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Vehicle Detection and Classification System Based on Magnetic Sensors: A Review

Ranya Ahmed kateeb[1], **and Dr. Saad A. Makki** [2]

[1]Computer Science Department
AL-Mustansiriyah University
Baghdad, Iraq

ABSTRACT

In an Intelligent Transportation System (ITS), vehicle identification and categorization (VIC) from a moving platform is critical (ITS). VIC is input into traffic control and management systems. Due to a variety of circumstances such as different types of cars, vehicles with nearly identical qualities having unique classes, and so on, in congested traffic, vehicle identification and classification is still a challenge. When compared to different sensors, the magnetic sensor has great implementation potential in the vehicle detection sector Because of its high sensitivities and lightweight. This paper aims to discuss how the magnetic characteristics of Vehicles can be used to detect and classify vehicles. First, a brief operating principle and properties of the most commonly used magnetic sensors are reviewed. This paper also reviewed the most recent applications, implementations, and research in using the magnetic sensor to detect and identify vehicles, as well as classify and determine Vehicle speeds.

Key Words: Intelligent Transportation System, Magnetic Field, Magnetic Sensors, Vehicle Detection, Vehicle Classification.

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1. INTRODUCTION

The increase of vehicles is a fundamental difficulty for vehicle type detection and classification in densely inhabited areas such as huge cities. The rise of technology has boosted interest in ITS [1]. Vehicle identification and classification is an important aspects of ITS. Vehicle classification and identification play a critical role in ensuring the safety and effectiveness of movement monitoring. Sensors such as radar, circle indicators, and street tubes have been used to collect the majority of activity information and estimates to date. The need for nosy institutions and alignment procedures is a downside of these sensors[2,3]. The three components of modern information technology are sensing technology, computing technology, and communication. Sensors are described as devices that can detect and transform essential measurements into usable signals using special methods or mathematical functions[4]. Sensitive elements and conversion elements are common components of sensors. To put it another way, a sensor is a detection device designed to detect external information and transform it into electrical signals using a certain mechanism. Sensors are classed as a magnetic, optical, acoustic wave, gas, humidity, or temperature sensors based on the input signal. to detect magnetic signals that may detect the strength, presence, change of a magnetic field, and direction, a magnetic sensor is used. In a variety of applications, the magnetic sensor has been utilized to analyze and control a wide range of operations. Magnetic sensors are used in a WSN. and the magnetic field of the vehicle is used to detect vehicles on the streets[5]. A magnetic sensor is used to measure the change in the magnetic field. When a fixed magnetic sensor is utilized, the magnetic field is uniform. the magnetic field lines are distributed When a machine passes thereabout to or over a magnetic sensor. The vehicle can also be discovered by monitoring the change in the magnetic field's value[6].

2. CLASSIFICATION OF MAGNETIC SENSORS

Magnetic sensors transform magnetic signals into electrical signals to detect magnetic fields' existence, density, and orientation. Magnetic sensors frequently use soft magnetic materials or semiconductors. Magnetic sensors have four components: a sensitive element, a conversion element, a conversion circuit, and an auxiliary power supply. Magnetic sensors use the magneto-electric effect as their fundamental functioning mechanism. Magnetic sensors, which are based on the magneto-electric effect principle, can be classed as Hall effect sensors, superconducting quantum interference device sensors, flux-gate sensors, magneto resistance sensors, inductive magnetic sensors, and frequency mixing magnetic sensors. This is something we'll discuss in this part[7].

2.1 Hall Effect Sensor

The Fluxgate sensor's magnetic core is comprised of soft magnetic materials with high permeability and the sensing parts consist of two coils (a driving coil and a sense coil) [8]. The magnetic saturation characteristics of soft magnetic materials, as well as Faraday's law of electromagnetic induction, are used to create this sensor. A weak direct current magnetic field can be converted to an alternating current voltage by the fluxgate sensor. It can measure DC and low-frequency AC magnetic fields as well as magnetic field components directly (the upper limit of frequency is about 10 kHz). It has a lot of drawbacks, including a lot of volumes, a lot of money, and a slow reaction time[9].

2.2 Fluxgate Sensor

Fluxgate sensors are a type of vector magnetometer that was produced in the first half of the 20th century. It has several features, including resolution, sensitivity, and dependability, as well as being physically tiny and using very little power to function. It can also measure the vector components of the magnetic field, making it a very useful instrument. Fluxgate sensors are used by geologists for reconnoitering and geophysicists to examine the geomagnetic field (which ranges from 20 to 75 Tesla on the surface of Earth). it's used by some engineers such as Satellites to locate and maintain the attitude of spacecraft, scientists utilize them in their studies, and bomb detection, vehicle detection, and target recognition are all things that the military employs them for. They are also used by some airport security systems to identify firearms. [10,11].

