Wireless Sensor Network for Traffic Monitoring

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***Abstract*—Intelligent Traffic Systems (ITS) management plays an important role in modern transportation systems. An important area in ITS research is the development of traffic monitoring systems that collect traffic information such as vehicle counting, speed measurements, and vehicle classification. This information allows for developing smart transportation systems that take into consideration the current traffic state in order to generate smart decisions. In this paper, we developed a Wireless Sensor Network (WSN) application for vehicle counting, vehicle classification, and speed measurement based on roadside magnetic sensors. Magnetic sensors can be deployed on the roadside to collect traffic data. Then, the data can be communicated using wireless channels to a central computer to be processed and analyzed. The traffic data will be saved in a database and can be shared with other transportation applications through the use of web services. This approach has many advantages includes real-time traffic monitoring, ensures proper monitoring of the roads, and requires less human intervention. The focus of this paper is on the development of the wireless sensor network and traffic data management. Simulated data is used to evaluate the system instead of deploying magnetic sensors. The software implementation of this paper is available at https://github.com/FadiHaq/WSN_TrafficMonitoring.**

***Index Terms*—Wireless Sensor Network (WSN), Intelligent Traffic Systems (ITS), Traffic Parameters, Anisotropic Magneto-Resistive (AMR) sensor.**

I. Introduction

Transportation is one of the most important human activities that have a major impact on economy and social interactions. It facilitates communication between various locations and it has a major influence on the flourishing of trade. On the other hand, it has side effects and negative impact on the environment due to pollution and emission of carbon dioxide. Traffic congestion causes significant amount of losses includes economic losses due to the traffic delay, increasing consumption of fuel, and increasing the chances of traffic accidents. One main cause of traffic congestion is the number of vehicles on road. The number of vehicles of all types is increasing constantly. More than 200 thousand vehicles are registered in the west bank according to the Palestinian Ministry of Transport of all types [1]. Such an increase led to saturation on many roads and semi-permanent congestion. Also, poor infrastructures of roads may cause congestion and traffic delay which can hinder the economic and social advancements of the area. Another important cause of traffic congestion is the traffic management system. Therefore, a smart traffic management system that can reduce traffic congestion will be invaluable. For example, by controlling the traffic light schedule dynamically based on the traffic flow parameters.

In order to improve the current traffic management systems, accurate real-time information about the traffic flow is necessary. This includes the number of vehicles, their types and speed. This information will allow developing ITS that minimizes total trip time. Furthermore, it will help engineering road networks where total trip time is minimized. Several technologies have been used to detect traffic flow parameters include: traffic count, vehicle size and weight, and vehicle speed. These technologies can be classified into two main categories, intrusive technologies and non-intrusive technologies. Intrusive technologies require the installation of the sensors onto or into the road service. This technology includes several devices such as, Bending Plate, Pneumatic Road Tube, Piezo-Electric Sensor, and Inductive Loop [2]. On the other hand, Non-Intrusive technologies do not interfere with the traffic flow either during installation or during operation. Non-intrusive devices include Passive and Active Infrared, Passive Magnetic, Microwave Doppler/Radar, Ultrasonic and Passive Acoustic, and Video Image Detection. Each of these technologies has its own limitation [2]. For instance, Video image detection requires expensive processors and sensitive to weather condition. Other technologies require high cost or have a small range of applications [3]. No matter which technology is used to measure the traffic flow parameters, this data must be communicated from road sites to a base station efficiently and reliably. Once the data is available in the base station, it can be processed, analyzed, saved and shared with other users. Also, the data can be made available to other computer applications through the use of web services which allow creating a smart traffic management system. The focus of this paper is on developing an application that allow gathering the data from the road sites, communicating the data to the base station through wireless channels, storing the data in a database, and making the data available to other users includes human or computer application. This paper does not focus on measuring the traffic road parameters themselves. Instead, we used a simulated data to evaluate our system.

In recent years, an efficient design of a Wireless Sensor Network (WSN) [4] received significant attention. A Sensor is a device that detects changes in a particular environment conditions, such as pressure, heat, light, earth magnetic field strength, etc. The output of the sensor is an electrical signal that is transmitted to a micro-controller for further processing. The gathered data from the sensors is then communicated using WSN to a base station computer for further processing. Software in the base-station can be used to determine the traffic flow parameters in the road network and triggers actions in the environment based on the collected data. Or, the data can be communicated to the cloud where it can be further processed, saved, and shared.

