ABSTRACT

FIRMWARE AND CLASSIFICATION ALGORITHM DEVELOPMENT FOR VEHICLE CLASSIFICATION

By

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Vehicle classification is one of the active research topic in Intelligent Transport System. This project proposes an approach to classify the vehicles on freeway with respect to the size of the vehicle. This vehicle classification is based on threshold based algorithm. This system consists of two AMR magneto-resistive sensors connected to TI msp430 development board. The data collected from the two magneto resistive sensors is analyzed and supplied to threshold based algorithm to differentiate the vehicles. With the use of minimum number features extracted from the data it was possible to produce very efficient algorithm that is capable of differentiating the vehicles.

FIRMWARE AND CLASSIFICATION ALGORITHM DEVELOPMENT FOR VEHICLE CLASSIFICATION

A PROJECT REPORT

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CHAPTER 1

INTRODUCTION

With the increase in traffic, the congestion in freeways and streets is increasing and it has become out of control in major cities of the nation. Over the decades this traffic congestion has become one of the major challenges that needs to be addressed. According to the estimation by the U. S. Department of Transportation the traffic will increase 40% by 2020 due to increase in mobility. Thus there is a need for very efficient and cost effective technology which can provide a good solution to this problem. With the use of advanced traffic control mechanisms it is possible to design an Intelligent Traffic System (ITS) [1]. ITS aims at providing solution for traffic analysis and control with advanced sensing techniques.

Advancement in the field of MEMS (Micro-Electro-Mechanical System) has made it easy to build a sensor node with miniaturized RF transceiver and low power microcontroller. These wireless sensor nodes are now replacing the traditional wired sensor system. In addition, these wireless MEMS sensor nodes are very cost effective, easy to install and maintain compared to traditional inductive loop sensors that are currently being used to collect the traffic data.

It is evident from the Fig 1 that induction loop sensor has a dimension of 6ft x 6ft and wired to get the power supply. The installation and maintenance of this system is complicated compared to wireless sensor nodes, which are very small and use less power and data can be transmitted easily to control unit for more analysis.

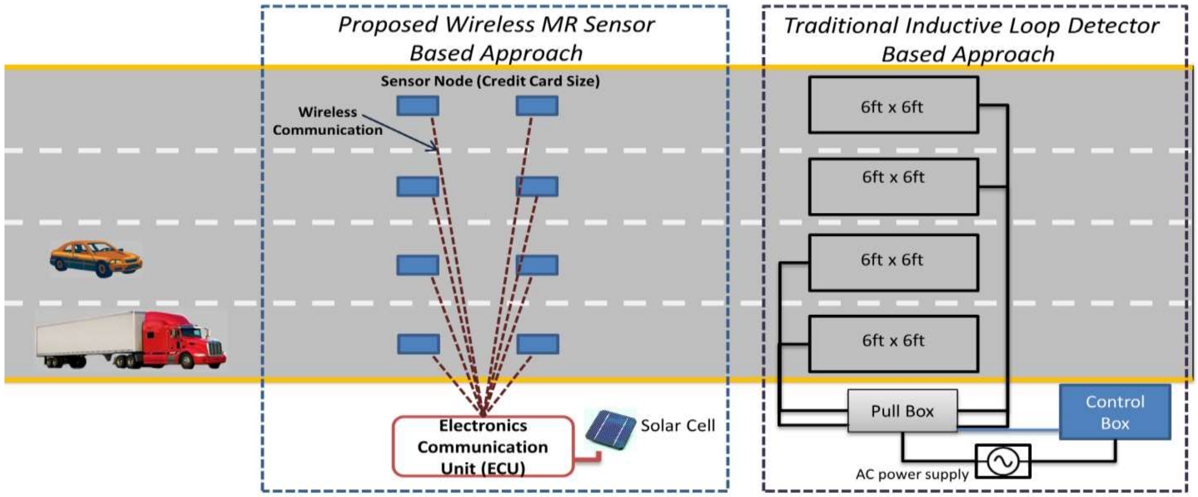

FIGURE 1 Comparison of wireless MR sensor based approach with induction loop based approach.

This project aims at providing a base line to develop Intelligent Traffic System as the one shown in Fig 1 by developing firmware for the sensor node to collect the data. Moreover, this project aims at providing an initial approach for vehicle detection and classification by building a testbed with wooden frame and sensor node attached to it. Three RC cars are used to collect the data and develop initial algorithm for vehicle classification.

CHAPTER 2

RELATED WORKS

As an interesting and active research topic many research groups are working on vehicle classification to provide very efficient algorithm. The work proposed by B. Yang, Y. Lei [2] uses triple axis AMR sensor to collect the vehicle magnetic signals from low speed vehicles. The proposed algorithm classifies the vehicles based on threshold state machine algorithm. Proposed algorithm makes use of five features extracted from the data obtained from AMR sensors. Also the use of FFT in the computation makes the algorithm complex and time consuming.

Similar work proposed by S. Kaewkamnerd et al. [3], [4] uses two AMR sensors attached to a microcontroller. Algorithm is based on decision tree with the data obtained by extracting various features from the signal received from the AMR sensors. The features extracted involves calculating of vehicle length, averaging of signals obtained from sensor, hill pattern comparison and energy estimation of the signals. This involves lots of computation.

The work done by I. Jolevski et. al [5] has almost the same approach as our proposed work in terms of conservation of energy. As discussed in this paper on of the best approach to conserve energy is to get only required number of samples to process and obtain higher classification rate. Although the sampling rate used is 50Hz the accuracy in the result is low when compared to the result obtained from our proposed method.

The work proposed by S. Taghvaeeyan et. al [6] is very interesting and follows different approach to classify the vehicles. Here the sensor node is placed on the side of the road which can classify the vehicles passing in the immediate adjacent lane. In order to cancel the noise added by the vehicles passing non adjacent line an algorithm based on magnetic signal model is used which reduces the false call error from 8% to 1%. Even though the results are based on robust algorithm, use of support vector machine and noise cancelling algorithm requires more energy for computation.

Authors used magnetic sensor for vehicle detection and signals from magnetic sensors are analyzed to get vehicle count, occupancy time, classification and speed. Here in [7] threshold based algorithm and state machines are used to get vehicle count and vehicle detection. With sampling rate of 40 three samples, normalized vehicle length, averaged vehicle energy and hill pattern are extracted and used for vehicle classification. The classification algorithm makes the decision based on the calculated length of the vehicle [7].

