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Beyond the loop: Researchers develop the next generation of vehicle detectors

A prototype piezoelectric beam sensor developed by Rajesh Rajamani (right), Krishna Vijayaraghavan, and Lee Alexander is one of the new sensor technologies being studied by the ITS Institute.

In order to manage traffic, you have to know where it is. For nearly 50 years, one of the most widely used tools for measuring traffic flows has been the loop detector—a large coil of electrically charged wire embedded beneath the pavement surface. When a large metal object passes overhead, the coil's electrical inductance changes, causing a change in the flow of electricity running through it and triggering the detector.

Today, new technologies are available that offer sensing capabilities beyond those of traditional loop detectors—as well as substantially lower costs. With support from the ITS Institute, several independent research groups at the University of Minnesota are developing new sensor technologies that will make tomorrow's roads smarter.

Introduced in the 1960s, pavement-embedded loop detectors gave engineers a powerful new tool to measure traffic flows. At that time, urban freeway systems were becoming increasingly important to metropolitan traffic, carrying high volumes of commuter traffic between suburban communities and central cities. Over the years, metropolitan areas have installed thousands of loop detectors. More than 6,000 loop detectors are now in place around the Minneapolis-St. Paul region.

The design of loop detectors, however, creates several disadvantages. One significant problem is cost—a single loop detector unit may cost several hundred dollars. Because they are embedded directly in the pavement, loop detectors are difficult to maintain. They require an external power source to operate, so electrical service must be installed along the roadway. When this service fails, detectors are difficult to repair or replace.

Batteryless wireless traffic sensors

A new type of traffic sensor that overcomes many of the limitations of loop detectors is taking shape in the mechanical engineering department laboratory of Rajesh Rajamani. Working with research fellow Lee Alexander and graduate student Krishna Vijayaraghavan, Rajamani is developing a self-powered wireless sensor for highway and arterial use that is more flexible and potentially less expensive than inductive loop systems.

The sensor consists of a beam embedded in the road surface and a data processing unit installed within a few hundred feet. Piezoelectric materials in the beam convert mechanical energy (in the form of pressure and vibration from cars passing over the beam) into electrical energy, providing enough voltage to power an onboard electronic system that wirelessly transmits a signal to the wireless processing unit.

The shape of the piezoelectric beam sensor—a thin bar rather than a large loop—makes it easier to install than a loop detector. There is also no need to connect the beam sensor to power supply lines or data transmission cables.

The narrow shape also unlocks sensing options beyond the capabilities of loop detectors. A piezoelectric unit can detect not only the presence of a vehicle, but can

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INSIDE

Huber Awards honor outstanding graduate students

Graduate students **Shan Hu** and **Evan Ribnick** received Matthew J. Huber awards at the Center for Transportation Studies' annual meeting and awards luncheon March 25. The award is named in honor of the late Professor Emeritus Matthew J. Huber (civil engineering) in recognition of his long and valuable contributions to the teaching and study of transportation.

Shan Hu is a master's candidate in engineering management

CTS assistant director Gina Baas congratulates Shan Hu and her advisor, Xun Yu.

(mechanical engineering) at the University of Minnesota Duluth, with an expected graduation in May. Her work focuses on nonintrusive detection of driver drowsiness through a sensing system that monitors the heart rate of vehicle drivers. This project is one of four national finalists in the 3rd Collegiate Student Safety Technology Design Competition.

Her advisor, Xun Yu, joked that the "problem" with Hu, his first graduate student, is that she raised his expectations: "I don't know if I can have any other so good. I feel lucky to work with her." Hu said she is glad her research contributes to the field of transportation.

Ribnick, a doctoral candidate

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Pre-college outreach engages young minds

The ITS Institute was an exhibitor for the second year in a row at TechFest, a one-day event focusing on engineering, held at The Works, a "hands-on science and technology museum." This year, the Institute's exhibit focused on remote aerial vehicle research by **Demoz Gebre-Egziabher** of the aerospace engineering department. The Institute is providing funding for Gebre-Egziabher to develop autonomous or semi-autonomous aerial vehicles that can monitor traffic movements, detect disruptions, and perform a wide variety of other surveillance and monitoring tasks under both normal and emergency conditions.

A $2,000 travel grant provided by the Institute helped several Native American students and their families attend the National American Indian Science and Engineering Fair in St. Paul March 26–28. The annual event, sponsored by the American Indian Science and Engineering Society, offers talented young students the opportunity to compete for scholarships and prizes, and encourages students in grades 5–12 to prepare for careers in science and technology-related fields. The Institute was also an exhibitor at this year's event.

This summer, the Institute will again provide assistance and funding for a series of science-focused day camps for grade school students organized by computer science professor Nikolaos Papanikolopoulos and his graduate students. Last year, students from across the Twin Cities region came to the Minneapolis campus to engage in hands-on learning activities related to ITS applications and other technology topics; enrolment for this year has already been strong and another successful set of events is anticipated this summer.