The use of Wireless Sensor Network in automatic management system has received attention in multiple domains. This include smart hospital [5] and smart agriculture [6]. The need and challenges of the integration of WSN and cloud computing and how they are approached are discussed as well [7] [8] [9] [10]. In transportation, Kafi et. al. [11] conducted a study of using WSN for Urban traffic monitoring. A smart traffic system that uses wireless sensor network was presented in [12]. Also, WSN was used in the design of a traffic Jams Avoidance [13], road safety [14], and traffic surveillance in smart cities [15].

In this paper, we designed our system assuming anisotropic magneto-resistive (AMR) magnetic sensors to be used as a sensing device. AMR sensors have been used to classify vehicles [16]. The rest of the paper is organized as follows. In section §II the system design and architecture with sensing system configuration is discussed. The hardware components, the implementation, and the results are described in Section §III. The conclusions is presented in Section §IV.

II. System Architecture

In this section, we show the design and architecture of the traffic monitoring system. The design consists of a software and hardware components. The hardware components consist of a WSN, magnetic sensors, and a base station. The software component includes a database to store the traffic parameters, a dashboard to visualize the traffic parameters (count, speed and classification of detected vehicle), and a web service interface to allow accessing the traffic data from other application. Figure 1 illustrates the architectural design of the traffic monitoring system. As shown in the figure, the WSN consists of four main components: sensor nodes, a gateway, a base station, and an Internet server. Sensor nodes gather the data from their attached sensors and process it to extract traffic parameters (count, shape, and speed). Then, through wireless links, they communicate this data through a gateway (coordinator node) to the base station. The gateway is connected to a base station computer which has unlimited computational resources, enhanced radio communication and unlimited power supply. The application running on the base station gathers the information from the WSN and communicates this information to a web server on the cloud. The web server saves the data in a database. In the following subsections, we further describe these elements and the main technologies that we used to implement them.

A. Sensing System

Our approach in this paper considers the use of magnetic sensors to measure the traffic parameters. In this approach, the earth magnetic field at a particular location on the side of the road is measured using a magnetic sensor. Once a vehicle passed by the sensor, the earth magnetic field in that location is perturbed. The perturbation in the earth magnetic field can be detected. Consequently, the number of vehicles passed by the sensor, the speed of the passing vehicle, and the size of the vehicle can be inferred from the perturbed signals measured by multiple sensors as described at the end of this section.

Our system design considers the use of the AMR Honeywell HMC2003 [17] magneto resistive sensor shown in Figure 2 that will be used in our future work. The HMC2003 is a highly-sensitive, three-axis magnetic sensor assembly used to measure low magnetic field strengths. It is capable of measuring 1/10000 of the earth magnetic field which makes it capable of detecting small perturbation in the earth magnetic field caused by passing vehicles. This sensor can measure the magnetic field along the x, y, and z axes. Figure 3 shows a possible configuration of the proposed sensing system which includes three three-axis AMR sensors placed on the side of the road to detect passing vehicles for the purpose of counting them and estimating their speed and size [18].

- Vehicles detection and counting: The signals along the z-axis have almost the same patterns for a large variety of vehicles. Hence, the magnetic readings of the z-axis of sensor 1 can be used for detecting and counting the passing vehicles.
- Speed estimation: The speed of the passing vehicle can be estimated by using two longitudinally spaced magnetic sensors (sensor 1 and sensor 2) as shown in Figure 3. Assuming the distance between the two sensors is $d_{1,2}$, the speed of the vehicle can be estimated from the detection time of the two sensors. If the detection time of sensors 1 and 2 are T_1 and T_2, the speed of vehicle can be calculated as:

$$v = \frac{d_{1,2}}{T_2 - T_1}$$

- Vehicles Classification: The proposed classification approach is based on using the size of magnetic disturbance. Multiple magnetic sensors can be placed at different location from the road. Then a correlation analysis or machine learning classification approach can be used to provide an estimate of the vehicle size. In Figure 3, we show a possible placement of a third sensor (sensor 3) vertically above sensor 1. The magnetic signals along the z-axis have patterns for different types of vehicles. Therefore, magnetic readings of the z-axis from multiple sensors can be used to give an estimate of the vehicle size as discussed in [18].