2.3 Magneto resistance Sensor

The magneto-resistance effect shows how the resistance of different metals or semiconductors changes as the magnetic field is applied to the changes. In 1857, William Thomson discovered the magneto resistance effect. It is caused by the Lorentz force acting on metal or semiconductor carriers traveling in a magnetic field. AMR, GMR, and TMR are magneto resistive sensors.

2.3.1 Anisotropic Magneto resistance Sensor (AMR)

AMR is one of the earth’s magnetic field sensors that work on the resistive effect principle. it measures the size and direction of the magnetic field. AMR is very simple in production; therefore it’s still available and cheap in the market. AMR sensor with resistive strips consisting of a thin nickel-iron sheet maintained on a silicon wafer [12][7].

2.3.2 Giant Magneto resistance Sensor (GMR)

GMR is a sensor device based on the magneto resistivity phenomenon, it has been discovered for the first time in 1988 by Peter Gruenberg and Albert Fert [2]. they find out the change in resistance is about 6 to 50% in the type of materials that compose of very thin multilayer of a different element of metal, because the magnetization of these metals is not aligned in the absence of an external magnetic field [13]. GMR is made of a multilayer of ferromagnetic material and no ferromagnetic material, respectively. Applications of GMR are as diverse as automotive sensors, solid-state compasses, disk drivers, and non-volatile magnetic memories[14].

2.3.3 **Tunnel Magneto resistance Sensor (TMR)**

In 1975, Julliere discovered the phenomena of (TMR) in the Co/Ge/Fe magnetic tunnel junction (MTJ). The TMR effect is a spin-dependent tunneling phenomenon in which the orientation of ferromagnetic materials on either side of the ferromagnetic layer, nonmagnetic insulating layer, or ferromagnetic layer (FM/I/FM) influences the tunneling resistance. The direction of the magnetic layer's magnetization affects the likelihood of electrons tunneling from one magnetic layer to another.. When the magnetization orientations are antiparallel, the resistance skyrockets, the chances of tunneling plummet, and almost no current get through the barrier layer. TMR sensors are small, low-cost, low-biological background, very sensitive, and high-throughput[8]. The TMR sensor has a 20-fold higher output than the AMR sensor and a six-fold higher output than the GMR sensor, indicating that it can be used in a variety of settings.[15].

2.4 Superconducting Quantum Interference Device Sensor

The SQUID sensor is a highly sensitive magnetic sensor based on a detection limit of 1014 T, the SQUID is a very susceptible magnetic sensor based on the Josephson phenomenon and flux quantization. Two superconductors are sandwiched between two layers of insulating material to form a Josephson junction [16]. For reliable measurements of weak magnetic fields, this sensor is frequently employed in applications such as magnetic resonance imaging (MRI), nondestructive evaluation (NDE), geomagnetic measurement, and so on. The SQUID must be provisioned with a refrigeration unit since the superconducting ring requires a low-temperature environment. The application of SQUID sensors is severely limited due to the hostile working environment and

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increased cost [17]. Due to the discovery of high-temperature superconductors in recent years, the working environment temperature has been increased to 77 K liquid nitrogen temperature, which is easier to achieve [18].

3. LITERATURE REVIEW

3.1 Vancin and Erdem suggested a model comprised of three magnetic sensors positioned 50 meters apart on the road, along with three experiments. The first is to identify traffic states as no traffic, light traffic, moderate traffic, severe traffic, and extremely heavy traffic. The traffic situation is determined by counting the number of vehicles that distribute the earth's magnetic field when passing the magnetic sensor every hour throughout the day. Based on the magnetic signature length, the vehicle was classified as a car, a minibus, a bus, or a truck in the second experiment. Determine the vehicle's direction from left to right or right to left in the third experiment, based on the orientation of the magnetic sensor's axis[19].

3.2 C. Xu *et al.*, discussed the progress the accuracy of automagical automobile classifiers when dealing with unbalanced datasets. A single anisotropic magnetoresistive sensor separates the cars into hatchbacks, sedans, buses, and multi-purpose vehicles (MPVs). Pattern identification is based on time and frequency domain variables, and three typical classification algorithms are used: k-nearest neighbor (KNN), support vector machine (SVM), and back-propagation neural network (BPNN). To begin, the KNN is a straightforward but powerful pattern recognition algorithm. It takes training samples from the feature space that is closest to K as input and outputs class membership. The object is allocated to the most popular class among its k-nearest neighbors after a majority of its neighbors vote to categorize it (k is a positive integer, typically small). A maximum margin classifier is the SVM. In other words, it assumes that the support vectors, or hyperplanes, having the largest distance to the closest points in the training set, achieve the best separation. The BPNN, one of the most extensively used neural networks, is employed in the final stage. It determines the weights that will be utilized in the network by calculating the gradient. The gradient is then used by the optimization process to alter the weights to minimize the loss function. The BPNN algorithm outperformed the competition by achieving the highest classification accuracy of 81.82 % [20].

