Intelligent Navigation

Farrell named global navigation leader, road testing intelligent navigation on CA roads

When blizzards strike the Sierra Nevada Mountains each year, highway access is cut off for months at a time as snow plows cannot find the buried highway. Electrical Engineering Professor Jay Farrell is working with Caltrans to keep the passes clear using Global Positioning System (GPS) and inertial navigation technology.

His work on intelligent added navigation systems has earned him a place on GPS World's list of "50 GNSS Leaders to Watch" (May 2008). GNSS (Global Navigation Satellite System) refers to the various satellite systems designed over the last few decades: GPS (USA), GLONASS (Russia), Galeleo (Europe), and Compass (China).

Farrell and his graduate students have been working with Caltrans for 12 years to develop reliable navigation systems with centimeter accuracy for vehicle control and guidance. Their navigation system combines high-resolution GPS positioning with magnetometers and inertial sensors to name a few. The work has received interest and funding from the U.S. Department of Transportation and the Federal Transit Administration.

In the coming year full field testing will determine whether a commercializable product has been achieved.

This year fair weather testing on a 10-mile stretch of I-80 at Donner Pass will be conducted, followed by a snow season test in 2010. Farrell said: "We're finished with testing and demonstrations off the highway in areas with clear communication pathways. This demonstration in a mountainous region with significant tree cover will be quite a challenge."

Such navigation assistance capabilities would be essential anywhere that snow or fog obscures visibility on roads or other transportation byways. "On some sections of highways thick fog forces the Highway Patrol to lead slow caravans of vehicles. This system would give authorities a safer, more efficient alternative. The benefits include enhanced driver safety and increased commerce in adverse weather conditions," Farrell said. The estimated cost of an I-80 road closure in the Donner Pass area is estimated to be more than $1 million per hour.

"There have been tremendous advances in the accuracy and reliability of autonomous navigation," Farrell said. He compared the improvement of navigation systems to those on the Apollo moon landers, which were accomplished with eight-bit computers. "Today we have 64-bit computer systems, GNSS, inexpensive inertial instruments, inexpensive and reliable communications. A challenge now is to produce accurate and reliable integrated navigation systems inexpensively."

Since its completion by the Department of Defense in 1995, commercial GPS has become a familiar appliance in which the user's receiver computes its three-dimensional position using a least four of the more than 24 GPS satellites in orbit above the earth.

GPS receivers (pseudorange) achieved an accuracy of about 10 meters, timing how long it takes satellite signals to arrive and multiplying by the speed-of-light, Farrell explained. Errors enter the calculation in numerous ways; atmospheric conditions, satellite and receiver clock errors, orbit aberrations, and delays in the device circuitry, he added.

"Differential pseudo range" produces one meter accuracy by communicating measurement corrections from a known base station location to moving vehicles. Differential carrier phase signals with resolved integer ambiguities can push positioning accuracy to the centimeter level, but requires advanced signal processing at multiple carrier frequencies within the receiver and advance state and parameter estimation within the vehicle navigation algorithms.

Single frequency GPS receiver chips in today's devices now cost as little as a few dollars, while two frequency GPS receivers are still pricey at about $10,000. Over the next decade the GPS Modernization Program is planned to provide three frequencies directly to the civilian user. "This will drive costs down and make all GPS application less expensive with higher performance and availability," Farrell said.

While Global Navigation Satellites Systems (GNSS) can directly provide measurements of receiver position and velocity, there are several challenges for vehicle control and guidance. Such GNSS measurements are only available when the receiver is able to track at least four satellites; the accuracy of the estimated position and velocity will depend on the satellite configuration; and, the bandwidth of those estimates is on the order of 1-2 Hertz.

For vehicle guidance and control, the state of the vehicle is required at a rate of at least 30 measurements per second, with a bandwidth of at least 15 Hertz. The vehicle state includes position, velocity, orientation relative to the road, angular rate, and acceleration. Each of these quantities has three components, which yields a total of 15 basic quantities to be estimated. Because this is a safety-of-life application, the system also needs to be able to characterize its accuracy and to predict its performance into the short-term future, to communicate to the user whether the accuracy specification is achieved. These application specifications are achieved by combining the GNSS information with measurements from inertial sensors: accelerometers and gyros. The theory behind such implementations is described in Farrell's recent book "Aided Navigation: GPS with High Rate Sensors" (McGraw-Hill 2008).

Farrell is also a collaborator on a UC Berkeley research project that is hitting the road later this year. The team is outfitting a public transit bus which is planned to provide daily service for a year on a four mile bus route on Highway 92 in the vicinity of Hayward, CA. While not a purely autonomous navigation system, it will provide transit riders with three layers of safety assurance: the driver, magnetometer readings of magnets embedded in the pavement, and GPS and inertial sensor readings.

"There is a very big difference between creating a prototype and bringing a product to market," said Farrell. "It's got to work every time, every day without fail."