Each node placed in a particular location gathers the magnetic field disturbance information resulting from vehicles passing from multiple attached sensors. This

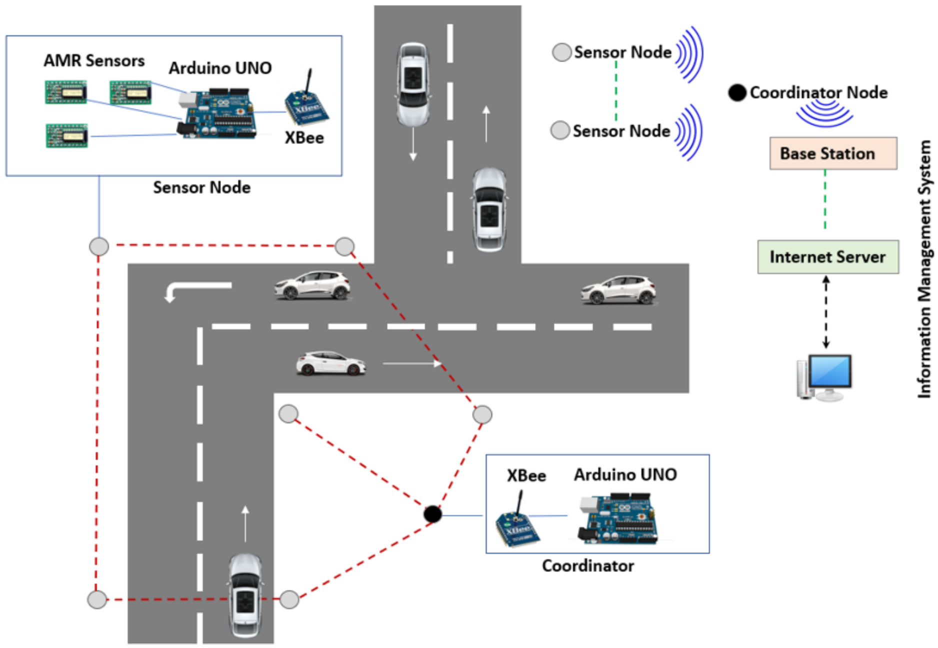

Fig. 1. System Architecture

information can be transferred to coordinator node using radios signals.

B. Wireless Sensor Network

An important part of the system architecture is the WSN shown in Figure 1. A WSN is a group of wireless sensor nodes distributed at different locations by the road side. Multiple magnetic sensors can be attached to a sensor node to sense perturbation in the earth magnetic field. Then, these perturbed signals can be used to determine the traffic parameters. Once a sensor node identifies a passing vehicle, it transfers this information to the master node. The master node is a special node that acts as a sink where information from all wireless nodes are transferred to the base-station through it. The master node (Coordinator) is connected to the base station computer. The base station computer is connected to the web application, which is a shared place for processing, managing, and saving the data in a database.

Fig. 2. Honeywell HMC2003

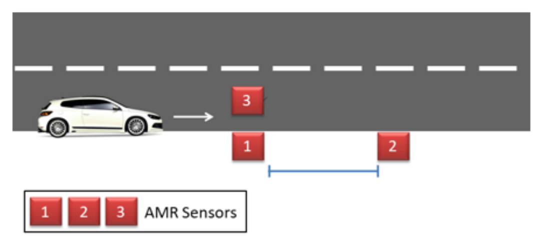

Fig. 3. A possible configuration of sensing system. Sensor 2 is placed longitudinally from sensor 1. Sensor 3 is placed vertically above sensor 1.

The WSN is developed based on the open source hardware platform Arduino Uno and XBee radios [19] for wireless communications. Arduino microcontrollers are open-source computing platforms based on a simple microcontroller board and a software development environment. The Arduino Integrated Development Environment (IDE) is based on the Processing programming language. It can be used to develop interactive applications that gather data from a variety of sensors and control a variety of actuators. Arduino applications can be standalone or they can interact with software running on a computer or on the cloud.

Wireless nodes, in a WSN, communicate with each other through XBee radio modules. XBee modules operate on a 2.4 GHz frequency band. Our choice to use Arduino is due to its flexibility to be customized and extended. It offers a digital and analog inputs as well as a digital and analog outputs. Further, it is easy to program and it can communicate with a computer through the USB serial port. In order to save power, XBee modules can be configured to enter into a sleep mode. In our design, the coordinator XBee, which is connected to the base station, is set to be awake all the time waiting for incoming data. The XBee modules of the sensor nodes are set to be on cyclic sleep mode. This allows an XBee module to sleep for a set amount of time. In order to reliably communicate data between the coordinator and the sensor nodes, a custom packet is created. The first byte in the packet is the header byte with a fixed value of 0x7E, the next field is the node ID, followed by the data bytes which includes the signals along the x, y and z- axes, followed by the last byte which is the checksum byte. In the following, we describe the process of these two nodes.

- Sensor Node process: The Arduino microcontroller in each sensor node reads the analog values of the magnetic field along the three axes given by the AMR sensor. These values can be used to detect if a vehicle is passed. If these values indicate a passing vehicle, the current time, the vehicle class, and the vehicle speed are assembled into a packet and sent to the coordinator in API mode. The process of the sensor node is shown in Figure 4.
- Coordinator Node process: The coordinator node is connected directly to the base station computer through the USB port. It gathers the data from the sensor nodes through wireless channels and passes it to the base station through the serial port.