3.3 **J. Zheng, et al.,** offers a multi-sensing fusion-based portable roadside vehicle detection system. The hardware platform, which consists of a sensor node and a laptop, is being built. HMC5883L three-axis magnetic sensor that runs at 50 Hz and a US100 ultrasonic sensor that operates at 30 Hz compensate for the sensor node's detecting element. A Bluetooth device is utilized for communication, and a microcontroller is used to capture raw data. The magnetic detection module, the ultrasonic detection module, and the data fusion module are the three sections of the fusion algorithm's structure. It operates in two stages, the detection phase, and the decision phase(the basic intersection fusion of the magnetic and ultrasonic algorithm (MUA)). The time window should be initially selected to compute the variance of the magnetic signals. The entire set of cases can be divided into four categories based on the detection results from two sensors, and these cases are: C1 denotes the presence of a vehicle from the adjacent lane as detected by the magnetic sensor and the ultrasonic sensor; C2 denotes the movement of a large vehicle from the nonadjacent lane; C3 denotes the passage of a pedestrian or non-motorized vehicle from the adjacent lane; C4 denotes the absence of any passing vehicles. The magnetic detection accuracy is 79.31 percent, and the ultrasonic detection accuracy is 90.34 percent, according to the experimental data. On a two-lane road, however, vehicle detection (fusion algorithm) accuracy can reach 97.14 percent[21].

3.4 **C. Xu, et al.,** depict a roadside SPMS for the vehicle detection system, Based on the integral of received signal strengths (RSSs)and magnetic signals. An RF-based vehicle detection system has been developed based on the features analysis of (RSSs) provided by wireless transceivers. To detect cars, the proposed vehicle detection method combines magnetic signals and RSSs. The proposed approach does not involve any changes to the hardware of wireless vehicle detectors, but it does necessitate certain changes to the embedded software, which also doesn't increase the vehicle detector's cost. the proposed RF-based method for extracting data features from RSSs to assess the condition of vehicles Because wireless transceivers consume more energy than magnetic sensors, the data characteristics of magnetic signals are insufficient to provide correct judgment on parking spot status, so they Fusions two sensor's data: RF-Based Method and Magnetism-Based Method. Only when the magnetism-based vehicle detection method enters an uncertain state is the RF-based vehicle detection method activated. The fundamental advantage of the prepose approach is that it achieves a fair balance between detection precision and power consumption, making it ideal for battery-powered applications. The lower the sensor sample rate, the less energy is consumed. The proposed method was put to the test in a genuine roadside parking lot, and the results show that with a 1 Hz sampling rate on the magnetic sensor, car recognition accuracy can reach 99.62 percent[22].

3.5 **X. Chen, et al.,** For recognizing and categorizing road cars, the researchers devised a new approach that contains AMR magnetic sensor, extracts the feature of magnetic signal, and classifies vehicles. This method is intended to study road traffic in ITS. A low-cost magnetometer and data collection equipment are used in this method, which is set up on the side of the road. They analyze vehicle magnetic signals and elicit the features of vehicles by the use of cepstrum, magnetic signals gap cepstrum, and frame energy as representations using Mel Frequency Cepstral Coefficients (MFCC), which are utilized to analyze and extract

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vehicle features from magnetic data utilizing the representation of cepstrum, frame energy, and gap cepstrum of magnetic signals. feature extraction, they have several levels. Preemphasis is the initial stage of MS feature extraction. This process balances the energy from lower and higher frequencies while enhancing the energy in high frequencies. Windowing. In the second stage, they take a small window of signal data and extract signal features from it. Signal value and window value are used in the windowing process. They define two windowing functions: "Rectangular" and "Hamming" to prevent discontinuities. The Windowing process will produce two separated statuses: a dynamic and a static state. for dynamic only energy is counted as a feature; for static, there are 3 features integration of cepstrum c, delta d, and double delta z. If the vehicle magnetic signal matches both the Nearest Neighbor Condition and Centroid Condition, then it can be classified. They have classified signals into four vehicle types: sedan, van, truck, and bus, using Vector Quantization (VQ). They've placed a 60-centimeter space between the sensor and passing automobiles. Because magnetic sensors are used, they save money on deployment and maintenance. They are detected. Accuracy 95 percent of sedans, 94 % of vans, 94 % of trucks 89 %, if there is a bus, and 100 % non-vehicle[23].

