Low-cost digital processing, advances in semiconductor technology, and new standards for wireless communications have made possible an innovative approach to vehicle detection. The Sensys™ Wireless Vehicle Detection System employs small battery-powered pavement-mounted magneto-resistive sensors that transmit their detection data in real-time via low-power radio technology to a nearby access point (or repeater). The combination of magneto-meter-based vehicle detection with wireless connectivity results in a new approach to an old problem.

**The Old Way.** For the last thirty years or so, inductive loops have been the industry’s “gold standard” for vehicle detection. Loops are capable of providing exceptional performance and accuracy for presence (stop bar) detection, advance detection, and system detection applications, independent of weather or other environmental conditions.

At the same time, inductive loops can experience relatively high failure rates -- the differential stress caused by the weight of passing vehicles, thermal expansion and contraction, pavement shifting due to sandy soil conditions, pavement failure, or minor roadway construction can all cause the wires embedded in the pavement to break. And although the materials employed by loops are relatively inexpensive, the installation costs associated with tearing up the roadway, closing lanes for hours at a time, and trenching as needed to support lead-in cabling ultimately lead to a relatively high overall life-cycle cost.

**A New Approach.** The Sensys Wireless Vehicle Detection System can be used in traffic monitoring and management applications as a direct replacement for conventional inductive loops. Like inductive loops, the wireless sensors can be located exactly where measurements are required, whether it is at a specific through lane, turn lane, or entrance or exit ramp. Unlike loops, however, each sensor is small, and installation simply requires boring a 4-inch / 10-cm diameter hole approximately 2 ¼ inches / 5.7 cm deep at the desired detection location, placing the sensor into the hole so that it is properly aligned with the direction of traffic, and sealing the hole with fast-drying epoxy. No lead-in cabling or long saw cuts are required, and the circular pavement hole produces the least amount of damage and stress to the roadway. Installation time per sensor is typically 5 to 10 minutes.

The magneto-resistive sensing devices employed in each wireless sensor measure the x-, y-, and z-axis components of the Earth’s magnetic field at a 128 Hz sampling rate. As vehicles come within range, changes in the x, y, or z axes of the measured magnetic field become apparent. When no vehicles are present, each sensor continually measures the background magnetic field to estimate a reference value. Each sensor automatically self-calibrates to the specific installation site and to any long-term variations of the local magnetic field by allowing this reference value to change over time.

Sophisticated signal processing algorithms in each sensor provide highly accurate vehicle detection as well as the ability to discriminate vehicles in adjacent lanes or vehicles that are traveling close to each other in the same lane. The detector technology is as accurate as a well-tuned inductive loop, while the small size of each sensor makes it less vulnerable to damage than a loop. Thanks to patent-pending innovations in low-power circuitry and communications protocols, the average battery life of a wireless sensor is 10 years, allowing the system to be used as a direct replacement for inductive loops in a wide range of traffic management and traffic data collection applications.

A single installation then consists of a number of wireless sensors installed in the roadway at various locations as required by the particular vehicle detection application, an access point to receive the data from the sensors and process and relay it onward, and one or more repeaters as may be needed to support sensors installed beyond the radio range of the access point. Each installation can communicate its detection data in several ways:

- via contact closure to a roadside traffic controller;
- via IP (Internet Protocol) communications over twisted pair, coaxial cable, fiber optic cable, cellular data services, or other connectivity to one or more central servers and traffic management systems; or
- via both paths, simultaneously supporting local traffic control as well as centralized traffic management and information systems.

**Wireless Sensor Communications.** As vehicle detections are made, each wireless sensor employs low-power radio technology to send time-stamped detection event data to a nearby access point or repeater. The radio communications between a wireless sensor and its communicating access point or repeater are two-way, allowing the sensor to receive commands and data as well as transmit data and status information. Each wireless sensor is uniquely addressable so its data can be independently collected and its operation independently controlled and monitored. New firmware upgrades to the sensors can also be transmitted by the access point, providing a simple, over-the-air mechanism to upgrade installed sensors without requiring their removal.

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The Sensys™ Wireless Vehicle Detection System

Operating in the globally available 2.4 GHz unlicensed frequency band, the radios employed by Sensys wireless sensors, access points, and repeaters are based on the Institute of Electrical and Electronic Engineers (IEEE) 802.15.4 PHY industry standard. At the transmit power levels used by the system, no operation or site license from government communications authorities is required for deployment.

The 802.15.4 Standard. The 802.15.4 task group of the IEEE developed the 802.15.4 standard to address Wireless Personal Area Network (WPAN) applications with relatively short ranges, low data rates, and low power consumption. Compared to Bluetooth, another WPAN standard, the 802.15.4 standard is intended to support smaller and more energy-efficient devices. With data rates capped at 250 kbps, applications of the standard include home networking (e.g., TV/DVD/CD remote controls), building and home automation (e.g., HVAC, security, lighting control, access control), industrial networks (e.g., asset management, process control, environmental/energy management), interactive toys, and remote metering.