C. Base Station Application

The base-station application listens to the serial port. Once the application reads a header byte, it knows it is the beginning of a new packet and it disassembles the packet and extracts the source node ID and the received data. The data with the real timestamp are then logged in a backend database. The application also shows a simple visual interface and displays the received data. The application allows the search for the traffic parameters within a specified date and time and displays the results as statistical charts. The database consists of a single table with the attributes (sensor ID, vehicle class, detection date, detection time, and vehicle speed). The base station process is shown in Figure 5.

III. Implementation and Results

In this section we describe the implementation and the evaluation of our system. The complete software code is available on github [20].

A. Hardware Components

The main components of a Wireless Sensor Node are: the microcontroller, Radio Frequency transceiver (RF), power source, and several attached sensors. There are several technologies that can be used to implement a WSN. The main difference between these technologies is the tradeoff between the ease of use and the cost. Another difference is the communication protocol that they support. In this project, we used the XBee module for the short-range low-power wireless communication. For the microcontroller, we used the Arduino Uno. For the environment sensors, we considered to use the HMC2003 [17] magnetic sensor in the future work.

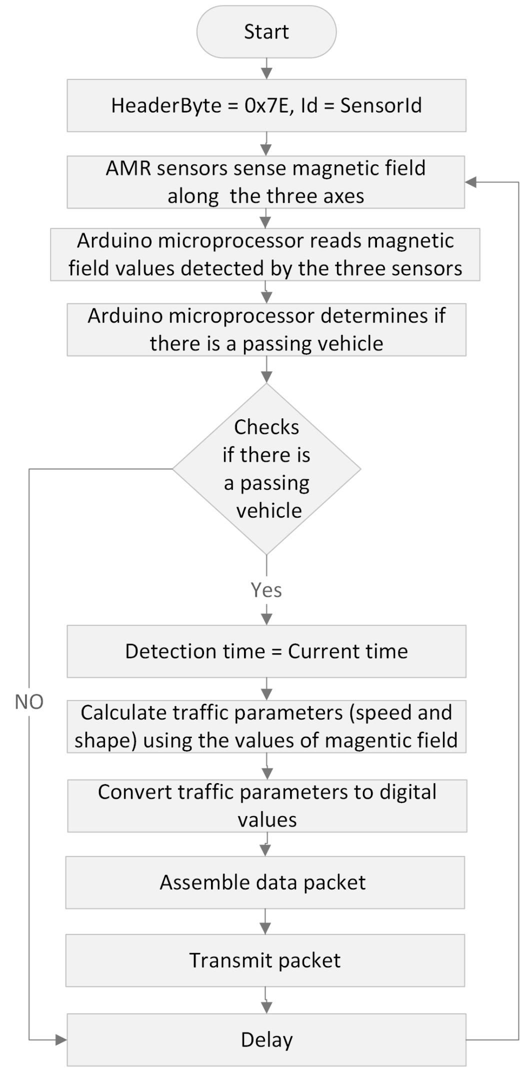

Fig. 4. Sensors Node Process.

Arduino microcontroller is the option chosen which covers all requirements. It allows the designers to control and sense the external electronic devices in the real world. Therefore, it is considered the core of a wireless sensor node. It collects data from the sensors, processes this data, decides when and where to send it, and receives data from other sensor nodes. It has to execute various programs, ranging from signal processing and communication protocols to application programs.

For the software, we used X-CTU software provided from Digi which allows us to set up the XBee modules for wireless connection. The X-CTU configures XBee module parameters such as the Node identification, destination address, PAN Id, operating channel, or applying configuration changes.

B. Evaluation

We decided to simulate the sensors data by creating a function that generates random data as an alternative to the magnetic sensor reading since the focus of this paper is

TABLE I
CONFIGURATION OF XBEE END DEVICES AND COORDINATOR

	Coordinator	End Device 1	End Device 2	End Device 3
Channel Number	C	C	C	C
PAN ID	1001	1001	1001	1001
Destination High	0	0	0	0
Destination Low	1	4	4	4
MY Address	4	1	2	3
Node Identifier	Coordinator	Sensor Node 1	Sensor Node 2	Sensor Node 3
Coordinator Enable	Coordinator	End Device	End device	End Device

