Wireless Magnetic Sensor Network for Collecting Vehicle Data

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Abstract—We develop a new traffic data collecting device. The device is based on magneto-resistive technology, in which the circuit resistance is changed with the imposing magnetic field. It is known that ferrous-body vehicles interfere with Earth’s magnetic field, which can be monitored with our device. The signal will then be processed and yields vehicle count, speed, occupancy time, and classification. We also design our device to communicate to its base station via radio frequency. We form a network of these many sensor nodes at places where traffic monitoring are required. Our system is very flexible and adapt to many environments of vehicle detection.

I. INTRODUCTION

The inductive loop has been established firmly as traffic data collecting device due to its simple magnetic disturbance measuring technology [1]. However, the inductive loop also has several major drawbacks. Its large size requires road surface preparation and lane closure for several hours if not days. Maintenance is also time-consuming. Relocation is not possible. Road maintenance usually damages the existing loop installation.

A similar vehicle detection technology to the inductive loop is the magnetic sensor. The magnetic sensor can passively measure small value of magnetic signal, meaning that it does not have to generate magnetic field as does the inductive loop. It can measure magnetic field as low as micro-Gauss, the level of Earth magnetic field change. Magneto-resistive sensor is semiconductor that has its resistance changes according to imposing magnetic field. The size of this type of sensor is very small. It can be employed in a wireless sensor node as it also consumes a small amount of power [2].

A Wireless Sensor Network (WSN), known for its aptness of smart environment monitoring, has gained more popularity among the Intelligent Transport System (ITS) community [3]. This is mainly due to its capability to communicate between a sensor node and a server node (data collection point) via radio frequency. Its wireless capability and small size make the installation process quick and easy. The installation can be finished at night time to avoid traffic congestion due to lane closure. Temporary placement of WSN allows traffic data collection for a few days. As an ideal model, we automatically collect, analyze and disseminate traffic data for an effective traffic management. In this paper, we design a magnetic WSN for traffic data collection as an alternative to the inductive loop. We will describe our system architecture in Section II. The architecture includes the magneto-resistive sensor, the RF transceiver, and the antenna. There is also an issue for accessing common media in wireless transmission. We employ two simple MAC protocols that are suitable for our tasks. These protocols are described in Section III. Then to make data collection useful, an analysis of magnetic signal to obtain vehicle count, speed, occupancy time, and classification are necessary and will be explained in Section IV. Data and results are presented in Section V. We conclude this work in Section VI.

II. SYSTEM ARCHITECTURE

The wireless magnetic sensor network consists of a number of sensor nodes and a server node. The sensor nodes are installed at locations that require traffic monitoring. The server node is placed at a nearby location. This server node can also be a gateway connection to a wide area network such as the Internet, GPRS, and satellite.

![Magnetic Sensor Node Components](image1)

![Magnetic Server Node Components](image2)

Fig. 1. Main components of the sensor node and server node of magnetic wireless sensor system.

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most commercial available antennas are not of suitable size. They are usually large at this frequency. We therefore design a small-sized printed antenna for the sensor node together with a server node’s antenna.

We design a small-sized antenna by means of increasing electrical length and dielectric substrate. The construction of sensor node antenna is of two rectangular-printed-spiral shape with U-strip. The antenna structure is flat and its physical dimension is only 5x5 cm². This makes it suitable for installation in a small package. The server node antenna however is of larger size to provide larger gain as size limitation is not as significant. It consists of two rectangular plates separated by dielectric posts. The size of server node’s antenna is 15x15 cm². The design of our antennas is shown in Fig. 2. These antennas give horizontal polarization as the wave propagates horizontal to the road surface.

Fig. 2. Antenna for sensor node (left) and server node (right).

III. MAC PROTOCOLS

According to our wireless sensor network configuration, the sensor nodes are placed to monitor a small traffic area. We choose our network topology as a simple star network in which each sensor node communicates directly with the server node. We propose two types of MAC protocols based on different scenarios.

A. Polling Protocol

Polling protocol is a simple MAC protocol that fits networks in which most sensor nodes do busily send data to the server node. The protocol allows the server node to periodically poll its sensor nodes. Sensor nodes can respond only when it is polled. Most of the time sensor nodes are put in the sleep mode when there are no data. It wakes up and sends data when receiving poll. This polling scheme provides medium access with no collision as only one sensor node can transmit to the server node at a particular instant.