Similar study was done by B. Yang, Y. Lei [2] which uses fixed threshold based machine learning algorithm to detect the vehicles. The features extracted are energy of signal, signal duration, average energy of signal, ratio of x axis signal, and ratio of positive and negative energy of signal for x axes and y axes. Classification is based on hierarchical tree methodology. Furthermore vehicle speed is not more than 40 mph. The average classification accuracy is 93.66%.

In Y. He et. al [8], novel algorithm is proposed using single point magnetic sensor. Feature extracted are processed using filter-filter wrapper model. The original waveform is converted into numerical format using data fusion technology. This provides vehicle classification based on clustering support vector machines. The cross validation results of 460 samples shows classification results more than 99%. Here the different algorithms, Fuzzy discrimination, back propagation artificial neural network and k nearest neighbor are compared with proposed algorithm. The proposed algorithm is complex and uses number features which requires more computation time.

Lan et al. [9] propose vehicle classification and detection using MEMS magnetic sensor. The magnetic signal measured by MEMS magnetic senor is related to type of vehicle and moving direction. The convexity and concavity areas and angles of that part of waveform are extracted. An improved support vector machine (ISVM) classifier is developed for vehicle detection and classification. The detection rate is low because of the use of single sensor.

In Zhang et al [10], the proposed work uses low cost and high sensitive magnetic sensors for vehicle detection via adaptive threshold technique. The vehicle length is estimated with the geometrical characteristic of the proximity sensor network. On-road experiments and simulations show high results up to 90% accuracy. In this work authors have developed magnetic sensor based vehicle detection and magnetic sensors are deployed as binary proximity sensor network to detect magnetic field distortion with a distributed threshold, and length of the vehicle is estimated via geometric characteristic of the topology. Neural network algorithm is used to identify vehicle type.

The main aim of this work is to provide a simple and efficient algorithm which can get better results. This proposed method uses very few features which are very easy to extract and simple computations to get 97.7% efficient result. Sampling rate used is 15Hz to get the good number of samples during the detection window. Then simple threshold based algorithm is used to classify the vehicles. The features extracted are maximum value, minimum value and hill pattern of Z axis.

CHAPTER 3

METHODOLOGY

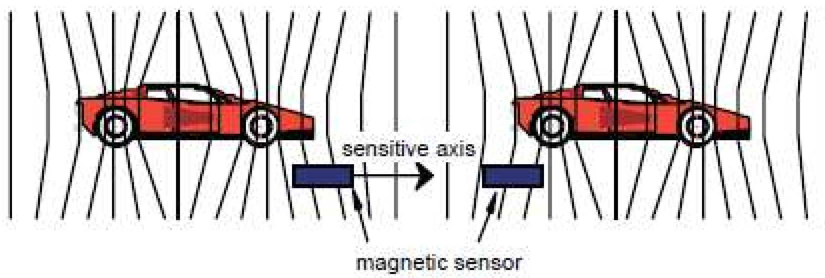

FIGURE 2. Magnetic sensor reading the defection in earth's magnetic field.

Magnetic field sensing is widely used by many magnetic sensors to detect the presence, strength and direction of earth's magnetic field. These magnetic sensors can be classified based on magnetic field sensing range. Magnetic sensor used in this project is AMR sensor which is also called as earth's field sensor [13]. The field sensing range is 1 microgauss to 10 gauss.

When an object made up of metal or containing a good amount of metal is passed over these AMR sensors, the sensor measures the deflection in earth's magnetic field at that place. With the thorough analysis of this change in magnetic field it is possible to detect the presence of the object and also by using this magnetic field data it is possible to classify the objects based on the amount metal in that object.

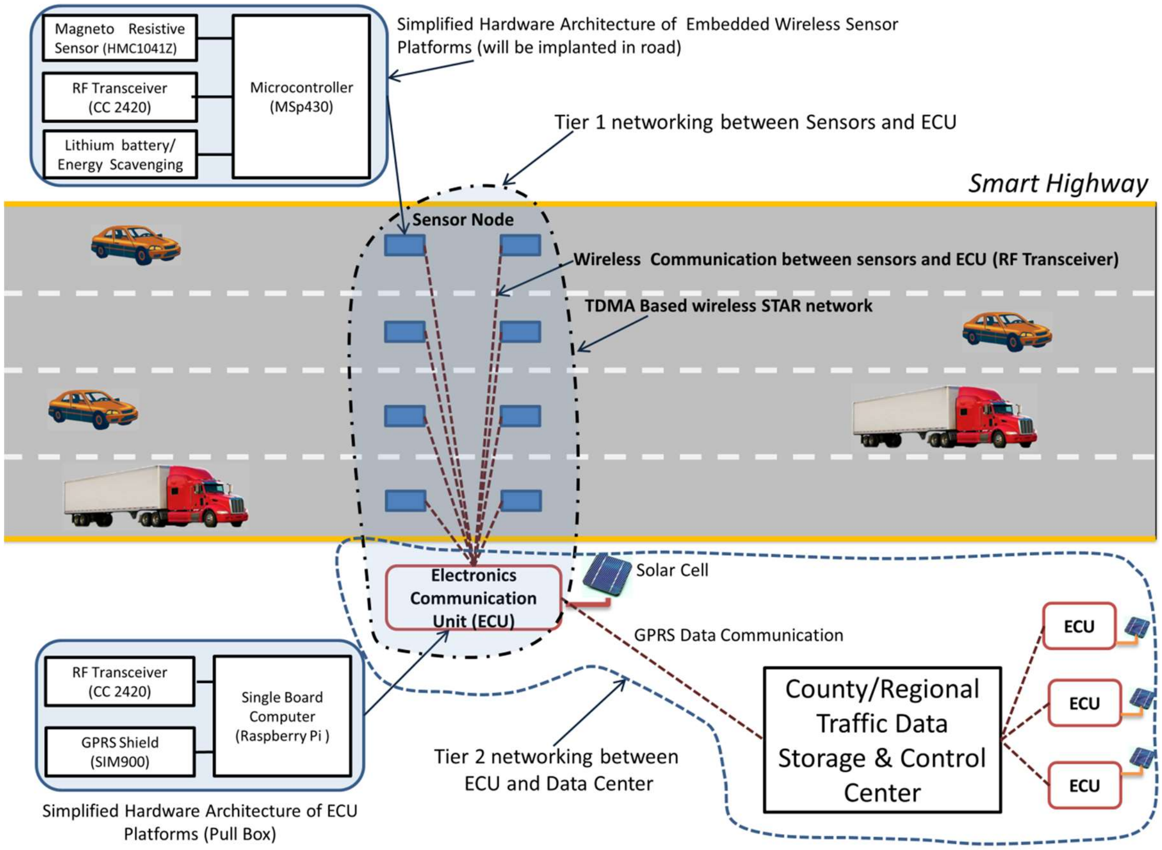

FIGURE 3. Intelligent traffic system with wireless sensor nodes.

