will play a more and more active role in future applications involving personal outdoor recreation, trucks and buses, police, fire and ambulances, integrated personal communications and cars.

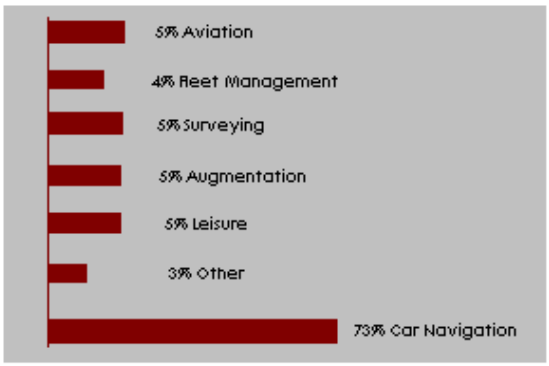

Figure 3: European GNSS Market 1999

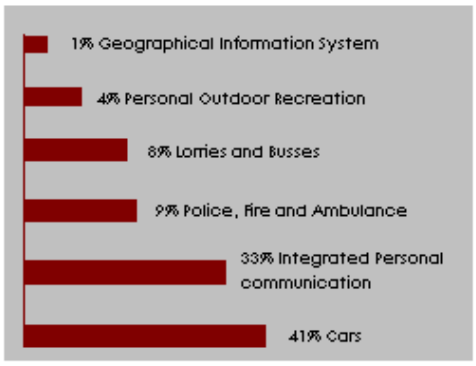

Figure 4 Breakdown of predicted European positioning market in 2015 by applications

To meet the challenges of diverse applications and a broadening market, the handheld GPS must continue to evolve. In this scenario, we use the term handheld to include increasingly miniaturized devices which are in fact wearable and imbedded in other devices. Likely innovations will include:

Process weak GPS signals Most of the recent handheld GPS are 12-channel parallel receivers with rugged design which provides quick satellite acquisition and enhanced all-weather reception. GPS signals can be received under moderate tree cover, and foliage. In the future, handheld GPS need to function reliably at home, the office, shopping malls, multi-story car parks, and urban canyons.

In addition, future handheld GPS will not only receive signals from existing commercial real-time DGPS correction services and government organizations, but also signals from the proposed European Galileo system.

Integration with other systems These will include GSM (GPRS, UMTS), ORBCOMM**,** Internet and other 3G wireless communication systems.

Combine functionality Single units will provide the existing functionality of a cellphone, PDA, personal navigation assistant, and Internet browser. The worldwide forecast of 852 million cellular phones by 2003 provides an expectation of mass-market, ubiquitous personal GPS positioning.

Full compatibility The implementation of the Bluetooth communication protocol and open software standards will facilitate seamless interaction between GPS and other devices. It can also be expected that accessories like external antenna, battery charger and memory card will be standardized for the convenience of customers.

Reduce power consumption Lower power consumption will be achieved, even though the manufacturers have already made significant progress to extend battery lifetime. Smaller, more efficient power sources will facilitate further miniaturization.

Reduce size and weight Current production GPS chipsets have a footprint of only several square millimetres. GPS are already imbedded in watches. Limiting factors in size and weight for other applications are predominantly interface ports, graphic displays, antenna and power sources. Innovative design and development will be required to move to ubiquitous wearable GPS.

Reduce price As GPS becomes a mass-market technology, prices for chipsets can be expected to decrease substantially. The expectation of the OEMs and the wireless manufacturers is that GPS functionality should cost no more than US$2 (Richardson, 2001) but we are currently a long way from this level of production.

5. CONCLUSIONS

After more than a decade of development, the handheld GPS has become an advanced, multi-functional navigation and mapping tool. There are a broad range of models with diversity of features, functionality and price. The handheld GPS has been widely used in a variety of applications in the air, on land and at sea.

In the coming decade, as GPS is further integrated with other systems and devices, its applications will be further enhanced and become increasingly sophisticated. Combining with the functionality of modern technologies such as Internet and wireless communications, at an affordable price for the general public, the handheld GPS will play an important role in the information era.

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