B. Modified Slotted Aloha Protocol

Polling protocol is not efficient in situations where most of the sensor nodes are idle. Most polls from server are wasted. To cope with this situation, we propose another simple MAC protocol based on a modification of slotted Aloha.

Slotted Aloha protocol allows sensor nodes to transmit at any fixed intervals (time slots). The server node synchronizes with each sensor node by sending a polling packet at the beginning of each time slot. This poll packet now does not contain specify sensor node’s ID. Any sensor node can send data with this poll. Slotted Aloha causes collision when two or more sensor nodes transmit in the same time slot. To avoid this collision, we simply modify the protocol such that each sensor node will have to randomly delay its start of data transmission to the server. This allows that data packet overlaps in each polling time slot.

IV. MAGNETIC DATA ANALYSIS

In this section, we process magnetic data to obtain vehicle count, speed, occupancy time and classification.

A. Preprocess the Data

Let $x^i$ be magnetic time series observed at the sensor node with magnetic sensor i, where i represents one of the two magnetic sensors. When it is not significant to differentiate between two magnetic sensors, we will simplify our notation by discarding the superscripted index i. $x_n$ is x-axis magnetic signals at time sample n.

We first smooth magnetic time series by performing moving average over n samples to reduce random noise. Then we compute differential magnitude, $M_n$, and its moving average, $\bar{M}_k$, as shown in Equations (1) and (2) respectively.

$$M_k = \sqrt{(\bar{x}_k - \bar{x}_{k-1})^2 + (\bar{y}_k - \bar{y}_{k-1})^2 + (\bar{z}_k - \bar{z}_{k-1})^2}$$

$$\bar{M}_k = \frac{M_k + M_{k-1} + \cdots + M_{k-n+1}}{n}$$

The differential magnitude is defined as the magnitude of the difference between current sample and previous one. We use the differential magnitude because there is a slow drift of time series. Differential signal will eliminate this slow drift effect and only convey changes of signal due to moving vehicles. We will perform vehicle detection on the moving average of the differential magnitude $\bar{M}_k$ to estimate the following traffic parameters: vehicle count, speed, occupancy time, and classification.

B. Vehicle Count

Vehicle count or detection is obtained with a four-state state machine as shown in Fig. 3. Two thresholds are employed to change from a current state to a next state.

A vehicle is counted when the state machine cycles through all four states starting from state S0 through states S1, S2, S3, and back to state S0 respectively. The threshold $M_i$ is to measure if the change of magnetic signal is of significant enough and is determined as caused by a vehicle. It determines the presence of a vehicle by the following comparison:

vehicle is not present if $\bar{M}_k < M_i$;
vehicle is present if $\bar{M}_k \geq M_i$.

In order to prevent mistaking abrupt noise for vehicle presence, the state machine includes the counter C that keeps track of vehicle presence duration. If the duration is too short, then it might be caused by some burst noises. In other words, it is expected that a vehicle presence should not exhibit a
temporary short duration of smoothed differential magnitude variation. Time sample threshold $C_i$ is employed for this distinction.

![State Machine Diagram]

Fig 3. Four-state state machine making decision on vehicle presence.

C. Speed

Vehicle speed is obtained with two magnetic sensors separately placed at a distance $d$. When a vehicle passes over, the signal change is first obtained with the near sensor. After time delay $t_d$, signal change is obtained with the far sensor. The speed $v$ is then computed as $v = \frac{d}{t_d}$.

D. Occupancy Time

Occupancy time $t_o$ can be easily obtained as the duration between the change from state S1 to state S2 in which a vehicle presence is confirmed and the change from state S3 to state S0 in which the same vehicle leaves the node.

E. Classification

Three features are extracted and are employed in hierarchical-tree classification algorithm. Features we extract consist of:

1) Normalized Vehicle Magnetic Length

We postulate that the vehicle magnetic length should strongly correlate with the vehicle body length. Therefore, the feature should satisfactorily distinguish vehicles based on their length. The vehicle magnetic length can be obtained with its speed and occupancy time as $L_m = v \cdot t_o$.