The fig 3 shows the scenario of ITS in action. Sensor nodes containing microcontroller, AMR sensor, RF transceiver and power supply is installed in the road. When the vehicle is passed on the sensor node the data collected will be transmitted to ECU (Electronic Communication Unit). Collected data will be transmitted to the regional traffic data center from ECU.

CHAPTER 4

SENSOR NODE

Sensor node contains microcontroller and AMR sensor. Honeywell's HMC5883L AMR sensor is interfaced with Texas Instruments MSP430 microcontroller development board. I^2C communication protocol is used for data transmission between the AMR sensor and MSP430 development board. Data collected from the sensor node is sent to computer through UART for vehicle detection and classification.

HMC5883L Magnetometer

Honeywell HMC5883L is a triple axis magnetometer which utilizes the Honeywell's Anisotropic Magnetoresistive (AMR) technology. This sensor is designed for low field magnetic sensing and has digital interface for applications such as magnetometry and compassing. Because of the AMR technology this sensor has advantages over other magnetic sensor technologies. The reason for using this particular sensor in this project is sensitivity and very reliability for low field data collection.

HMC5883L package includes high resolution HMC118X series magneto-resistive sensors, ASIC containing amplification automatic degaussing strap drivers, offset cancellation, and a 12-bit ADC, and an I^2C interface for easy interface [11].

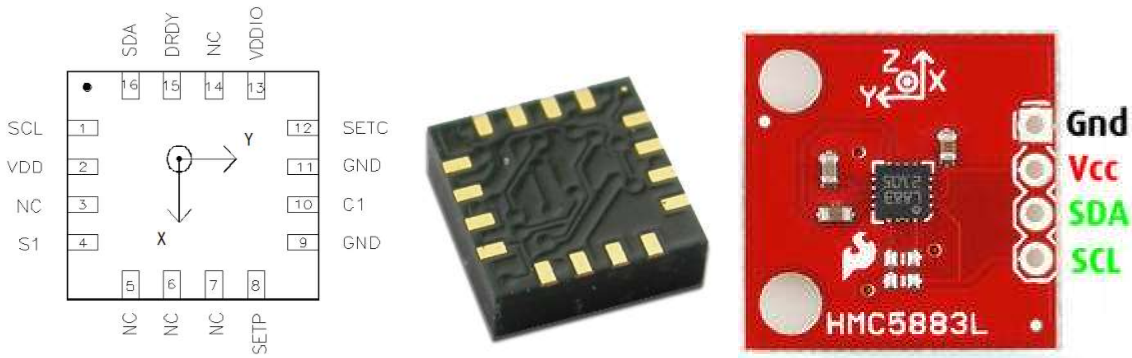

FIGURE 4. HMC5883L package, pin diagram and breakout board.

TABLE 1. HMC5883L Pin Description.

Pin	Name	Description
1	SCL	Serial Clock – I^2C Master/Slave Clock
2	VDD	Power Supply (2.16V to 3.6V)
3	NC	Not to be Connected
4	S1	Tie to VDDIO
5	NC	Not to be Connected
6	NC	Not to be Connected
7	NC	Not to be Connected
8	SETP	Set/Reset Strap Positive – S/R Capacitor (C2) Connection
9	GND	Supply Ground
10	C1	Reservoir Capacitor (C1) Connection
11	GND	Supply Ground
12	SETC	S/R Capacitor (C2) Connection – Driver Side
13	VDDIO	IO Power Supply (1.71V to VDD)
14	NC	Not to be Connected
15	DRDY	Data Ready, Interrupt Pin. Internally pulled high. Optional connection. Low for 250μsec when data is placed in the data output registers.
16	SDA	Serial Data – I^2C Master/Slave Data

Working of the Sensor

When the power is supplied to the sensor it reads the incident magnetic field along the direction of the three axis (as shown in the fig 4.3) and converts the magnetic field deflection in to differential output voltage. This sensor is made up of thin film of nickel-iron, this is the resistive material and in the presence of the magnetic field the change in the bridge resistance makes the corresponding change in the voltage across the bridge elements.

Steps involved in single measurement are, the ASIC

1. Sends a Set pulse.

2. Takes one measurement (Mset).

3. Sends a Reset pulse.

4. Takes another measurement (Mreset).

5. Puts the following output in sensor's data output register.

Output = [Mset – Mreset] / 2.

This type of measurement is done to remove the sensor offset and temperature dependency.

<u>Initialization of the Sensor</u>

These registers are needed to be set with the corresponding values to get the desired output.

TABLE 2. Register List

Address Location	Name	Access
00	Configuration Register A	Read/Write
01	Configuration Register B	Read/Write
02	Mode Register	Read/Write
03	Data Output X MSB Register	Read
04	Data Output X LSB Register	Read
05	Data Output Y MSB Register	Read
06	Data Output Y LSB Register	Read
07	Data Output Z MSB Register	Read
08	Data Output Z LSB Register	Read
09	Status Register	Read
10	Identification Register A	Read
11	Identification Register A	Read
12	Identification Register A	Read

Configuration Register A is used to set the data output rate and the measurement configuration. The register bits and the designated functions are as follows.

