On-road Wireless Sensor Network for Traffic Surveillance

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***Abstract*— In this paper, a traffic surveillance system using wireless sensor networks is introduced. Such traffic surveillance system should satisfy more requirements and overcome harder constraints because wireless network systems have some characteristics such as small hardware resources and less stability of communication. Such requirements include energy-efficient operation, reliable data transmission, and accurate operations. A traffic surveillance system using magnetic sensor network is designed and implemented to satisfy mentioned requirements. The designed traffic surveillance system is tested on indoor and outdoor test-beds.**

Keywords – WSN; Magnetic Sensor; Traffic Surveillance.

I. INTRODUCTION AND PREVIOUS WORKS

Recently, as various sensor network technologies for ubiquitous computing have been being researched actively, the convergence of existing applications and the sensor network technologies has been being a key issue in several industrial and scientific fields. For example, in the Intelligent Transport System field, the convergence of diverse services, research issues and sensor network technologies has been being suggested [1][2].

Some previous works on wireless sensor network based on magnetic sensor nodes [3][4][5] were introduced to adapt the sensor network technologies on real road environments. The previous works focus on each research topics related to wireless sensor network such as energy efficiency, detection accuracy, traffic management, and so on. However, they do not suggest overall and essential requirements to successfully adapt wireless magnetic sensor network on road networks and do not describe their overall system which are the most important for manufacturing sensor nodes.

In this paper, as a kind of the convergence of wireless sensor networks and Telematics/ITS environments, we design and implement a prototype of a whole traffic surveillance system using wireless magnetic sensor networks on roads. For that, we suggest key and essential requirements and overall architecture including sub-components and signal processing mechanisms reflecting the requirements are explained.

This paper is structured as followings. In section 2, we explain the overall design and structure of the traffic surveillance system including system requirements. In section 3, we conduct some experiments and show the results. In section 4, we conclude this paper.

II. ON-ROAD WIRELESS SENSOR NETWORK FOR TRAFFIC SURVEILLANCE

In this section, the overall design and structure of the traffic surveillance system including system requirements will be explained.

A. Key Requirements

A traffic surveillance system using wireless sensor networks should consider the following requirements [6].

- Energy-efficiency on sensor networks
- Accurate vehicle detection
- Reliable and real-time data transmission on wireless communication
- Real-time sensor data processing and vehicle detection
- Efficient and intuitive management of sensor networks and services

There can be some variations on such requirements according to installation environments of the vehicle detection system. For example, some real-time properties, such as the limit time for system responses, can differ from types of real-roads, such as high-way and in-city roads.

B. System Architecture

Figure 1 below shows the overall structure of the designed traffic surveillance system. The traffic surveillance system mainly consists of three parts according to their functions - 1) vehicle detection layer, 2) data management layer, and 3) monitoring & application layer. The vehicle detection layer consist of magnetic sensor nodes installed on surface of real-roads, gate-nodes to relay vehicle detection data, and base-stations to process detection data and to calculate speed of vehicles. More specifically, the magnetic sensor nodes detect vehicles based on variations of magnetic fields of earth caused by moving vehicles. The magnetic sensor nodes also transfer the vehicle detection information to gate-nodes or base-stations with detection time (local ticks). Base-stations receive the detection information from magnetic sensor nodes or gate-nodes, and process them to extract more useful data such as speed of vehicles. The data management layer provides broader services based on information transmitted from base-stations, such as traffic status of some districts. The monitoring and application layer

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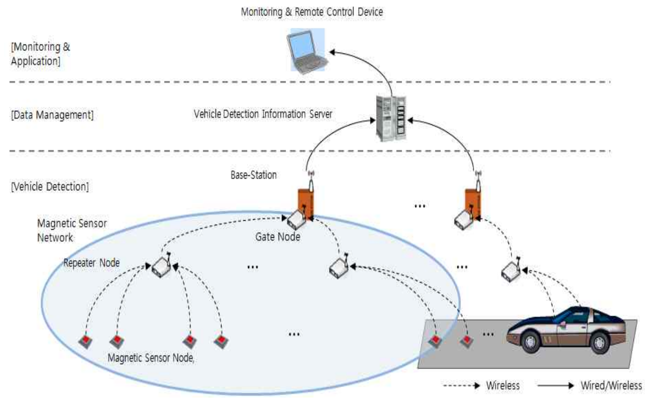


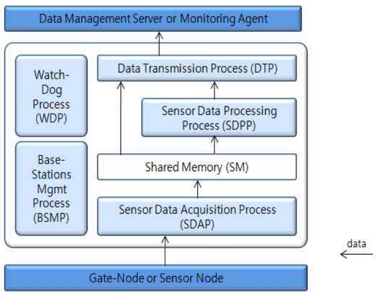
Figure 1. Overall structure of the traffic surveillance system based on magnetic sensor networks

provides more customized services to end-users, such as system monitoring and personalized services.