3.6 **M. Salman and S. A. Makki,** presents a new magnetic sensor-based vehicle identification and disclosure system that depends on the vehicle's magnetic map and magnetic sensors, this study suggested a new vehicle identification system and new methodologies for vehicle detection and identification. A non-magnetic material frame has been devised as part of a novel system. Four magnetic sensors have been installed in the frame at strategic locations to detect magnetic fields surrounding the car. Each sensor signal was measured and sent to a computer to be stored, analyzed, and identified. When the car passes over the frame, magnetic sensors send out signals new database is built by using the reference signal or data in the designed identification signal. To examine and determine the vehicle type, two methods were used. To discover similarities between magnetic sensor data and reference signals, the first methodology for the identification system was using normalized cross-correlation based on the Fast Fourier Transform. The matching pattern approach is used in the second method, in which sensor signals are transformed into an image and the two patterns are compared for vehicle identification The first strategy for vehicle identification was 90 percent accurate, whereas the second technique was 95 percent accurate[24].

3.7 **C. Li** , proposed the MagMonitoras a novel device that detects and estimates vehicle speeds by measuring and modeling local magnetic field disruption caused by moving vehicles. The MagMonitor requires only the installation of a small magnetic sensor along the route. They developed MagMonitor which is a vehicle classification and speed estimation system that categorizes vehicles based on their magnetic properties and estimates vehicle types and speeds based on normalized and filtered magnetic waveform characteristics. In addition, road testing was conducted to ensure that the proposed technique was effective. The magnetic sensor that was employed in the experiment is small, inexpensive, and environmentally benign. The first step of the system is: Image processing is used to categorize the objects. they used a low pass filter to get rid of the earth and magnetic noise that affects the detection process of the passing vehicles. based on the incoming signal of the signal processing they determine the threshold, only the vehicle's signal that is above the threshold is counted. after the vehicle volume is gained, the magnetic perturbation images could be added to the dataset of vehicle perturbation. Magnetic perturbations vary depending on several things such as magnetic dipoles number and time responses of vehicles, which produce different signals for instance the vibration length and maxima number. These characteristics can be used to classify vehicle types. they used multiple support vector machines (MSVM) to estimate vehicle type and speed. It achieved an 87 percent correct categorization rate. second vehicle speed estimation: they separate speed estimation models and compare them with real speeds of vehicles to produce estimated vehicle speeds. They evaluate the values of every fitting model by segregating automobiles' driving time vehicle categories: sedan, SUV, and bus [25].

Table.1. Summary of VDC Based On The Magnetic Sensor

	Study	Features	Method\ algorithm	Accuracy	Results
1	**Vancin and Erdem, 2017**	Average of Magnetic Signal Length (MSL)	Threshold	95%	• Car • Minibus • Bus • truck
2	**C. Xu, et al., 2018**	• maximum position • Minimum position • peak-to-peak(p2p) value • mean value	SVM, BPNN, KNN	81.82%	• Hatchbacks • Sedans • Buses • multi-purpose

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		• standard deviation value • signal energy • the magnitude of the frequency signal • (L) the sampling points			vehicles(MPVs).
3	**J. Zheng, et al., 2019**	Without features	Sensors-data fusion and Adaptive Adjustment Algorithm for Reference Baselines	99.62%	• no vehicle • some vehicles the behind • some vehicles on both
4	**C. Xu, et al., 2019**	Without features	data fusion algorithm	97.14%	Only detection
5	**X. Chen, et al., 2019**	• integration of cepstrum c • delta d • double delta z • Energy	Vector Quantization (VQ)	94.4 %	• Sedans • Vans • Trucks • Bus • No vehicle.
6	**M. Salman and S. A. Makki, 2019**	Without features	1-normalized cross-correlation 2-fast normalized cross-correlation	1- 90% 2- 95%	• Mini car • bus
7	**C. Li, 2020**	number of maxima and length of vibration	Support vector machine (SVM)	87%	• Sedan • SUV • bus.

4. CONCLUSION

The primary magnetic field sensors have been briefly mentioned. We also demonstrate how to recognize and classify road vehicles' magnetic detection, feature extraction from magnetic signals, and categorization, as well as speed calculation techniques. Magnetic sensors provide advantages over other sensors, including cost-effectiveness, small size, resistance to environmental influences such as heat, wind, bad weather, and higher accuracy. Based on literature it is discovered that utilizing a magnetic sensor with an ultrasonic sensor or fusion using the signal of magnetic sensors and assessing the signal intensity to detect the vehicle produces more accurate results than using magnetic sensor data alone.

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