TABLE 3. Configuration Register A

CRA7	CRA6	CRA5	CRA4	CRA3	CRA2	CRA1	CRA0
(0)	MA1(0)	MA0(0)	DO2(1)	DO1(0)	DO0(0)	MS1(0)	MS0(0)

TABLE 4. Configuration Register A Bit Designations

Location	Name	Description
CRA7	CRA7	Bit CRA7 is reserved for future function. Set to 0 when configuring CRA.
CRA6 to CRA5	MA1 to MA0	Select number of samples averaged (1 to 8) per measurement output. 00 = 1(Default); 01 = 2; 10 = 4; 11 = 8
CRA4 to CRA2	DO2 to DO1	Data Output Rate Bits. These bits set the rate at which data is written to all three data output registers.
CRA1 to CRA0	MS1 to MS0	Measurement Configuration Bits. These bits define the measurement flow of the device.

.

TABLE 5. Data Output Rates

DO2	DO1	DO0	Typical Data Output Rate (Hz)
0	0	0	0.75
0	0	1	1.5
0	1	0	3
0	1	1	7.5
1	0	0	15 (Default)
1	0	1	30
1	1	0	75
1	1	1	Reserved

TABLE 6. Measurement Modes

MS1	MS0	Measurement Mode
0	0	Normal measurement configuration (Default). In normal measurement configuration the device follows normal measurement flow.
0	1	Positive bias configuration for X, Y, and Z axes. In this configuration, a positive current is forced across the resistive load for all three axes.
1	0	Negative bias configuration for X, Y and Z axes. In this configuration, a negative current is forced across the resistive load for all three axes.
1	1	This configuration is reserved.

So by observing the table of configuration register A we can say that sensor is set to have

1. 0 sample averaging.

2. 15Hz sampling rate

3. Normal measurement mode.

Configuration register B is used to set gain. The register bits and the designated functions are as follows.

TABLE 7. Configuration Register B

CRB7	CRB6	CRB5	CRB4	CRB3	CRB2	CRB1	CRB0
GN2(0)	GN1(0)	GN0(1)	(0)	(0)	(0)	(0)	(0)

TABLE 8. Configuration Register B Bit Designations

Location	Name	Description
CRB7 to CRB5	GN2 to GN0	Gain Configuration Bits. These bits configure the gain for the device. The gain configuration is common for all channels.
CRB4 to CRB0	0	These bits must be cleared for correct operation.

.

So by observing the table of configuration register B we can say that sensor is set to have a gain of 1090 LSb/Gauss.

Mode register is used to set the operating mode of the sensor. The register bits and the designated functions are as follows.

TABLE 9. Mode Register

MR7	MR6	MR5	MR4	MR3	MR2	MR1	MR0
HS(0)	(0)	(0)	(0)	(0)	(0)	MD1(0)	MD0(1)

TABLE 10. Operating Modes

MD1	MD0	Operating Mode
0	0	Continuous - measurement mode. In continuous - measurement mode, the device continuously performs measurements and places the result in the data register. RDY goes high when new data is placed in all three registers. After a power - on or a write to the mode or configuration register, the first measurement set is available from all three data output registers after a period of $2/f_{DO}$ and subsequent measurements are available at a frequency of f_{DO}, where f_{DO} is the frequency of data output.
0	1	Single - measurement mode (Default). When single - measurement mode is selected, device performs a single measurement, sets RDY high and returned to idle mode. Mode register returns to idle mode bit values. The measurement remains in the data output register and RDY remains high until the data output register is read or another measurement is performed.
1	0	Idle Mode. Device is placed in idle mode.
1	1	Idle Mode. Device is placed in idle mode.

So by observing the table of mode register we can say that sensor is set to operate in single–measurement mode.

Summarizing the initialization process, the pseudo code to initialize and get the data from sensor in continuous–measurement mode is as follows.

1. Write CRA(00)–send 0x3C 0x00 0x70 (8-average, 15Hz default, normal measurement)

2. Write CRB(01)–send 0x3C 0x01 0xA0 (Gain=5).

3. Write Mode(02)–send 0x3C 0x02 0x00 (Continuous–measurement mode)

4. Wait 6 ms or monitor status register or DRDY hardware interrupt pin

5. Loop

Send 0x3D 0x06 (Read all 6 bytes.)

Convert three 16-bit 2's compliment hex values to decimal values and assign to X, Y, Z respectively.

Send 0x3C 0x03 (point to first data register 03).

Wair about 67ms (if 15Hz rate or monitor status register or DRDY hardware interrupt pin.

End_Loop.

Data transfer begins with issue of START signal by msp430 and the AMR sensor address follows the START signal. AMR sensor address byte contains 7 bit address (0x1E) and LSB for read/write bit. At the 9^{th} clock pulse sensor issues the ACK (or NACK). After this the msp430 will send the data for write operation or the sensor will clock the data with read operation. Data transmission will be terminated with the issue of STOP signal by msp430.

I^2C Protocol

I^2C Inter Integrated Circuit protocol was designed by Phillips Semiconductors (now NXP Semiconductors) for communication between components on same board. It is also called as two wire bus as it uses Serial Clock (SCL) and Serial Data (SDA) for clock and data transfer. The available clock speeds are 0–100 KHz, 0–400 KHz, 0–1 MHz, 0–3.4 MHz

Each device connected to the bus is software addressable with unique address. As in the case of AMR sensor the address is 0x3C / 0x3D depending on read or write operation. I2C has simple master–slave relationship and also supports multi master mode with bus arbitration. Connection mode used here is simple master–slave arrangement.

Master is a device which initiates the data transfer and generates the clock signal to permit the transfer. The device which is being addressed by the master is called slave.

