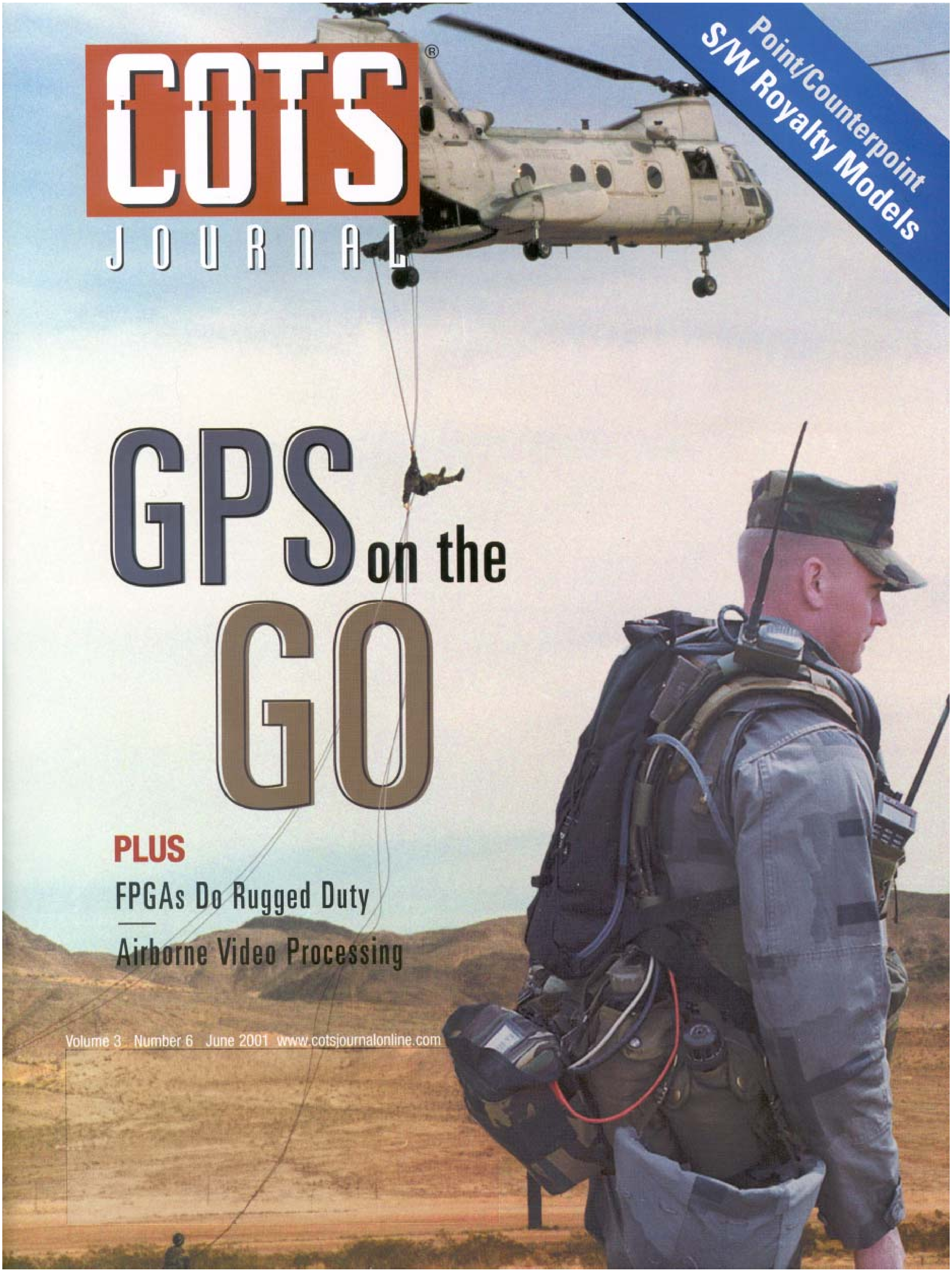
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GPS: A Military Technological Wonder the World over

Originally developed for the U.S. military, GPS is used ubiquitously worldwide. Moreover, while the military spawned the commercial and civilian markets for GPS, COTS uses have now provided "spin on" benefits back to new military users like the U.S. Marine Corps' Urban Warrior program.

Doug Stead, President and Founder
Tri-M Systems

Owned and operated by the U.S. Department of Defense, the Global Positioning Systems (GPS) infrastructure cost over $ l 2 billion since its inception, had its satellites first starting deployment in the mid-1970s and reached its full-operational capacity in July of 1995. The program's primary purpose was and is to meet the navigational requirements of all branches of the U.S. defense for a global, all-weather, 24-hour: precision navigation system.