Extensions and variations of the 802.15.4 standard are possible. For example, the ZigBee Alliance has developed a suite of ZigBee communications protocols that...
run on top of the 802.15.4 standard to further extend its capabilities in order to support mesh networking.

Adaptation of 802.15.4 for Vehicle Detection. For purposes of vehicle detection, the Sensys Wireless Vehicle Detection System relies upon a standard 802.15.4 transceiver IC in combination with Sensys-proprietary protocols implemented in firmware. The same radio communications technology is used between an access point and a repeater as between a sensor and an access point or repeater.

In order to achieve communications reliability with very low latency and extremely low power consumption as required for vehicle detection, the protocol controls how the radio channel is used and how transmissions by numerous wireless sensors to an access point or repeater are coordinated. The protocol is a time-synchronous communications scheme that synchronizes the clocks of all the sensors in a given installation to a common reference clock provided by the local access point. The transmit and receive times of all the sensors at an installation are coordinated by the access point so that each wireless sensor is allocated specific fixed-interval time slots in which it is able to transmit or receive.

Generically, such a channel access method is known as Time Division Multiple Access or TDMA. Using TDMA, possible interference among sensors and the time spent transmitting or receiving is minimized, thereby helping to reduce sensor power consumption to an extremely low level. Communications reliability is further ensured by requiring that each sensor’s data transmission is explicitly acknowledged by the access point – if a sensor does not receive an acknowledgement from the access point within an expected time interval, it repeats its data transmission.

Applications. Sensys wireless sensors can provide the same data as inductive loops with exceptional accuracy and reliability: vehicle volume, occupancy, speed, presence, length classification, headway, gap, direction of travel, and queue length. Performance is not affected by weather, glare, shadows, or the angle of the sun, and the sensors can be installed precisely where detection is required. This wide range of capabilities makes this system suitable for such varied traffic management applications as:

- freeways or arterials monitoring (count stations or system detection)
- advance detection (traffic calming or dilemma zone protection)
- stop bar (presence) detection

The basic architecture of the Wireless Vehicle Detection System – battery-powered pavement-mounted sensors that communicate wirelessly to a pole-mounted access point or repeater – means that the system can readily overcome deployment complications such as split roadways, flyovers, bridges, long distances from the traffic signal controller, high water tables, poor pavement quality, or other site-specific issues that would otherwise make the installation of inductive loops impractical or impossible. And where the deployment of a mid-block or advance detection system using inductive loops can require expensive trenching and conduit installation, these costs can be completely avoided with the Sensys vehicle detection system.

The Wireless Vehicle Detection System can be used with Type 170, NEMA TS1, NEMA TS2, or Type 2070 ATC traffic controllers by installing one or more contact closure cards into the detector shelf of the controller and connecting them to the access point(s). The real-time detection signals of the wireless sensors received by the access point are then converted into contact closure signals to the traffic controller that can be easily configured in the same way that inductive loops are configured to interface with a traffic controller. This capability means that wireless sensors can be readily used with existing traffic controllers to replace broken
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inductive loops, maximizing the value of existing infrastructure.

The Wireless Vehicle Detection System natively employs IP communications to allow traffic data collected by the vehicle detection system to be readily processed, archived, accessed, and distributed via private or public networks. IP connectivity also permits real-time remote monitoring of all connected installations so that each Sensys access point and all its associated wireless sensors can be monitored, configured, and updated remotely. To support IP connectivity, the access point has an integrated twisted-pair Ethernet connection as well as options for integrated cellular data modems to provide communications over either GSM cellular networks (using EDGE/GPRS data services) or CDMA cellular networks (using CDMA 1xRTT data services).

Detection data collected by the Wireless Vehicle Detection System can thus provide real-time traffic data to local roadside traffic signal controllers, to centralized Traffic Management Centers and Advanced Traveler Information Systems, to freeway and arterial traffic management systems, or to adaptive traffic signal control systems such as SCOOT, SCATS, or ACS Lite. Moreover, the vehicle detection system can provide its real-time detection data to both local traffic controllers and central traffic management systems simultaneously, increasing its flexibility.

Conclusion. By combining state-of-the-art magnetic sensors with innovative low-power radio technology, Sensys has created a reliable, accurate, and cost-effective vehicle detection system with an average 10-year battery life and the flexibility to address a wide range of traffic management applications. To date, the system has been installed in over 22 states and 6 countries. This fusion of sophisticated detection and wireless communications technologies to create a new pavement-mounted vehicle detection system will likely find many more applications to meet today’s traffic management challenges.

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OMJC Signal Inc.
P.O. Box 1594
Waterloo, IA 50704
(800) 776-5999/(319) 236-0200
FAX: (319) 236-1554
Email: sales@omjcsignal.com
Website: www.omjcsignal.com