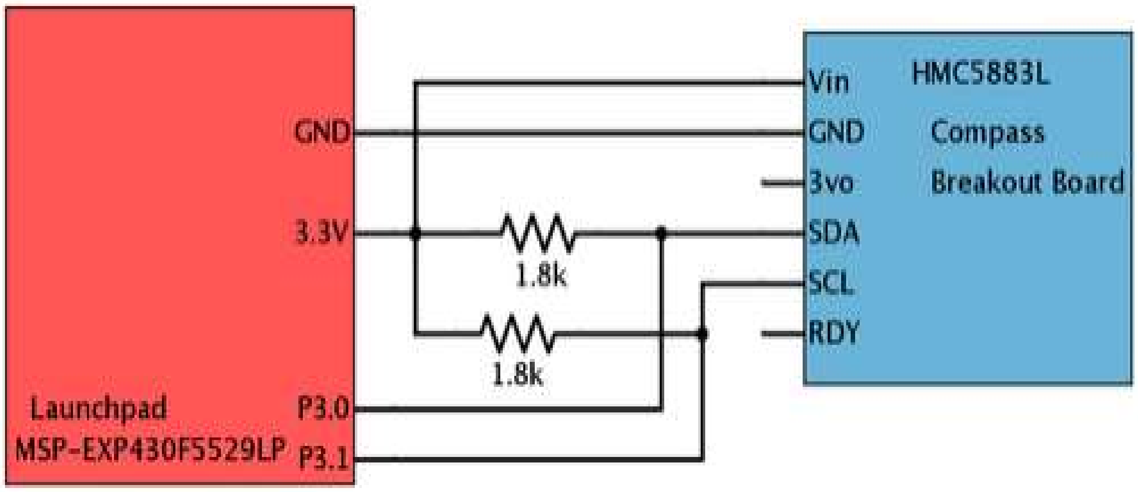

FIGURE 5. Master–Slave arrangement.

The fig 5 shows the Master–Slave arrangement where msp430 development board is master and AMR sensor is a slave. SDA and SCL are bidirectional lines connected to positive supply voltage via pull up resistors. Without these pull up resistors it is not possible for SDA and SCL to go high. SDA and SCL has logic level of LOW ($0.3V_{dd}$) and HIGH ($0.7V_{dd}$). Data on SDA will be stable during SCL is HIGH.

SDA can only change when SCL is HIGH. The fig 6 shows I^2C data frame format. START and STOP signals are generated by master. A HIGH to LOW on SDA when SCL is HIGH is START condition. A LOW to HIGH on SDA when SCL is HIGH is STOP condition. Each data byte is 8 bit long including read/write bit and is followed by acknowledgement (ACK).

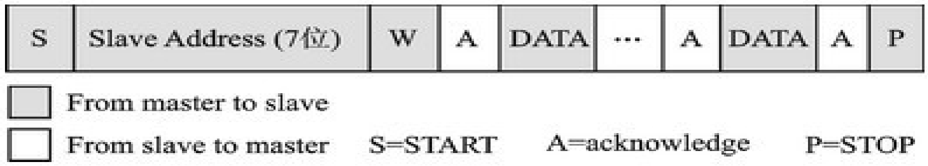

FIGURE 6. I^2C data frame format.

Some of the advantages are

1. Requires only two lines.

2. Flexible data transmission rate.

3. Long distance communication than SPI.

<u>Data</u>

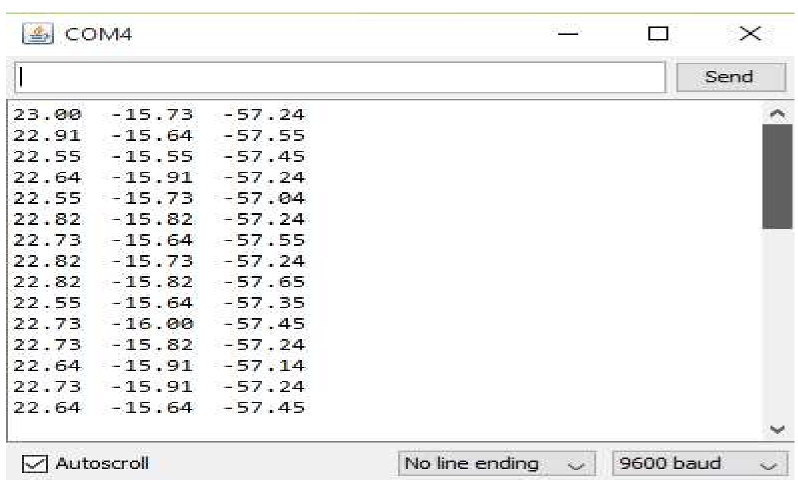

FIGURE 7. Magnetic field deflection along the X, Y and Z direction.

<u>Texas Instruments MSP430 Development Board</u>

Texas Instruments MSP430F5529 version is 16-Bit RISC architecture [12] processor, famous for its performance and low power consumption. The factors influenced with selection of this microcontroller were ease of use, better performance and low power consumption, which are very essential for real time implementation of this project.

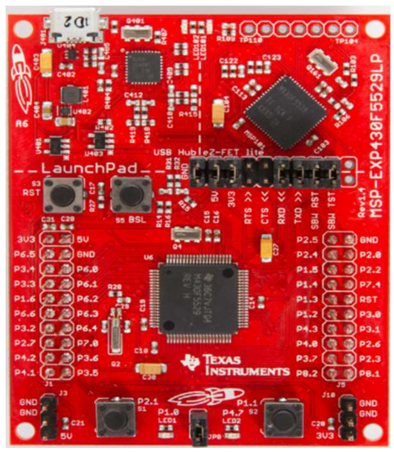

FIGURE 8. MSP430F5529 development board.

Some of the features are

1. Low supply voltage range from 3.6V down to 1.8V.

2. Ultralow power consumption with 290 µA/MHz at 8 MHz for flash program execution. 150 µA/MHz at 8 MHz for RAM program execution.

3. Real-Time Clock with Crystal, Watchdog, and Supply Supervisor Operational, Full RAM Retention, Fast Wake-Up time.

4. 16-Bit RISC Architecture, Extended Memory, up to 25-MHz System Clock.

5. Two Universal Serial Communication Interfaces.

6. 12-Bit Analog-to-Digital (A/D) Converter (MSP430F552x Only) With Internal Reference, Sample-and-Hold, and Autoscan Feature.

CHAPTER 5

TESTBED

FIGURE 9. Wooden fence and white plastic sheet attached on the wooden fence.