By design, a provision was also made for use by civilians. Today the number of military GPS receivers is dwarfed in comparison with the millions and millions of civilian receivers in use throughout the world. Clearly, GPS was and continues to be a very important American national technological asset, because what was once originally military technology has "spun off" to the commercial world, which now provides COTS products back into defense applications.

But perhaps more important, the development and implementation of GPS provides such tremendous benefits and services as the world's first freely usable, worldwide, ubiquitous utility. it's created its own paradigm shift—rivaled only by the Internet—in its benefit to the ordinary man. How can this be?

Figure 1

A collection of readily available COTS Global Positioning System (GPS) hardware. This is an assortment of handheld receivers from Garmin and Lowrance, together with a collection of Tri-M magnetic and bulkhead-mounting Mighty-Mouse 1 & II and Skymaster active antennas. Also shown are two OEM GPS receivers, an electronic compass and a Differential GPS (DGPS) and Coast Guard data correction beacon receiver. Note that the center middle antenna was adopted by the U.S. Marine Corps' Warfighting Labs that deployed more than 900 of these units to collect tracking data on individual soldiers involved in large-scale training exercises.

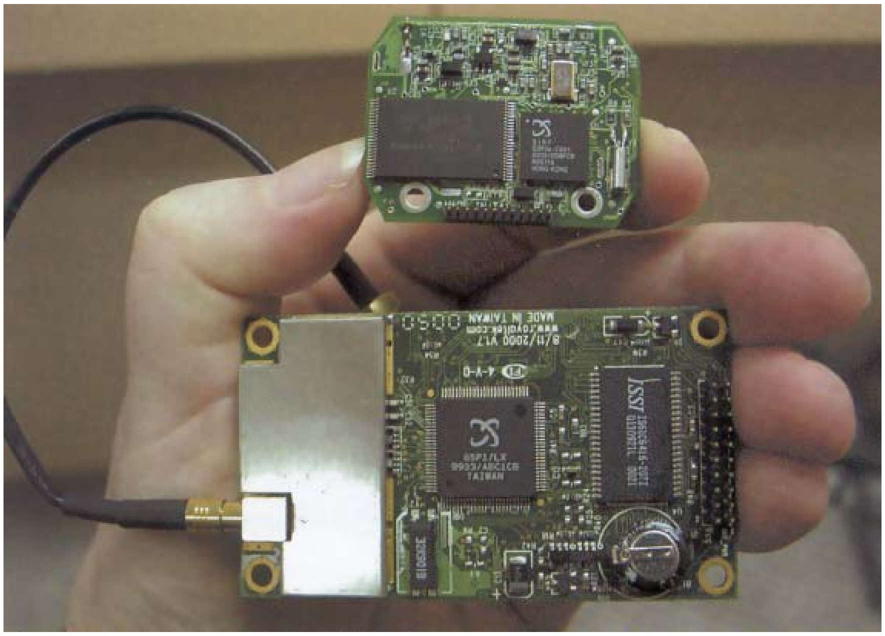

Figure 2
The two GPS receivers in the hand show the progress made during the last 18 months in this arena. The larger unit is an REB12R (71 x 41 x 7 mm) 12-channel receiver that's DGPS-ready, and the smaller unit is an REB2100 (40 x 31.5 x 6.5 mm), weighing a miniscule 8.6 grams. Both receivers will re-acquire a satellite signal lost because of the effects of urban canyon or foliage environments in an incredible 0.1 second. Amazingly, both of these OEM receivers are priced below $100 in small quantities.

COTS Market Forces

In addition to the military use of GPS equipment, this technology has also been widely adopted by business, science and industry—to say nothing of its acceptance by the general public for recreational uses. With the demand for this kind of accurate data in so many applications, GPS receiver technology has become so inexpensive that most people can afford to purchase a GPS receiver. GPS hardware technology has matured to the point of becoming a commodity component (Figure l). In 1996 the entire GPS industry generated about $1.5 billion in revenues, but it's expected to explode to an estimated $10 billion by the end of the year 2001. Examples of some of the major market segments include:

- **OEM**: Where Value-added Resellers (VARS) and other product manufacturers of all types design in component GPS receivers into products.

- **Aviation**: Commercial and general.

- **Marine**: With both a commercial sector of 11 million registered vessels and a recreational market that's considerably larger in opportunity size.

- **Surveying and mapping**: Which has been revolutionized with millimeter-accurate GPS survey equipment.

