The design method and research status of vehicle detection system based on geomagnetic detection principle

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Abstract. Vehicle detection systems are applied to obtain real-time information of vehicles, realize traffic control and reduce traffic pressure. This paper reviews geomagnetic sensors as well as the research status of the vehicle detection system. Presented in the paper are also our work on the vehicle detection system, including detection algorithms and experimental results. It is found that the GMR based vehicle detection system has a detection accuracy up to 98% with a high potential for application in the road traffic control area.

1. Introduction
Control and management play an important role in improving and optimizing the road traffic. Vehicle detection systems are used to obtain traffic flow information. The research on vehicle detection dates back to the 1980s [1]. The commonly used vehicle detection technology include ring coil, ultrasonic, infrared, geomagnetic and video. However, these detection techniques generally have a varied of disadvantages, including low detection accuracy, complicated installation, high cost and high power consumption [2]. In recent years, due to the rapid development of solid state magnetic sensors with low power and high sensitivity, it becomes feasible to develop vehicle detection with high precision, easy installation, low power consumption and low cost, that can meet practical applications.

In this paper, reviewed first are the magnetic sensors and vehicle detection systems. Followed are the design and results by our research group, demonstrating that a detection accuracy could be more than 98%.

2. Geomagnetic Sensors and Detection Principle
Geomagnetic sensors, which can detect changes in the geomagnetic field, can be used for road vehicle detection and this technology is widely used in the field of road traffic detection. The geomagnetic sensors used for vehicle detection in the current market mainly include AMR sensor, GMR sensor and TMR sensor. These three kinds of geomagnetic sensors have different principles, and also exhibit different characteristics.

The AMR sensor is short for anisotropic magneto resistive sensor based on anisotropic magneto resistive effect, which is defined as the change in the resistivity of ferromagnetic material with the change of its magnetization and the angle of the direction of the current [2]. The AMR bridge structure under the action of external magnetic field is shown in Figure 1-(a).

\[ R_1 = R_2 = R_3 = R_4 = R \] (1)
\[ V_{\text{out}} = V_{cc} \times \frac{\Delta R}{R} \]  \tag{2}

In the equation (1), \( R \) is the resistance of four anisotropic magnetic resistors in the AMR bridge. In the equation (2), \( V_{\text{out}} \) is the output voltage of AMR sensor under the action of external magnetic field and \( \Delta R \) stands the change in resistance values of four anisotropic magnetic resistors under external magnetic field. \( V_{cc} \) is the supply voltage.

The GMR sensor is short for giant magneto resistive sensor based on giant magneto resistive effect, which is defined as that the resistivity of the magnetic material has great changes in the external magnetic field compared with no external magnetic field. The GMR bridge structure under the action of external magnetic field is shown in Figure 1-(b).

\[ V_{\text{out}} = V_{cc} \times \frac{\Delta R}{2R + \Delta R} \]  \tag{3}

In the equation (3), \( V_{\text{out}} \) is the output voltage of GMR sensor under the action of external magnetic field and \( R \) is the resistance of four giant magnetic resistors in the GMR bridge. \( \Delta R \) stands the change in resistance values of four giant magnetic resistors under external magnetic field. \( V_{cc} \) is the supply voltage.

The TMR sensor is short for tunnel magneto resistive sensor based on tunnel magneto resistive effect, which is that the magnetization direction of the ferromagnetic slice can be independently switched under the action of an external magnetic field. The TMR bridge structure is shown in Figure 1-(c).

Figure 1. Bridge structure of geomagnetic sensor.

In the vehicle detection, the key parameter is the geomagnetic field intensity, which locates in the range of 0.5Oe-0.6Oe. From Table 1, it can be seen that the three kinds of geomagnetic sensors can meet the application requirements of geomagnetic vehicle detection. The AMR sensor is the most widely used geomagnetic sensor, which has the advantages of good linearity and low hysteresis. However, due to the fact that the linear region is narrow and the detection field is easy to saturate, the bias voltage of the sensor needs to be removed by simply switching the magnetic properties of the iron nickel film. The GMR sensor is simple to use and can work normally only with a stable power supply. GMR sensors are fabricated by semiconductor integrated process, and they are characterized by small size, high sensitivity and good linearity. They are widely used in electronic compass, gear sensors, current sensors, and magnetic switches having a very broad market prospects. The TMR sensor is the fourth generation of magneto resistive sensors in the world. Compared with GMR sensors and AMR sensors, it has great advantages in size, power consumption, sensitivity, linearity, range of operation...
and temperature stability. However, the technology of TMR sensor is still not mature enough, and products in this field are rarely to be seen.