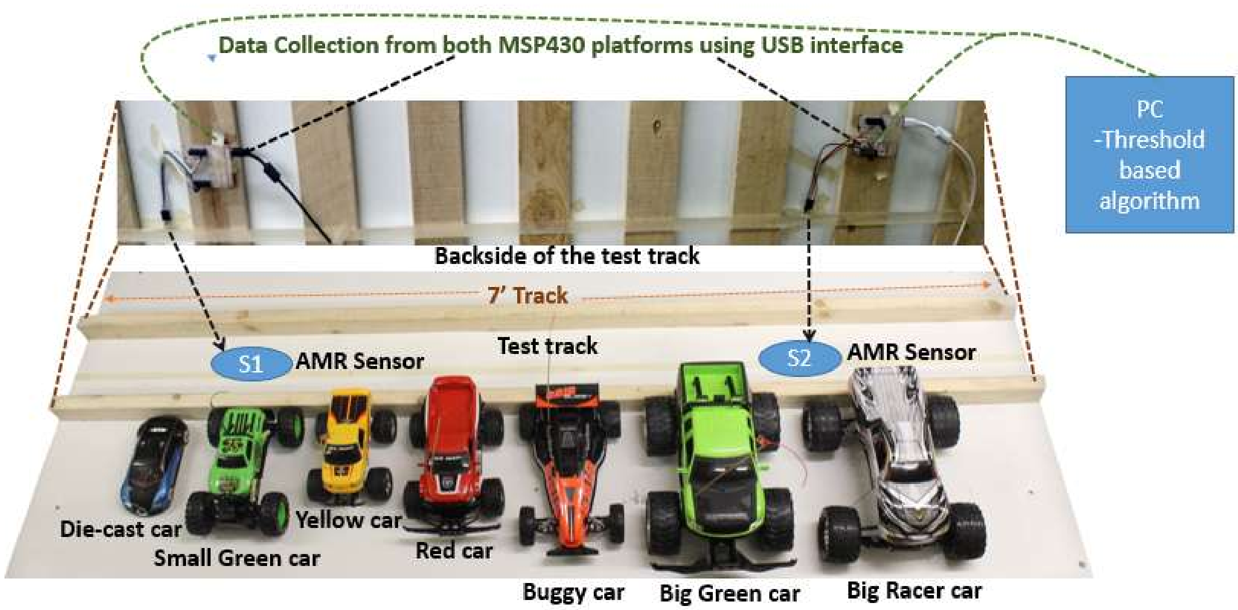

FIGURE 10. System testbed with RC cars.

Testbed is constructed using a wooden fence and white plastic sheet nailed on top of it to make a smooth surface to run the RC cars [1]. Sensors along with msp430 development board are fixed at the bottom of the wooden plank and the position of the sensors are marked on the plastic sheet (S1 and S2). Two wooden rails are fixed on top of the plank to make the RC cars to move in a straight path so that better readings can be obtained from the sensor.

Sensors are connected to the computer which has the threshold based algorithm running to classify the RC cars. Algorithm is written in matlab and result of the detection and vehicle type is displayed in the matlab console.

```
Command Window
count = 4
z1-min = -108.160
z1-max = -7.140
Sensor1 Vehicle = Small Green car
occupancy time sensor 1 = 400ms
velocity sensor1 = 0.81m/s
z2-min = -60.920
z2-max = -11.530
Sensor2 Vehicle = Small Green car
occupancy time sensor 2 = 300ms
velocity sensor2 = 1.08m/s

velocity between 2 sensor = 1.12m/s
```

FIGURE 11. Output in MATLAB console.

CHAPTER 6

ALGORITHM

Vehicle classification is based on the various features extracted by the data collected from the sensor. This vehicle classification algorithm makes use of the readings taken from Z axis of the sensor as Z axis is pointing up direction and is perpendicular to the vehicles passing over the sensor. This results in better quality of data for analysis. The features that are extracted from the Z axis readings are maximum value, minimum value and hill pattern.

Hill pattern is generated by comparing the two consecutive values. If the previous value is greater than the current value a signal with +1 amplitude is generated. If the previous value is less than the current value a signal with -1 amplitude is generated.

With the observation of sensor readings of the earth's magnetic field a base value and threshold value for the Z axis is decided. When vehicle approaches the sensor Z axis readings will be collected in an array and when the data cross the threshold value the detection window readings will be collected in a separate array.

Then these data are used to get the maximum value, minimum value and to generate the hill pattern based on which RC cars are classified.