- **Consumer handhold and PCMCIA notebook markets**: Where prices have plummeted from the first commercial handheld GPS receiver in 1989 that sold for $3,000 to today's price of $199 or less (Figure 2).

Figure 3
Tri-M will soon release the REB2200 from Royaltek, an amazingly small, 23- x 23- mm, 3.3-V DC, 12-channel GPS receiver that's also DGPS- and WASS-capable.
It's shown here with Tri-M's Micro Skymaster on top, an active ceramic patch GPS antenna built around a 24-dB gain low-noise amplifier that consumes only 11 mA.

- **Automotive GPS market**: So large that it's really a market all on its own. It consists of two major subsegments: "In-Vehicle Navigation" that allows drivers to navigate by means of in-dash displays and in-vehicle map/routing databases and "Fleet Management and Automated Vehicle Location" (AVL) systems that track and manage everything from pickups and deliveries, vehicle maintenance, routing, security, fuel consumption and even driver payroll.

GPS Infrastructure

There are 29 GPS satellites (including several spares) currently in orbit around the earth. Each is orbiting the earth at a minimum of 10.600 riles above the surface, and each circumnavigates the earth every l2 hours. These satellites have been placed in orbit so that from any given point on the earth's surface, a minimum of four satellites will be in view above the local horizon.

Each satellite has an extremely accurate atomic clock together with a computer and a radio. Each satellite keeps track of its own orbit and position and continually broadcasts its status, position, ID and time signal. This allows intelligent GPS receivers, such as the postage stamp-sized Royaltek REB2100, to solve four equations to determine latitude, longitude, height and time, instantly (Figure 3).

A GPS receiver computes its location by "triangulation" using the position and bearing information from a minimum of 3 to as many as 12 satellites. This makes it possible for anyone with a low-cost handhold GPS receiver to pinpoint his or her exact geographic location. Military GPS receivers (PY code-capable) are accurate to sub-5 meters. Nonmilitary (CA code) receivers, until recently, produced location accuracies of 100 meters Circular Error Probability (CEP), 95% of the time. On instruction from the U.S. Congress, Selective Availability (SA), the intentional introduction of random dithering, was recently turned off. COTS GPS receivers are now able to produce (X, Y) coordinates in the sub-25 meter accuracy range. This effectively enables anyone with a very inexpensive GPS to locate themselves on most common scale maps to better than a pencil point. Keep in mind that the standard GPS output from the least expensive receiver is still much more accurate than most maps in use today.

Many civilian GPS applications such as emergency vehicle tracking or aircraft landing systems, often require great accuracy. Over the years, numerous methods have been developed to increase the accuracy of the standard COTS GPS receiver and thereby circumvent the factors that introduce calculation errors, including those produced by SA. Two of the more common methods used are Differential GPS (DGPS) and Wide Area Augmentation System (WAAS).

Both these methods work by providing the standard GPS receiver with a supplementary stream of known good data. The GPS receiver then uses this data in conjunction with the satellite data stream to remove errors effectively resulting from SA, precision trigonometric rounding (the tiny mathematical rounding errors introduced by triangulation calculations) and atmospherics (tiny time differences caused by EM waves traveling at different speeds through the atmosphere). This thereby improves accuracy to sub-5 meters for GPS and sub-2 meters for WAAS.

When a GPS receiver locks onto a minimum of three satellite signals, it can calculate a two-dimensional (X,Y) latitude and longitude location. With four or more satellite signals, the GPS receiver can also calculate altitude giving a three-dimensional (X, Y and Z) location. Whether man-packed or vehicle-mounted, the moving GPS receiver can also provide information on ground speed: heading, number of satellites, UTC (translated to "Coordinated Universal Time") and local time/date information.

With this information, the GPS receivers can also calculate myriad other useful information, such as crosswinds, tides, flows, drift, acceleration and deceleration, to name just a few. Add this data to other known geographic information, and it's possible to predict a wide variety of future events easily and very accurately including estimated time of arrival (ETA), point of no return, time to alternate and fuel burn.

ASCII output

Most OEM GPS and the better handhold receivers provide usable data output in the form of a once-per-second serial data stream. These l Hz serial data messages are usually output in one of two protocols: an industry standard called NMEA-0183 or the manufacturer's own proprietary binary interface. NMEA-0183 from the National Marine Electronics Association sets the standard for electrical and data protocol interfaces in marine instrumentation. Though it's a protocol that predates the development of GPS but one that has allowed earlier navigational technologies to talk with each other it became a natural for all GPS manufacturers that supported this NMEA standard.