| Sensor | Size (mm) | Temperature (°C) | Consumption (mA) | Sensitivity (mv/V/Oe) | Working range (Oe) |
|--------|-----------|------------------|------------------|----------------------|-------------------|
| AMR    | 1*1       | <150             | 1~10             | 1                    | 0.001~10          |
| GMR    | 2*2       | <150             | 1~10             | 3                    | 0.1~30            |
| TMR    | 0.5*0.5   | <200             | 0.001~0.01       | 20                   | 0.001~200         |

Currently, there are many researches on geomagnetic detection vehicle detection system around the word. Kang of Korea designed a vehicle detector based on AMR sensor. The detector consists of a single axis AMR sensor and a corresponding peripheral circuit. The experimental results from three stages show that the vehicle detector has good detection performance in low speed traffic measurement with an average error of 0.3% [3].

Honeywell uses an AMR sensor of three axes for vehicle detection test, and analyses the output characteristics on three axes. The experimental results show that when the vehicle is farther from the sensor, the sensitivity of the sensor is lower. The single axis AMR sensor can be used to detect the direction and the appearance of the vehicle. The dual axis AMR sensor can be used to determine the speed and analyze the direction of the vehicle. The three axis AMR sensor can be used in vehicle classification [4].

The MIT Knaian uses HMC1021S, a single axis AMR sensor produced by Honeywell, to conduct vehicle detection test. The system receives and processes the data through the TMS430 microprocessor, and transmits the data to the base station through the wireless communication module. For parking space detection, the system uses the state machine algorithm. The vehicle detection system is tested on a street, and the results show that the system can accurately detect the traffic flow at different times [5].

The Harbin Institute of Technology has designed a hardware platform which uses single axis TMR sensor as detection unit, ZigBee as wireless communication protocol. The system can monitor vehicle information and upload data in real time. The system adopts the baseline adaptive state machine detection algorithm. Through the comparison and analysis of the actual test results, using BP neural network as the system vehicle classification algorithm, the recognition accuracy can reach 88.92%.

### 3. Design and Detection Algorithm

In 2012, our research team designed a vehicle detection system based on GMR sensors. The system uses the single axis SAS03-1 sensor produced by SpinIC as the geomagnetic field information acquisition module. The test result shows that the system can meet the practical application requirements. In 2014, based on the previous work, our research team developed a wireless parking space detection system based on GMR sensor of three axes. The system adopts the improved fixed threshold algorithm. The baseline value is updated by collecting the baseline value of the parking space in the condition of no car regularly. In 2015, our research group improved the algorithm of parking detection system, and developed a two level baseline tracking detection algorithm. The algorithm sets two thresholds, controlling the baseline tracking by small threshold, and judging the parking space status through the large threshold. By setting two thresholds, the algorithm avoids the system errors caused by the drift of the baseline, and also compensates for the system errors due to vehicle disturbances.

In 2017, our research team designed a parking area detection system integrating the ZigBee network into the Ethernet. In the hardware aspect, the detection node of the system uses dual axis SAS022-1 and single axis VA100F3 produced by SpinIC as the geomagnetic field information
acquisition module, CC2530 as the main controller and RF transceiver, ZigBee protocol for wireless communication, TPS63001 as the master chip for power management module. The detection nodes object is shown in Figure 2 and Figure 3 shows the hardware framework of the detection node.

**Figure 2.** Detection nodes object.

**Figure 3.** Hardware framework of detection node.

In the software aspect, the system first uses the sliding average filter algorithm to filter the signals collected by the GMR sensors, and this method can effectively remove noise interference. The equation (4) shows the principle of the sliding filter algorithm.

\[
T(k) = \begin{cases} 
A(1) + A(2) + \cdots + A(k) \\
\frac{A(k-N+1) + A(k-N+2) + \cdots + A(k)}{N}
\end{cases}
\]

\[ k < N \]

\[ k \geq N \]

In the equation (4), \( A(k) \) stands the original signals collected by GMR sensors and \( T(k) \) is the filtered signals. \( N \) is the window length of the sliding average filter defined as 5 in the system.

The system uses the baseline adaptive state machine detection algorithm to determine the parking space status. The flow chart of the baseline adaptive state machine detection algorithm is shown in Figure 4. In the flow chart, \( T_{\text{min}} \) stands for small thresholds, and \( T_{\text{max}} \) means large thresholds. Firstly, the baseline value is determined in the vehicle detection region without vehicle and the value is defined as \( T_v \). After the baseline value has been successfully initialized, the magnetic time sequence of the sensor is input to the state machine defined as \( T \). If \(|T - T_v|\) is less than \( T_{\text{min}} \), it is non-triggering state at this time and the state can be judged as the interference of the external environment. Then the weighted function should be used to update the baseline value and continue to collect the magnetic field data of the detection area as shown in equation (5); if \(|T - T_v|\) is greater than \( T_{\text{min}} \) and less than \( T_{\text{max}} \), it is Semi trigger state at this time and the state can be judged as the interference of the vehicle. Then the baseline updates should be stopped at this point; if \(|T - T_v|\) is greater than \( T_{\text{max}} \), it is fully triggered state at this time and the vehicle has completely entered the detection area at this point. Also the baseline remains unchanged.