Flowchart

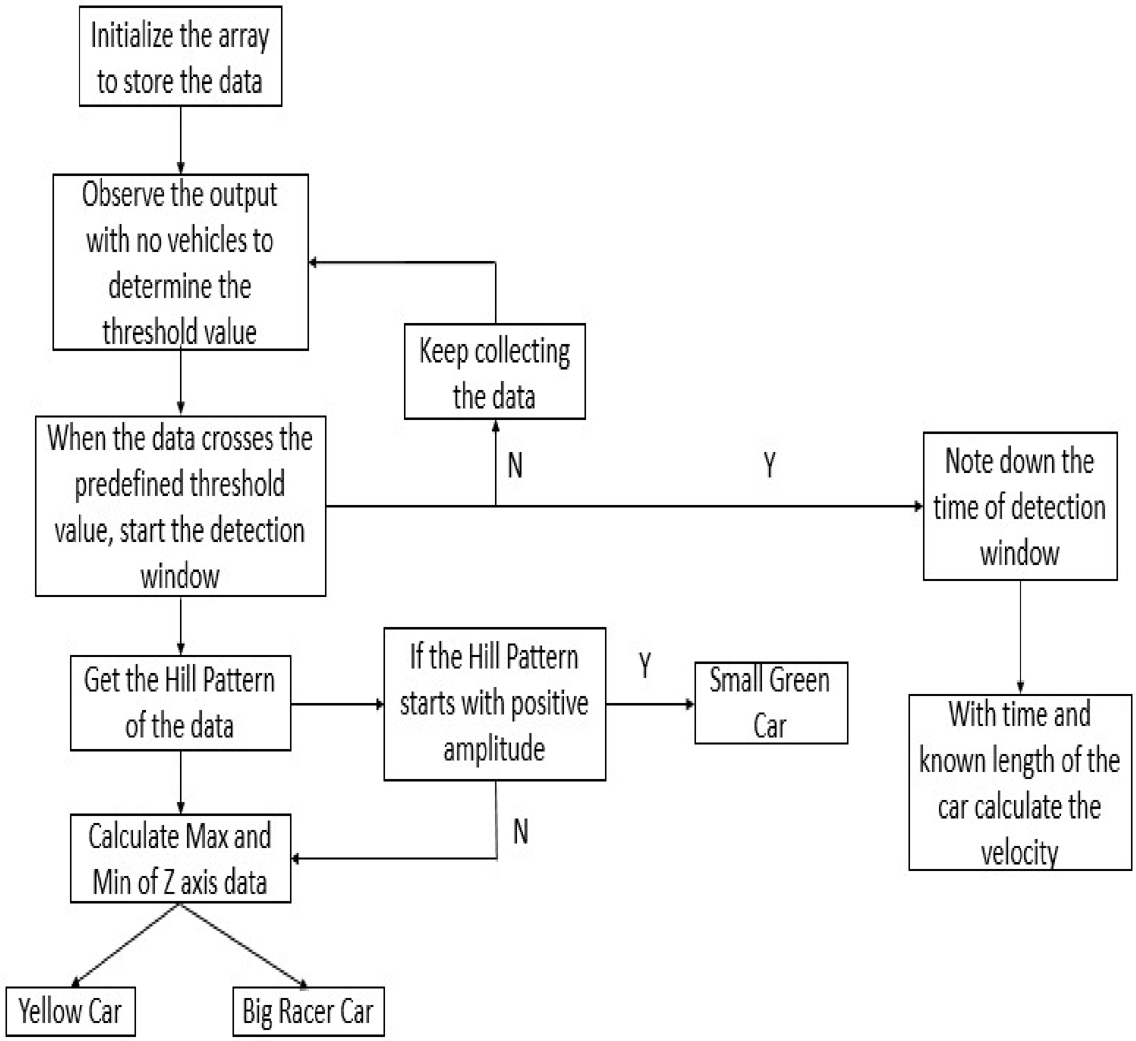

FIGURE 12. Algorithm.

CHAPTER 7

RESULT

Three RC cars are used to collect the data and all the cars are successfully classified with classification rate of 97.7% with sensor 1 and 96.6% with sensor 2. Each car is made to run for 30 times and result of classification for each run is monitored. Table 11 and Table 12 below summarizes the result.

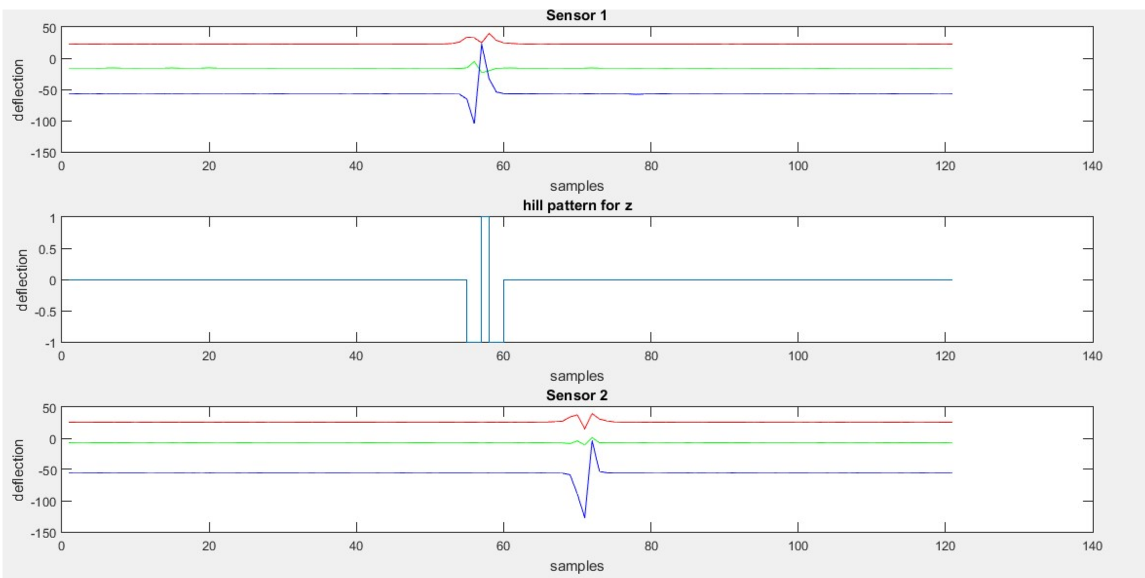

FIGURE 13. Sensor 1, Sensor 2 and hill pattern for yellow car.

```
Command Window
count = 5
z1-min = -105.000
z1-max = 22.350
z1-(max+min) = 127.350
Sensor1 Vehicle = Yellow car
occupancy time sensor 1 = 500ms
velocity sensor1 = 0.50m/s

z2-min = -127.140
z2-max = -3.880
z2-(max+min) = 123.260
Sensor2 Vehicle = Yellow car
occupancy time sensor 2 = 500ms
velocity sensor2 = 0.50m/s

velocity between 2 sensor = 0.80m/s
```

FIGURE 14. Sensor 1 and Sensor 2 classification of yellow car.