To better understand the type of information being produced by the GPS receiver, it may be helpful to look at one of the many standard NMEA-0183: message strings. The data output from a GPS receiver is via a serial link at 4,800 baud, 8 bits, 2 stop bits and no parity bit. All characters in a NMEA message are ASCII text, with the exception of the carriage return and line feed that is used as a message delimiter.

Each sentence starts with a "$" followed by a two-letter "talker ID" and a three-letter "sentence ID," followed by a number of data fields separated by commas and terminated by an optional checksum and a carriage return/line feed. A sentence may contain up to 82 characters including the "$" and CR/LF.

One of the most commonly used NMEA messages is called "Global Positioning System Fix Data" (GGA). A typical GGA may look like the following:

U.S. Marine Corps' Urban Warrior

Though "commoditized" by COTS civilian markets, GPS remains a military asset that's become critical, not just for precision avionics guidance systems but for the forwardly deployed soldier in both the Army and Marine Corps. The fact that U.S. Marines are affectionately (and respectfully) called names like "jungle snake-eater" or "desert dog-face" belies the fact that Marines are often the first called for deployment into hostile situations in which they risk their lives in the service of their country. Despite the sometimes last-minute nature of their missions, a marine leader must still meet the mandated objectives and efficiently prosecute the assigned task.

To do this requires an accurate understanding of the problem and the tactical situation, together with the capability, availability and exact location of the men and resources available. And the chances for a mission's success are made all the better if the commander can receive information dynamically and in real time through to mission conclusion. It goes without saying that given this information and its intelligent use, lives and resources will be saved while minimizing the risk of failure.

Deadly force commanders in our technologically bound era will soon have access to this data, thanks to advances in GPS and wireless technologies that help to build their situational awareness. In addition to better command decisions, a reduction in friendly fire, unintended collateral damage and civilian casualties may be minimized as the chaos of action is more easily interpreted.

```
GGA,123519,4807.038,N,01131.324,E,1,08,0.9,545.4,M,46.9,M, , ,
```

Where:

Data	**Descriptive field meaning**
`GGA,`	Sentence name in this case = Global Positioning System Fix Data
`123519,`	Fix taken at 12:35:19 UTC
`4807038, N,`	Latitude 48 deg 07.038' North
`01131324, E,`	Longitude 11 deg 31.324' East
`1`	Fix quality: 0=invalid, l=GPS fix, 2=DGPS fix
`08,`	Number of satellites being tracked
`0.9,`	Horizontal dilution of position
`545.4, M,`	Altitude, Meters, above mean sea level
`46.9, M,`	Height of geoid (mean sea level) above WGS84 ellipsoid
(empty field),	Time in seconds since last DGPS update
(empty field),	DGPS station ID number

The ICON system developed by SRI International is a Tactical Command and Control system that provides this vital in situ information where and when it's needed. As a primary contractor for the U.S. Marine Corps, SRI was tasked to develop, manufacture and deploy a wireless real-time tracking system to be used in large-scale training exercises.

The system as deployed kept track of each of the over 900 individuals and vehicles participating in a 3-day exercise code-named “Urban Warrior,” run in Oakland, California. SRI’s INCON system simultaneously collects, monitors, displays and logs near-real-time movements of all Marines and vehicles involved in the operation.

INCON'S main objectives, aside from after-action analysis, are to turn a massive amount of data into useful and timely information for all levels of the chain of command. The location of any asset or group of assets is displayed as overlays on a computerized map or maps, appropriate and usable to each level within the command chain. The system allows from Corporals to Generals to see and react with tactical commands within their area of responsibility.

The INCON system comprises two elements: the Integrated GPS Radio System (IGRS) and the command and control infrastructure. IGRS is worn by each user and consists of a very small computer, two-way digital communication system, GPS receiver, GPS antenna, an LCD display for text massaging together with a location indicator with push-button query and acknowledgement functions (Figure 4). These units were integrated with the standard MILS laser vest system. In addition, some IGRS units also provided an interface to capture and report digital camera images or laser ranging systems.

The IGRS unit is essentially a wearable integrated computer, GPS and wireless communication link interfaced to a MILS laser system. This IGRS function is to provide status and position data from a single soldier or vehicle up the chain of homeland. It also allows for two-way digital communication and receiving of digital messages including differential (DGPS) correction data, text massaging of orders and acceptance confirmation, along with bi-directional notification of a training “kill” by both direct or indirect simulated fire.

In addition, the IGRS unit is also capable of continuing to track each soldier even when individual soldiers enter suitably instrumented multistory buildings that GPS satellite signals can’t penetrate. Each IGRS man-pack also incorporates an ultrasonic transponder system that continues reporting its location as the soldier moves from room to room and floor to floor.