\[
T_v(k) = \begin{cases} 
T_v(k-1) \times (1-a) + T(k) \times a \\
T_v(k-1)
\end{cases}
\]

\[ 0 \leq a \leq 1 \]

In the equation (5), \( T_v(k) \) is the current updated baseline value, and \( T_v(k-1) \) is the baseline value of the previous state. \( T(k) \) is the current measurements, and \( a \) is the weighting coefficient.
The detection algorithm combines the baseline adaptive algorithm with the state machine algorithm and avoids the shortcomings of the two algorithms, the accuracy of the system is therefore improved.

4. Experimental Results
In 2017, our research team tested the improved vehicle detection system. Considering the actual application of parking spaces, the detection nodes were placed in the center of the parking space to minimize the false detection rate and improve the stability of the system. For the No.1 parking space, a household car was made to pass from the south to the north with a low speed, while for the No.2 parking space the same car was made to pass from the east to the west. And the nodes collected the data of magnetic field disturbance generated by vehicle.

Figure 5-(a), (b) and (c) show the curves of the output voltage of X axis, Y axis and Z axis respectively as the vehicle passes through the GMR sensor in the parking spaces. In the figures, X1, Y1, Z1 represent the voltage output curves of the vehicle passing from the east to the west. X2, Y2, Z2 represent the voltage output curves of the vehicle passing from the south to the north. A1 and A2 indicate the time when the headstock passes through the sensor. B1 and B2 indicate the time when the tailstock passes through the sensor.
According to the voltage output, the following conclusions can be obtained: Firstly, the law of magnetic disturbance of parking space is not related to the geographical direction of parking space. It is only determined by the direction of sensitive axis. Secondly, the same sensitive axis shows the same output voltage under the same vehicle interference. Thirdly, when the vehicle is far away from the sensor, the output voltage of the three axes remains unchanged. When the vehicle passes through the sensor, the output voltage changes significantly, especially when the wheel and the engine pass through the sensor. This is mainly because the wheel and engine are composed of ferromagnetic materials, which can cause a great disturbance to the earth's magnetic field, and leads to a great change of the output voltage.

Judging from the variation of the single axis, the disturbance of the vehicle may be caused by certain error. In order to improve the reliability of the system, the output voltage of the three axes should be analyzed comprehensively [6]. In this study, the output voltage is analyzed in accordance with equation (6).

$$H(k) = |X(k) - x| + |Y(k) - y| + |Z(k) - z|$$  \hspace{1cm} (6)

In the equation (6), $X(k)$, $Y(k)$ and $Z(k)$ respectively represent the output voltages. $x$, $y$ and $z$ respectively indicate the stable baseline voltage of the three axes of the sensor without interference.
from the vehicle. The $H(k)$ represents the result of the combined processing of the three axes output voltage as shown in Figure 5-(d), where the point A indicates that the headstock passes the sensor, and the point B indicates that the end of the vehicle passes the sensor. Through this method, the overall variation of the geomagnetic field under the influence of vehicle interference can be analyzed more clearly and intuitively.

According to Figure 5-(d), when the vehicle is far away from the sensor, the output of $H(k)$ is 0 and remains stable. From the A moment to the B moment, $H(k)$ has a more obvious output change. When the vehicle engine and wheel close to the sensor, $H(k)$ has the most obvious change. The changing of $H(k)$ are basically above 0.05V, and at this time the vehicle is in the parking space. Therefore, $H(k)$ parameter can provide a reliable reference for the system to set the appropriate threshold in practical applications. Finally, the system is installed in the parking lot for real test, and test results show that the detection accuracy can reach 98%.

5. Conclusions

The vehicle detection system designed by our research team has a detection accuracy up to 98% with the advantages of easy installation, low power consumption and low cost. The system with three-axial GMR sensor can avoid the certain error by single axis. Moreover, the detection algorithm of the baseline adaptive state machine avoids the drawbacks of the baseline adaptive algorithm and the state machine algorithm.

Although the research with respect to the vehicle detection system has made a great progress, the vehicle detection system has some limitations when it is put into practical use in the increasingly complicated traffic environment. Further studies in the future is still needed for the improvement of the vehicle detection system in hardware characteristics and detection algorithms. The present study provides valuable reference for the development of geomagnetic vehicle detection systems in the future.

References

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