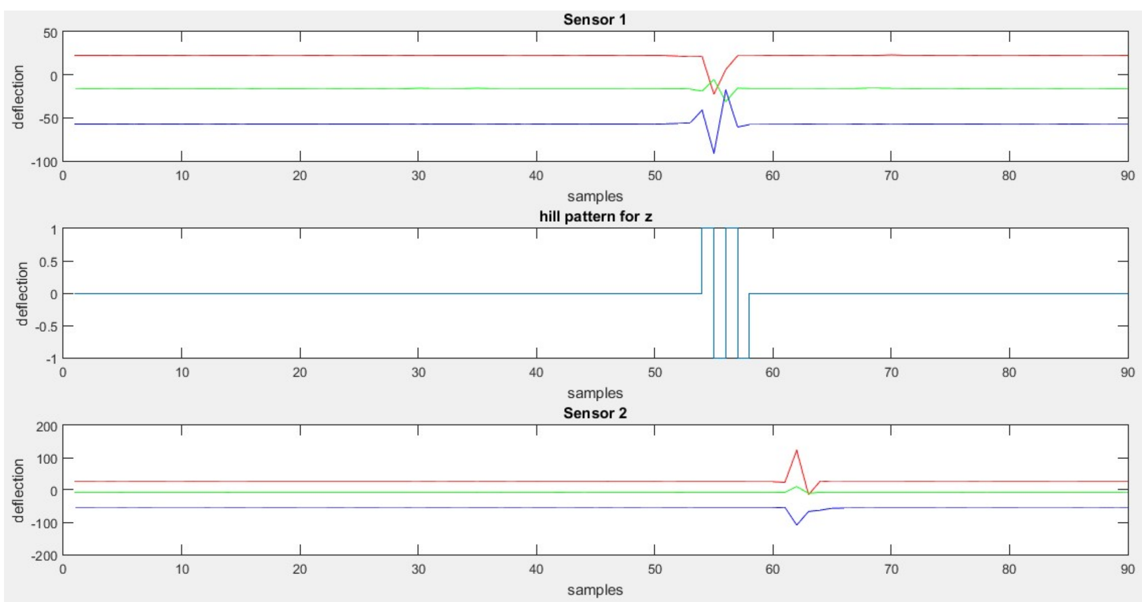

FIGURE 15. Sensor 1, Sensor 2 and hill pattern for small green car.

```
Command Window
count = 4
z1-min = -108.160
z1-max = -7.140
Sensor1 Vehicle = Small Green car
occupancy time sensor 1 = 400ms
velocity sensor1 = 0.81m/s
z2-min = -60.920
z2-max = -11.530
Sensor2 Vehicle = Small Green car
occupancy time sensor 2 = 300ms
velocity sensor2 = 1.08m/s

velocity between 2 sensor = 1.12m/s
```

FIGURE 16. Sensor 1 and Sensor 2 classification of small green car.

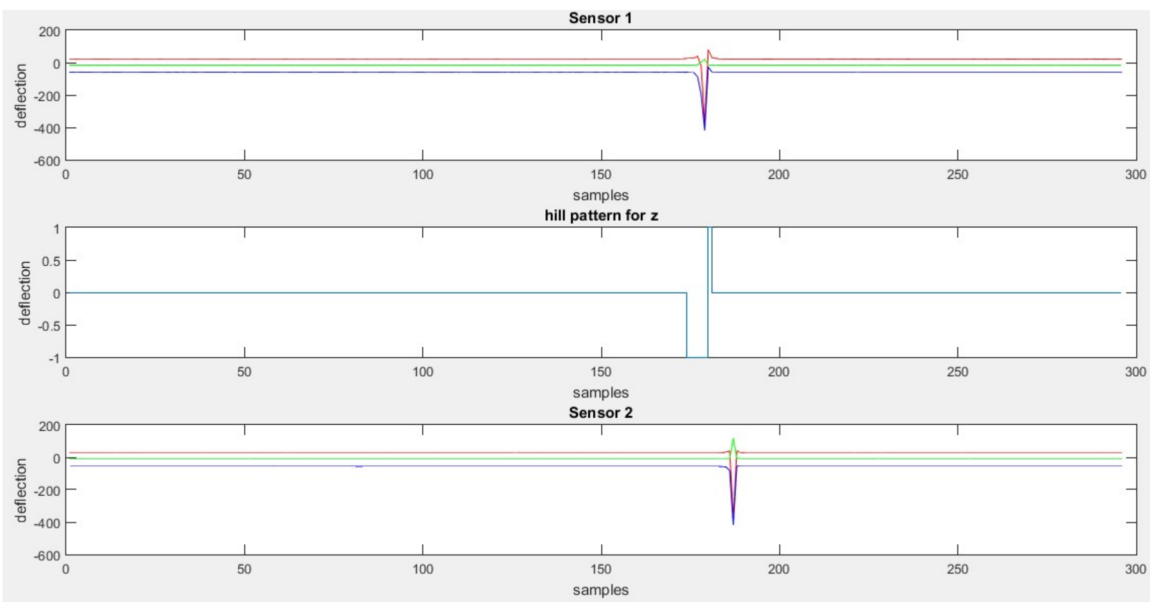

FIGURE 17. Sensor 1, Sensor 2 and hill pattern for big racer car.

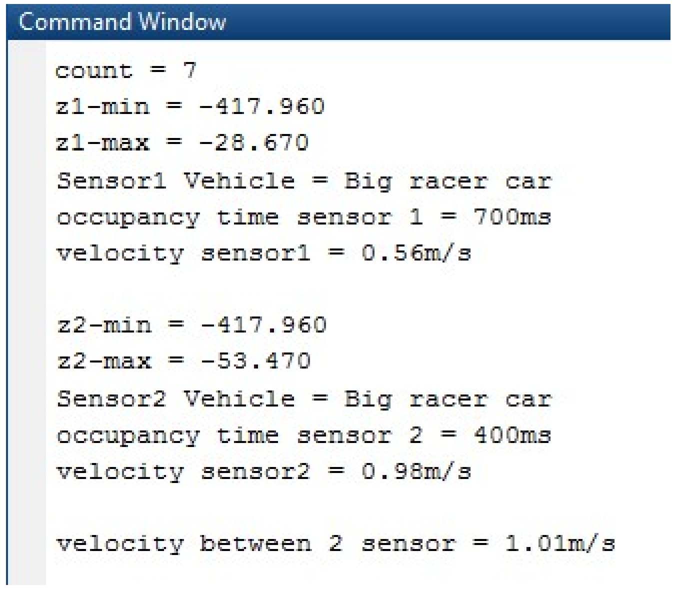

FIGURE 18. Sensor 1 and Sensor 2 classification of big racer car.

TABLE 11. Result of AMR Sensor 1

Car	Number of Run	Individual classification rate	Total classification rate
Yellow Car	30	96.6%	97.7%
Small Green Car	30	100%	
Big Racer Car	30	96.6%	

TABLE 12. Result of AMR Sensor 2

Car	Number of Run	Individual classification rate	Total classification rate
Yellow Car	30	93.3%	96.6%
Small Green Car	30	100%	
Big Racer Car	30	96.6%	

CHAPTER 8

CONCLUSION AND FUTURE WORK

The firmware for the collection of data from sensor was successfully tested and the algorithm to classify the RC cars was tested with success rate of 97.7% with sensor 1 and 96.6% with sensor 2. With this base firmware and algorithm, research can be extended to include more number of RC cars to detect the effectiveness of the algorithm.

Data collection and algorithm refinement has to be done in different scenarios to get the most effective algorithm which can be applied in all possible scenarios. Data collection of sensor has to be carried out by keep the sensor at varying depths in the ground to determine the sensitivity of the sensor.

Sensor node can be placed in the parking space and the data collected from the real vehicles can be used to refine the algorithm to successfully classify the vehicles in real time. Multilane scenario has to be tested in order avoid the sensor detecting the vehicle passing in the adjacent lane.

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