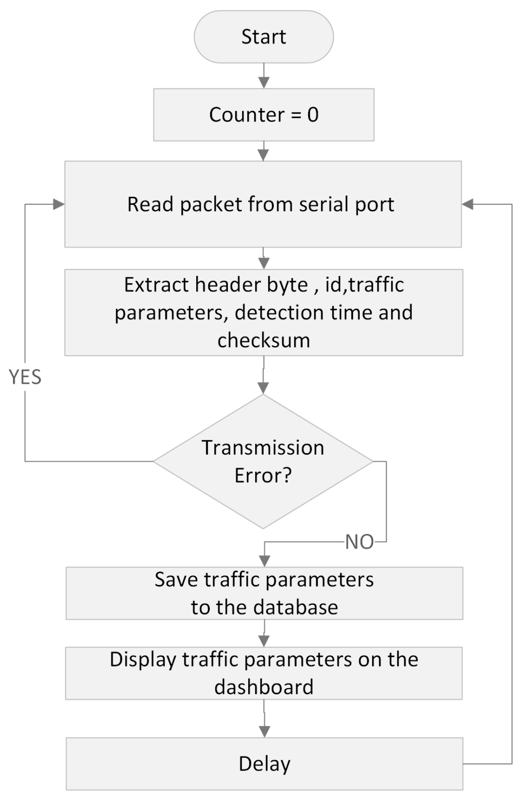

Fig. 5. Base station process

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7E 00 12 81 00 01 47 02 00 64 17 06 00 00 07 E3 10 25 19 00 4D 2E
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Fig. 6. API frame received in hex by coordinator

on building the wireless sensor network and the data communication and not the application of the magnetic sensor itself. In this simulation, each sensor node generates a random vehicle speed and size at random time, and sends them to the coordinator node. The coordinator node receives API frames from sensor nodes like the one shown in Figure 6 and writes them to the serial port in the order they received.

Before the wireless nodes can communicate with each other, they must be configured. The configurations of the XBee modules on the sensor and coordinator nodes are shown in Table. 1. After the configuration process complete, all XBee

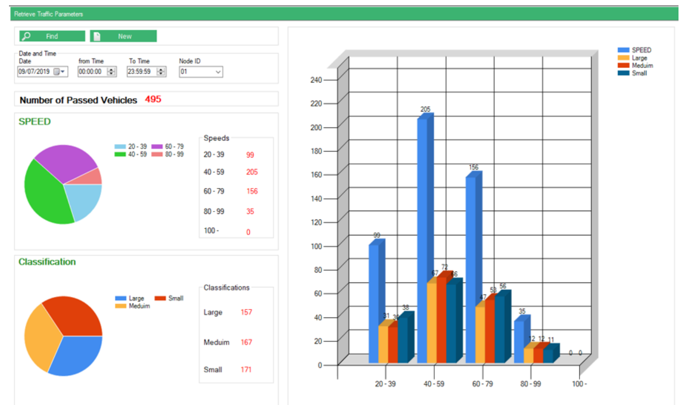

Fig. 7. Sstatistical retrieved traffic parameters collected from the node 1.

modules can exchange data. The coordinator node gathers the packets from the sensor nodes and writes them to the serial port, which is connected to the base station computer. The base station application reads packets from the serial port, extracts traffic parameters from the packets and stores them in a database as described in §II. The main tasks of a sensor node in this simulation are:

1) Define the 16-bit address of the coordinator XBee module which is 0xFFFF.
2) Setup sleep mode.
3) Generate a random vehicle speed drawn from the normal distribution with a mean of 55 and a standard deviation of 18. Also, randomly select the size of the vehicle from the list (small, medium and large).
4) Set the detection date and time as the current date and time.
5) Assemble the packet from the simulated traffic parametrs and the detection time.
6) Send the packet to the coordinator node, wait for 5 seconds and repeat.

To validate our system, we have created a Windows application that retrieves traffic parameters from the database and displays them to the user. The application allows the user to select the time interval and the sensor node ID. Data collected from a particular node corresponds to the traffic parameters at the location of the node on the road. The traffic parameters are displayed to the user in the form of pie charts and histogram. Figure 7 illustrates the application's output screen. The figure shows the traffic parameters collected from node 1 in a particular interval. The top pie chart displays the distribution of vehicles speed in that location in the specified interval. The lower pie chart displays the distribution of vehicles sizes in the same time interval. The histogram in the right side of the figure shows the number of cars for each vehicle size in a speed category.

IV. Conclusion

In this paper we provided an architectural design for an automatic traffic monitering system that evaluates the main traffic parameters which includes, traffic count, speed, and vehicle size. This information is crucial and necessary for desining and developing an intellegent traffic system. The paper focuses on the implementation of the Wireless Sensor Network component of this system only. We are currently integrating the AMR magnetic sensor to be used in this environment.

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