2) Averaged Vehicle Energy

Averaged vehicle energy gives information on how a vehicle affects the earth magnetic field at the sensor node. Large body vehicles should have more effect than small body vehicles. Also, the closer the body to the sensor node yields larger change of the signal. Averaged vehicle energy $E$ is defined as the sum of energy of smoothed differential magnitude $\sum M_k \cdot t_s$, divided by the vehicle magnetic length $L_m$, $E = \frac{\sum M_k}{L_m / t_s}$.

3) Hill Pattern and Number of Peaks

Hill pattern is used in [4]. It is a pattern extracted from magnitude signal based on its slope. Hill-pattern is employed as it is believed that different vehicles possess different parts of structures and different numbers of axles. We represent positive slope with 1 and negative slope with 0.

We propose a simple classification based on hierarchical tree methodology. Following the tree in Fig. 4, we identify the bus and motorcycle by their length as the vehicle length distributions are clearly distinguished from other types of vehicles. For motorcycle, the Hill-peak is small and is useful for its classification. These three features are employed in path 1 to mainly identify motorcycles and cars. A more thorough look into the groups of cars, pickup, and vans is then considered based on combination of the three features similar to the one in Fig. 4.

![Classification Tree Diagram]

Fig 4. Classification tree based on the three features: normalized vehicle length, averaged energy, and number of Hill-pattern peaks, is employed to identify vehicles into 5 types: motorcycles, cars, pickups, vans and buses. Each feature is hierarchically applied. Path 2 is similarly divided into another hierarchical tree.

V. DATA AND RESULTS

We setup our magnetic sensor and collect our data at an entrance to the Thammasart University, Rangsit Campus, Thailand. We place on the middle of the lane our sensor node about 5 meters behind the security booth. We process our data to obtain all traffic parameters and employ them for classification. We are interested to showing how our classification algorithm works in this result. To obtain the ground truth, we also record visual data with a digital video camera.

We obtain the earth magnetic field variations. We sample the signal at 40 samples/sec. The total number of vehicles we observed is 393. Out of this total, we visually classify into 65 motorcycles, 154 passenger cars, 98 pickup trucks, 34 vans, and 42 buses.

The distribution of normalized vehicle magnetic length is shown in Fig. 5. It is clearly seen that motorcycle and bus distributions are clearly separated from the rest. The distributions of average energy of 5 types of vehicles are shown in Fig 6. The van’s energy is shown to be relatively higher than the rest due to its low body and is useful for distinguish van from the rest. The distributions of number of peaks for 5 types of vehicles are shown in Fig 7. The bus shows highest number of peaks while the motorcycle shows the least number of peaks.

The experimental results are conducted based on magnetic signal observed with 393 vehicles. The data is processed and classified into five types: motorcycle, car, pickup, van and bus. The length, peak and averaged energy are extracted and used in classification process. The overall 80.92 percent of the vehicles are classified correctly. In Table 1, the
The classification results of each vehicle type are shown. The motorcycle and bus achieve high accuracy because their magnetic lengths are clearly distinguished to the other three types. The discrimination of three types (car, pickup and van) is fuzzy using only the length, therefore the further classification are needed using peak and averaged energy. The accuracies of car, pickup and van are 77.92, 66.33 and 76.47 percent respectively.

In order to improve the overall classification result, additional features that are able to distinguish those vehicles must be employed. This is still an ongoing research to find appropriate computationally simple features that can be efficiently employed for classifying cars, pickups and vans.

VI. CONCLUSION

We demonstrate a simple vehicle detector based on magneto-resistive sensor technology. It is known that ferrous-body vehicles interfere with Earth’s magnetic field, which can be monitored with our device. Our design consists of two magneto-resistive sensors, a microprocessor, a transceiver, and an antenna. The design is small and suitable for fast installation and maintenance. Its relocation is easy as the node can be pulled out from the road surface. It is able to detect vehicles, and calculate occupancy time, speed, and classification. We also design our device to communicate to its base via radio frequency. We form a network of these many sensor nodes at places where traffic monitoring are required. Two simple MAC protocols are presented: polling and modified slotted Aloha. Polling protocol is suitable for a network whose most sensor nodes have data to transmit all the time. However, modified slotted Aloha is suitable for a network whose only a few sensor nodes send data to their server. This protocol reallocates available time slots for busy sensor nodes.

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REFERENCES