In this paper, we have focused on the vehicle detection layer, especially wireless sensor network and base-stations, because remains are related to flexible functions according to kinds of traffic-related services.

C. *Base-Stations*

A base-station collects vehicle detection data from magnetic sensor network, processes them to produce more valuable information, for example, speed of a vehicle, and provides them to upper layers. Figure 2 and Table I show the S/W structure and H/W aspects of a base-station.



(a) S/W structure of a base-station

Item	Description
CPU	MPC5200 400MHz (Power PC Core)
Memory (SDRAM)	SDR-SDRAM 128 MB
Memory (Flash)	Flash 64MB
Network	10/100 Mbps 1Port
Serial Interface	MPC5200 Internal 3 Port, External 4 Channel
USB	USB 2.0 OTC Controller
Storage Device	CF Memory, ATA IDE HDD
Operating Temperature	-30 ~ 75℃
Operating System	Linux

(b-1) Specification of Base-Station H/W

(b-2) Main-Board of Base-Station

(b-3) Case of Base-Station

(b) Specification and H/W appearance of a base-station

Figure 2. S/W and H/W of a base-station

TABLE I. STRUCTURE OF BASE-STATION PROCESSES

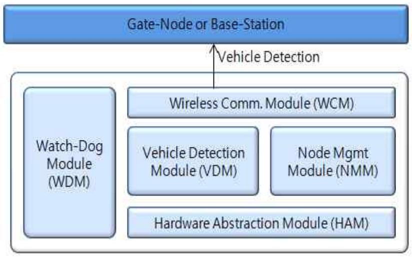
Module Name	Description
Sensor Data Acquisition Process (SDAP)	This process receives vehicle detection data from gate-nodes or sensor nodes, and checks validity of the detection. If valid, this process sends them to the shared memory (SM).
Shared Memory (SM)	This is a memory structure to share data among several processes efficiently. Some locks are used to prevent data corruption and to provide synchronized access.
Sensor Data Processing Process (SDPP)	This process extracts more valuable information, for example, speed of the vehicle, from the received detection data. Error information is logged.
Data Transmission Process (DTP)	This process transfers some data and information to external devices such as data management servers in data management layer, or monitoring agents.
Watch-Dog Process (WDP)	This process checks whether all other processes in a base-station operate normally or not. If there are some errors, this process triggers reset procedures for each process.
Base-Station Management Process (BSMP)	This process manages overall operations in a base-station. Target of the management includes operation status, storage availability, RTC (Real Time Clock) status, and so on.

D. *Wireless Sensor Networks*

Wireless sensor network consists of some magnetic sensor-nodes and gate-nodes. The gate-nodes enlarge

TABLE II. STRUCTURE OF SENSOR NODE MODULES

Module Name	Description
Hardware Abstraction Module (HAM)	This module abstracts interfaces for hardware setup and several node operations.
Vehicle Detection Module (VDM)	This module decides whether a vehicle exists or not by executing the pre-defined vehicle detection algorithm. Some filtering mechanisms are used to filter noise.
Node Management Module (NMM)	This module controls execution status of a sensor-node. Also, this module provides recovery procedures and configuration backup.
Watch-Dog Module (WDM)	This module enforces reset options if some runtime errors occurred during node operations.
Wireless Communication Module (WCM)	This module transfers the vehicle detection data to outside of the sensor-nodes. If packet loss in the transmission occurred, it tries to resend by buffering and keeping acknowledgement status. TDMA mechanism [7] with time synchronization protocol is used for packet transmissions.



(a) S/W structure of a sensor-node

Item	Description
MCU	MSP430F2618T
RF Chip	CC2520 [8]
Magnetic Sensor	HMC1043 [9]
Battery	D-size

(b-1) Specification of a Magnetic Sensor Node H/W

(b-2) Appearance of a Magnetic Sensor Node

(b-3) Case of a Magnetic Sensor Node

(b) Specification and H/W appearance of a sensor-node

Figure 3. S/W and H/W of a sensor-node

communicable scope by relay some data packet from sensor-nodes to a base-station. Table II and Figure 3 show the S/W structure and H/W aspects of a sensor-node (The structure and specification of a gate-node is similar to those of a sensor-node except that a gate-node do not include magnetic sensors.) Normally, sensor nodes for vehicle detection are installed on surface of roads, and gate-nodes are installed on a pole on road-side. Therefore, sensor node packaging is different from that of a gate-node. Figure 2(b-3) shows the package of a sensor node.

