

GPS Industry Prepares for Boom

The fledgling industry surrounding the Global Positioning System is poised for explosive growth over the next four years, owing in large part to continuing technological advances and a growing number of potential commercial and consumer applications. Commercial GPS products are expected to reach at least \$5 billion—perhaps even twice that—in annual sales by the year 2000, creating some 100,000 jobs in the process, many of them in high-technology areas that employ PhD physicists. Some experts predict that the GPS industry will eventually eclipse communication satellites in the commercial use of space.

The phenomenal success of GPS is a classic example of how military technology can translate into civilian applications. Developed and deployed by the U.S. Department of Defense, the complete GPS consists of a constellation of 24 satellites orbiting the earth twice a day at an altitude of 12,000 miles, as well as five ground stations to monitor and manage the satellite constellation. Although the system has been in use to some extent since the first operational prototype satellite was launched in 1978, the signal's availability to civilians was limited to just a few hours a day at first, increasing gradually until GPS was declared fully operational in December 1994.

How it works

Using atomic clocks and location data, GPS satellites transmit continuous time and position information 24 hours a day to a GPS receiver, which listens to three or more satellites at once to determine the user's position on earth. By measuring the time interval between the transmission and the reception of a satellite signal, the GPS receiver calculates the distance between the user and each satellite, and then uses the



Biologists in Brazil use the Magellan NAV 5000 PRO in wildlife research projects in a lowland region called the Pantanal.

distance measurements of at least three satellites to arrive at an accurate position.

Signals are broadcast over two frequencies of different wavelengths, generated synchronously so that a user who receives both signals can directly calibrate the ionospheric group delay and apply appropriate corrections. The civilian frequency contains a clear acquisition code broadcast at a bit rate of 1.023 MHz, providing accuracy of 25 meters or so, although accuracies in the centimeter range have since been achieved using differential measurement techniques.

An encrypted pseudo-code is broadcast over both frequencies at a higher bit rate of 10.23 MHz, and is reserved for military use. In addition, civilian GPS receivers are sometimes subjected to selective availability interference by the U.S. Government, which inserts random errors into the data transmitted over the civilian frequency, thus reducing accuracy to maintain military security.

Breakthroughs

Military applications of GPS include mine sweeping, aircraft landing, and infantry operations, the effectiveness of

which were clearly demonstrated during the Gulf War. However, commercial and consumer applications are far outstripping military uses. Civil GPS sets currently outnumber military sets by more than 10 to 1, and that ratio will continue to increase.

"I think the key is that the military GPS technology has become affordable for commercial industry," said Dick Johnson, director of engineering and planning for driver information systems in Rockwell International's automotive division. Technological advances in the semiconductor chip industry (especially the development of VLSI technology)

helped reduce the size and cost of the devices. The first GPS receiver for civilian use, available in 1984, retailed for \$150,000 and required two men to carry it onto the survey field. The first hand-held units appeared in 1989, priced at \$3,000. By 1995 the price had dropped to approximately \$200 per unit.

According to Charles Trimble, president and CEO of Trimble Navigation Ltd, the development of other breakthrough technologies in the 1980s also contributed to the current boom in commercial and consumer GPS applications. They included differential and carrier phase measurement techniques, the demonstration of real-time kinematics, and dual-frequency GPS receivers.

From its inception, GPS has been able to pinpoint locations to within 100 meters using the civilian frequency, but some precision applications require a greater degree of accuracy. The 1980s saw the development of a technique called differential GPS, which uses ground stations as additional reference points. DGPS cancels out pesky errors that result from delays caused by Earth's ionosphere and atmosphere, as well

as from selective availability, providing civilian users with improved location accuracies of about one meter.

Researchers also demonstrated the successful application of real-time kinematics to GPS receivers. Around the same time, the first dual-frequency GPS receivers appeared on the market. These devices use a squaring technique to reconstruct the carrier signal on the restricted frequency and create a difference frequency with a broader wavelength, making it easier to track the signal and reacquire it rapidly after interruption. These advances enabled the development of the first portable devices, which today are capable of maintaining centimeter accuracy in a moving environment.