CTS program coordinator Shawn Haag explains the inner workings of an uninhabited aerial vehicle to TechFest visitors.

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in electrical engineering at the Twin Cities campus, expects to complete his degree in September. His research, centered around computer vision and image processing, has focused extensively on transportation-related applications, including a specific project sponsored by the Department of Homeland Security to develop an automatic surveillance system to protect busy transportation hubs.

Gina Baas, Evan Ribnick, and Nikolaos Papanikolopoulos

His advisor, **Nikolaos Papanikolopoulos**, said Ribnick is a "dream student" who has been published in some of the best academic journals. "He is a true scholar and a very professional individual," he added. Ribnick said that as a researcher, he wants to develop technology that is useful and applicable in the real world. "This award indicates that we're headed in the right direction," he said.

NATSRL Research Workshop showcases current projects

The Northland Advanced Transportation Systems Research Laboratories (NATSRL) Research Workshop on Intelligent Transportation Systems March 12 featured presentations on a diverse set of current research projects by faculty and student researchers and faculty members. The annual event is a showcase for intelligent transportation systems research on the University of Minnesota's Duluth campus and also an opportunity for researchers to share information.

Established in 2000, NATSRL manages an advanced research program to develop innovative technologies that support transportation in northern areas. NATSRL is an affiliate of the ITS Institute.

NATSRL director Eil Kwon, professor of civil engineering, said this year's workshop presentations showed the variety of cutting-edge research underway on the Duluth campus.

Research projects presented at this year's workshop included:

- Portable Cellular Wireless Mesh Sensor Network for Vehicle Tracking in an Intersection
- Real-Time Non-intrusive Detection of Driver Drowsiness
- Intelligent Pavement Sensor for Traffic Detection
- Development of Novel Hydrogen Storage Materials for Road Traffic Related Applications
- Development of a Low-Cost Interface between Cell Phones and DSRC-based Vehicle Unit for Efficient Use of VII Infrastructure
- Snow Rendering for Interactive Snowplow Simulation: Supporting Safety in Snowplow Design
- Improving Safety and Efficiency of Roadway Maintenance Using Robotics—Feasibility Study
- Detection of Water and Ice on Bridge Structures by Time Domain Reflectometry/Dielectric Relaxation Spectroscopy
- Development of a New Tracking System based on CMOS Vision Processor Hardware
- Identifying Methods and Metrics for Evaluating Interagency Coordination in Traffic Incident Management
- Exploring Effective Methods to Evaluate and Optimize the Systematic Implementation of Proactive ITS Safety Strategies

NATSRL director Eil Kwon

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also count each axle that passes over it and determine the length of the vehicle. This information will give traffic managers important new data on what kind of vehicles are using roads.

Taek Kwon's portable wireless sensor nodes could make manual intersection traffic counters like this obsolete.

Wireless mesh sensing

On the University's Duluth campus, the advantages of wireless sensing are also key to research by Taek Mu Kwon of the electrical and computer engineering department. Kwon directs the Transportation Data Research Laboratory, managing data from the Twin Cities' freeway loop detector system. But in a recent research project, he turned his attention to the challenge of monitoring complex traffic patterns in arterial intersections.

Engineers analyzing intersection traffic are often forced to rely on manual data collection—workers record the movements of vehicles through the intersection using handheld data loggers, an approach that is both tedious and error-prone. Kwon's research aims to automate the process with small wireless sensor nodes that are easy to install temporarily on the road surface.

Kwon's sensor nodes are designed to be installed in groups, with each sensor responsible for detecting vehicles in a single lane of traffic. Once in place, the sensor nodes automatically configure themselves as a "mesh" network, moving the raw data to a processing unit that extracts vehicle trajectories. The sensors are particularly suitable for short-term installations because each one is powered by its own battery and mounted on the road surface with an adhesive, but they can also be connected to an external power source for longer-term applications.

A mesh network is defined by multiple links between nodes. In a mesh topology, data can hop from node to node to reach a destination, rather than being transmitted directly to and from a central point. In a full mesh network, the number of links increases rapidly as more nodes are added. Kwon's sensor network strikes a balance between flexibility and complexity via a partial-mesh topology, in which each sensor is connected to at least two other nodes in order to provide alternative data routes, but not to every other node in the system.

In operation, each sensor node in an intersection registers the magnetic disturbance caused by a vehicle passing directly over it and transmits the exact time of that event through the mesh network to a data logger positioned nearby. The nodes' communication protocol ensures that their internal clocks are synchronized, so the timing of every vehicle detection event is recorded accurately.

To turn raw sensor output into usable information, the collected data are processed using a tracking algorithm that reconstructs vehicle trajectories from vehicle detection events. Because individual sensor nodes are responsible for each lane of traffic, individual nodes can be designated as "entrance" and "exit" nodes. Taking into account the geometry of the intersection, the tracking algorithm matches vehicle detection events recorded by entrance nodes with events recorded by exit nodes. The result is a set of node-to-node trajectories representing the movements of individual vehicles.