To provide energy efficiency property, a sensor-node operates on sleep-and-wakeup concept to enlarge life-time of sensor nodes [10]. In other words, when there is no vehicle or specific events, the sensor node enters to sleep mode in which non-essential H/W components are in sleep, and if a vehicle is approaching or some timers are expired, the sensor node wakes up to process the required operations. The figure 4 shows this concept. Moreover, to maximize energy efficiency, more sophisticated method called "dynamic sleep-and-wakeup interval" is used. With the concept, the sensor nodes change some intervals of some node operations dynamically according to existence of a moving vehicle. That is, if it is decided that a moving vehicle exists, the signal sampling operations operates are executed on normal interval, and if it is assumed that there is no a vehicle on the sensor node, the interval of sampling operation is adjusted larger than that of normal.

E. Signal Processing and Vehicle Detection

A sensor-node detects a vehicle by analyzing variations of magnitude of magnetic fields occurred by a moving vehicle. Therefore, a baseline - the level of raw signal which can be obtained when there is no vehicles - is needed to be compared some raw signals acquired when a vehicle is moving. To reduce the complexity of magnetic signal

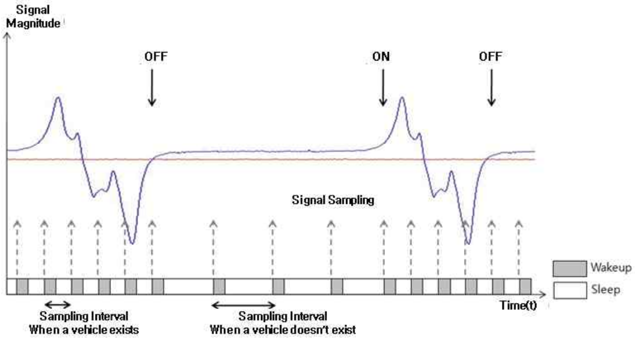
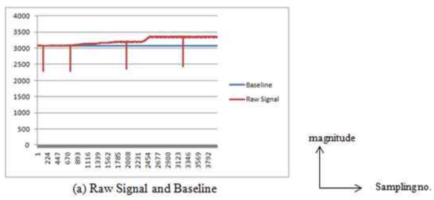


Figure 4. Dynamic sleep-and-wakeup interval mechanism

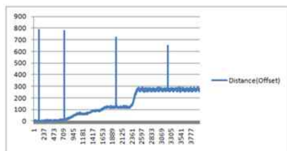
processing and vehicle detection algorithms, not raw magnetic signal values is considered, but pre-processed signals are used for vehicle detection.

Raw magnetic signals include some noises. Such noises should be removed to detect moving vehicles more clearly. There can be various methods to remove noises in raw signals. For example, the calculation of the average of recent N signals is the easiest method to alleviate noise effect. However, the average filter has a disadvantage, that is, it spreads the effect of noises to near signal samplings. In this paper, we adopt a method called interval-based average filter to remove noises. In the filter, if the difference of the magnitude of two signals – the first and the last of a given interval – is smaller than normal noise, all the signals between the two signals modified to the average of the two signals. To remove noises effectively using the interval-based average filter, the interval should be small enough to catch only noises. This filtering method doesn't spread the effect of noises to other signals and the length of the interval (width) and the normal noise level can be algorithm tuning parameters. Figure 5 shows the mentioned signal filtering concepts.

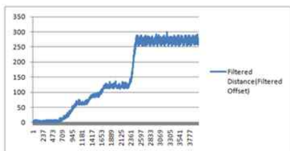
After filtering the raw magnetic signals, the filtered signal becomes to input data of the designed vehicle detection algorithm. In this paper, pattern-based vehicle detection algorithm is designed and used. Increase and decrease pattern of filtered signals can be abstracted as UP and DOWN pattern of which descriptions are followings.