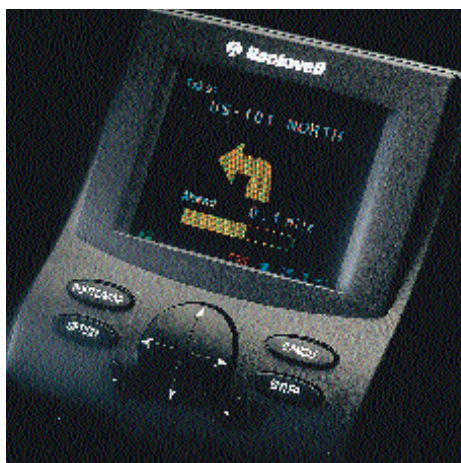
Commercial markets

Only a handful of companies are major players in the GPS industry, according to Michael Swieck, executive secretary of the U.S. GPS Industry Council, and most of them are growing 20–40% annually. Trimble Navigation leads the overall GPS market with annual sales of more than \$150 million, specializing in highly accurate electronic systems for surveying applications. Ashtech also specializes in surveying applications. Magellan Systems Corp dominates the market for hand-held units, while Rockwell International is the clear leader in the military market.

GPS receivers were first used commercially to recalibrate the positioning systems used by offshore oil companies. They quickly found application in surveying, and today they also have widespread use in military, marine and aviation applications.

One of the most exciting research areas for physicists lies in the refinement of carrier phase measurement to eventually produce improved accuracies in the millimeter range, according to Sergei Gourevitch, a former particle physicist who is now chief scientist for Ashtech Inc. Using double difference, the technique measures the phase of the actual carrier signal, accumulating data over time to gradually refine the estimate.

The resulting high-precision measure-



ments make GPS solutions particularly attractive to ionospheric physicists, who use GPS for atmospheric studies, and to geophysicists, who apply it to earthquake monitoring and measuring continental drift. Trimble foresees GPS being used to control heavy machinery in construction and agriculture, and in municipal emergency response and fleet tracking systems.

The greatest excitement over the potential of GPS applications centers on the consumer market. In the last few years, there has been a very large increase in the use of GPS devices for recreational purposes, including hiking, mountaineering, hunting, fishing, boating, diving, and even playing golf. Fishermen use the GPS system to return to fertile fishing holes, for example, and golfers use it to pinpoint the location of their golf carts in relation to the tees.

The increase in consumer applications is aided by the availability of smaller, low-cost receivers such as Rockwell's NavCard, a five-channel GPS receiver that can track up to nine satellites and is contained in a Personal Computer Memory Card International Association (PCMCIA) type II format. This year the company came out with a low-power alternative that can reduce the receiver's average power consumption to less than 650 milliwatts using the company's state-of-the-art digital/analog technology. Ashtech announced a joint effort with Phillips Semiconductors in September to develop a user-friendly, two-chip GPS chip set intended for use in cellular phones, automotive navigation units, and other wireless technology applications. The set consists of a radio-frequency front end chip and a baseband chip with an embedded processor.

The most recent consumer market to flourish is passenger vehicle navigation. Although initially available as an added luxury feature at a cost of about \$3,000, this application, in the view of some analysts,

will become the most pervasive commercial use of GPS. General Motors Corp introduced the first vehicle navigation system in 1993, and soon after Magellan signed a contract to supply three Japanese automakers with the electronic devices for a navigation system. Rockwell does the same for Oldsmobile, as well as Avis and Hertz rental car companies. The availability of high-quality road databases is key to further expansion in passenger car navigation. Detailed map databases are currently available only for major metropolitan areas. GPS manufacturers are working with outside vendors to develop an intelligent vehicle highway system that stores all the national highway roads on CD-ROM, combining that with auxiliary databases tailored to specific geographical regions.

Related software

GPS is also fostering growth in related software products for generating computerized maps, known as geographic information systems. The clear global leader in this market is ESRI, Inc, based in Redlands, California, with 1993 sales of \$120 million. The company's software packages are used by oil firms to create detailed geologic maps for exploration, by railroads for monitoring track conditions, and by geologists to track the aftershocks of earthquakes.

Ashtech manufactures database manager software and a number of software packages designed to meet specific needs in the surveying and navigation sectors. Rockwell developed its CityTracker software for GPS receivers to improve solution stability during urban navigation, since the increase of interference from buildings and underpasses, for example, can cause "jumps" on the navigation screen.

"The GPS is one of the greatest success stories of all time; it's becoming a household word," said Tom Hunter, Ashtech's vice president of sales. "But we in the industry need to work very closely with Washington to ensure that as the industry itself moves forward, it remains consistent with the overall philosophy and policy of the U.S. Government." □