The data from each IGRS is transmitted via a digital wireless radio to the second element, the INCON command and control infrastructure, which is composed of two base stations, a wireless digital gateway and a redundant Data Collection Systems (DCS) storage and backup system. The base station transmits back to each IGRS unit a DGPS correction data package together with a synchronization pulse that then causes the IGRS to transmit its status message, including the position information.

Because each IGRS unit is able to use DGPS information, resolution accuracy averaged sub-2 meters. This information is available both in real time and for after-action review and analysis for display on computer screens with a map-based geographic situation display. This easy-to-read, easy-to-understand map displays the position of each individual and provides commanders with a familiar background for quickly understanding the unfolding situation.

In addition, a customizable, intuitive user interface allows users to sketch and distribute reconnaissance and logistics plans quickly and to issue and execute orders from any portable computer tied into the INCON system. Furthermore, the system also stores all data to multiple database servers, and data replication maintains data integrity and consistency while allowing post-operation review, debriefing and analysis.

Examples of ways commanders may use the INCON/IGRS wireless communication structure may include “Chemical Weapons detected. Go to MOPP-4. Press 1 when at MOPP-4.” Or perhaps “Incident in NW quadrant, link up with Charley Patrol hill 788.” or “Return to base; press 4 to acknowledge.” The IGRS user has three choices of warning of an incoming message: vibration, buzzer or flashing light. The message display also has four membrane keys that can be pre-programmed with short text replies or requests such as “sit rep: All’s quiet; proceeding with mission.” or “EMERGENCY send help NOW!”

A direct and very important benefit to the ICON-equipped digital solder of the future will be

Figure 4
At slightly less than 11 lb, the IGRS/MILS unit is intentionally weighted to simulate a full ammunition load in addition to performing as a bi-directional digital gate to the Marine.

the system's capability to report real-time heath monitoring of the individual soldier. Reporting and tracking this valuable data will allow future commanders to see life vital signs, such as respiration, body temperature, blood pressure and blood oxygenation. This information will not only give the force commanders the ability to judge remaining endurance of his human resources more accurately but may also provide an early warning of chemical or biological toxins being deployed in the area of operation.

However, the real benefit to the soldier of tomorrow will be for the medical monitoring staff to be alerted when individuals are injured. They'll be notified of the exact location and will be capable of routing medics to treat and recover the injured soldier, even if the soldier is alone and unable to request assistance. This technology advancement is inextricably linked to GPS and, once deployed, will continue to reduce battle mortality rates in much the same way as the helicopter and MASH units have in the past.

Tri-M Systems joined SRI as a supplier technology partner. Because a majority of IGRS units are battery operated and man-packed, significant engineering effort was expended to achieve 24-hour operation on a single set of 8 standard alkaline “D” cells. Because the GPS receiver also had to acquire and keep locked on satellites in both an urban setting as well as a jungle canopy, SRI selected the Tri-M Mighty-Mouse antenna. This antenna produces 28-dB gain while consuming less than 11 mA at 5-V input, a reduction in power consumption of 50% in comparison with its product peers at the time.

The balance of the IGRS unit consisted of a low-bandwidth VHF radio, a Canadian Marconi GPS and an SRI custom-designed microprocessor board that managed bi-directional radio communication using a time-sliced multi-access protocol. All communications are carried out using standard Internet Protocol (IP) addressing, which allows the system to be easily integrated into almost any existing computer networking system. The ICON system is currently under review and test with the Royal Canadian Mounted Police (RCMP) to be used by their Emergency Response Teams.

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GPS Creates a Good Career

The future for GPS technology continues to expand at an exponential rate as more and more products supplement their primary functions with accurate position and timing data. This explosion of time and location data has fostered one of the hottest new post-secondary degrees: Geodesy and Geomatics Engineering.

Graduates bearing this parchment are being courted and snapped up prior to graduation. Two universities at the cutting edge of this profession are:

- The university of New Brunswick, Faculty of Engineering (see [http://www.unb.ca/GGE]), headed by Dr. Richard Langley, Professor of Geodesy and Precision Navigation

- The University of Calgary, headed by Dr. K. P. Schwarz, Professor of the Department of Geomantics Engineering (see [http://www.ensu.ucalgary.ca/])

For those no longer young enough to study and earn a degree in this science, a very good practical source of information on GPS, software and maps is posted and maintained by Joe Mehaffey and Jack Yeazel. This information can be found at [http://joe.mehaffey.com/].