Carbon nanotube pavements

A very different approach to sensor design is being taken by Xun Yu in the mechanical and industrial engineering department of the University of Minnesota Duluth. Yu's current research seeks to turn the pavement itself into a sensor by exploiting the electromechanical properties of carbon nanotubes.

Since their discovery nearly 20 years ago, carbon nanotubes—cylindrical carbon molecules in which atoms are organized into hollow cylinders that are only a few atoms in diameter but up to millions of atoms long—have attracted the interest of researchers in many fields due to their unusual properties. In addition to being extremely strong, carbon nanotubes are electrical semiconductors that exhibit linear changes in electrical resistance in response to mechanical stress, a quality known as piezoresistance.

Yu is attempting to put piezoresistance to work by mixing carbon nanotubes (CNTs) with cement. In a well-formulated CNT/cement composite, evenly distributed nanotubes would form a web of carbon filaments spanning the entire paved area. Installing a simple set of electrodes to measure electrical resistance would turn the pavement into a single large pressure sensor.

Though such a sensor design is mechanically simple, with no complex circuits or moving parts, fabricating CNT/cement composites that can perform effectively as sensors is far more challenging than pouring a cupful of nanotubes into a cement mixer. CNTs have an unfortunate tendency to clump together when placed in solution, forming discrete blobs rather than the even, continuous network that piezoresistive sensing requires. To overcome this tendency, Yu is studying different chemical methods of encouraging CNTs to disperse, with an eye toward identifying methods that can be incorporated into commercial concrete mixing processes.

In addition to developing a manufacturing process for CNT/cement composites, Yu's sensor concept also depends on developing a thorough understanding of their electrical and mechanical properties. In the laboratory, Yu is currently investigating composites' piezoresistive response to dynamic and static stresses, as well as the effects of temperature, humidity, and other environmental factors.

The Intelligent Transportation Systems Institute
Center for Transportation Studies, University of Minnesota
200 Transportation and Safety Building, 511 Washington Avenue S.E., Minneapolis, MN 55455-0375
Phone: 612-626-1077 • Fax: 612-625-6381 • E-mail: its@umn.edu • Web: www.its.umn.edu
ITS Institute Director: Max Donath • Media Contact: Gina Baas • Editor: Peter Park Nelson • Graphic Design: Cadie Wright Adhikary

SMART-Signal garners 2009 CTS Research Partnership Award

SMART-Signal ("Systematic Monitoring of Arterial Road Traffic Signals") is a real-time arterial performance monitoring system that uses traffic data from existing signal systems. The project was a joint effort of the University, Hennepin County, Mn/DOT, and the private sector. The research was funded by the ITS Institute and the Minnesota Local Road Research Board, with significant in-kind support from Hennepin County.

The annual award recognizes research projects within the Center for Transportation Studies program that have resulted in significant impacts on transportation, and rewards teams of individuals who have drawn on the strengths of their diverse partnerships to achieve those results. The ITS Institute is housed within CTS.

Bob Green, Henry Liu, Steve Misgen, and Eric Drager accepted the 2009 Research Partnership Award from CTS Assistant Director Dawn Spanhake.

Henry Liu, an assistant professor in the Department of Civil Engineering, accepted the award on behalf of the project partners. Although traffic engineers have tools to measure real-time freeway performance, he said, similar approaches for urban arterials do not exist but are urgently needed. The development of SMART-Signal fills in this gap. "We can do much better to manage traffic... if we have the right tools." SMART-Signal has been instrumented on 11 arterial intersections since February 2007 and on six highway intersections since January 2008; another test site with 14 intersections is scheduled to be instrumented. The research team's evaluation found that system performance compares well with real-world data, Liu said. Results from an independent evaluation are also very encouraging. Continuing research is focused on enhancing the system to allow automatic signal adjustment based on traffic conditions.

The University is currently in the patent application process to protect the intellectual property, Liu said. He also noted that his team has received a grant from the National Cooperative Highway Research Program to extend their work on SMART-Signal, and that the system is used as an education module in a civil engineering course at the University.

Project partners recognized for the development of SMART-Signal include:
University of Minnesota: Henry Liu, Wenteng Ma, Xinkai Wu, Heng Hu
Hennepin County: Eric Drager, James Grube, Roy Doron, Darryl Dobesh, Tom Switzer
Alliant Engineering: Bob Green
Mn/DOT: Steve Misgen, Ronald Christopherson, Mike Dittel, Shirlee Sherkow.

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ITS Institute
University of Minnesota
200 Transportation and Safety Building
511 Washington Avenue S.E.
Minneapolis, MN 55455-0375

Phone: 612-626-1077
Fax: 612-625-6381
E-mail: its@umn.edu
Web: www.its.umn.edu