(a) Raw Signal and Baseline



(b) Distance (Offset) between Raw Signal and Baseline



(c) Filtered Distance (Offset) between Raw Signal and Baseline

Figure 5. Magnetic signal filtering and processing for vehicle detection

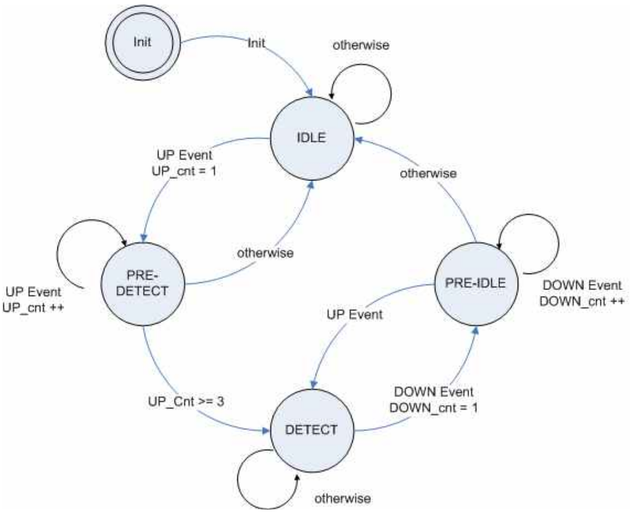


Figure 6. The state transition diagram to detect a moving vehicle

- UP
  The magnitude of magnetic signal increased more than given height during the given successive sampling interval.

- DOWN
  The magnitude of magnetic signal decreased more than given height during the given successive sampling interval.

The vehicle detection algorithm decides whether a vehicle exists or not based on the patterns of UP and DOWN. That is, for example, if successive UPs more than the number of a given value (as a parameter) are given, the algorithm decides that a vehicle is approaching, and, in like manner, if successive DOWNs more than the number of a given value (as a parameter) are given, the algorithm decides that a moving vehicle goes away from the position of the sensor-node. Figure 6 below shows such detection algorithm as a form of state transition machine diagram.

F. *Speed Calculation*

A base-station calculates speed \using vehicle detection data from sensor-nodes, distance between two sensor-nodes, and time data (clock ticks) of the vehicle detection. However, because the designed vehicle detection system collects data from wireless sensor network using TDMA communication mechanism, there can be several exceptional cases like below. The exceptions should be carefully designed because such exception processing can affect accuracy and performance of overall detection systems and services.

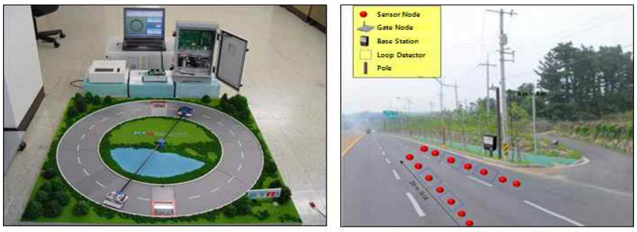
- Time synchronization error between the magnetic sensor network and a base-station
- Loss of ON or OFF data during wireless communication\
- Duplicated transmission of ON or OFF data due to possibilities of packet loss.

III. INDOOR AND OUTDOOR TEST-BEDS

To test and evaluate the vehicle detection system designed and implemented in this paper, several indoor tests and outdoor tests were prepared.

For the indoor tests, a small test-bed was prepared. Several magnetic sensor nodes and a small loop detector were installed on the indoor test-bed, and a model car rotates on the indoor test-bed. The rotation speed of the model car is controlled by external notebook and controller software. Figure 7(a) shows the indoor test-bed. The indoor tests was conducted during about 4 days, the overall accuracy of speed obtained by vehicle detection system related to that of the small loop system was about 98%, although some minor errors were also detected. Because indoor space had clean radio environments and there was just a test car, there were almost no transmission error and no packet loss.

To test the designed system in real-road environments, an outdoor test-bed was constructed as shown at the figure 7(b).



(a) Indoor test-bed (b) Outdoor test-bed

Figure 7. Indoor and Outdoor test-beds

The outdoor test-bed has eight magnetic sensor nodes, one gate-node and one base-station, and one loop system at the same place. The base-station compares the speeds obtained from the designed vehicle detection system and the loop system. The outdoor test is on-going and the results of the tests are being monitoring using a web-site. The overall results will come out about four month later. Analysis on the results of outdoor test-beds will be conducted intensively in various ways, and next paper will cover the analysis results.

IV. CONCLUSIONS AND FUTURE WORKS

In this paper, a vehicle detection system using magnetic sensor network was designed and implemented. Some requirements to be satisfied by the designed system were summarized. The S/W and H/W specification and design were introduced. Also, to test the designed system some indoor and outdoor test-beds were constructed. The result of indoor-tests was excellent, and several outdoor tests are on-going. As future works, some hard test in real-road environments will be conducted. As research topics, real-time vehicle classifications and accurate tracking of a moving vehicle are being considered.

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