MR 센서를 이용한 새로운 차량 검지기에 관한 연구
A Study on the New Vehicle Detector Using MR Sensor

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ABSTRACT

This paper proposed a new type of vehicle detector using a MR sensor. and addressed detector's apparatuses and detecting algorithms. Proposed detector has been tested on a local highway between Mishiryong and Sokcho in Korea. Through extensive field tests, the outputs of the detector in response to various kinds of passing vehicles have been collected and analyzed. It is verified from the analyses that the outputs of the detector take on very different aspects with each vehicle, so that information on not only traffic count but vehicle types could be extracted from the outputs. And, with the proposed detector, traffic volumes on the two lanes in the tested region were measured and compared when both congested and clear traffic situations.

1.Introduction

As road traffic has been increasing dramatically Transportation Management Systems (TMS) have been developed to achieve more efficient transportation management as well as to increase stability of the systems. Vehicle detectors[1~3]are the most fundamental elements of the TMS and are used to collect information from passing vehicles on the road, such as traffic volume, occupancy rate and speed.

This paper proposes a new type of vehicle detector using an earth magnetic field sensor, MR (magneto-resistive) sensor[4~6], and addresses its characteristics on the basis of experimental results.

The detector consists of a MR sensor, mechanical and electronic apparatuses, and algorithms. The MR sensor is formed with six magnetically variable resistors in a solid-state body. Four of the resistors are shaped into a Wheatstone-bridge for sensing vehicles and biased with a dc voltage. If resistances of one or more of the resistors are altered by variation of earth's magnetic field caused by a passing vehicle over the sensor, the sensor produces an output indicative of the vehicle. Mechanical apparatuses are for case waterproofing and easy maintenance and repair of the detector. Electronic apparatuses include sensor output amplifiers, compensating circuits for earth's magnetic field adjacent the detector, signal-offset removing circuits, signal converting comparators circuits, and a microprocessor and communication interface. Vehicle detecting algorithm is programmed in microprocessor only to count vehicles for the moment.

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Experiments have been executed with three stages. At first stage, laboratory analyses for characteristics of the sensor were done thoroughly and therefrom validity of the proposed compensation circuits and algorithms were confirmed. At second stage, proposed detector has been tested on a regional highway between Mishiryong and Sokcho in Korea. Through extensive field tests, the outputs of the detector in response to various kinds of passing vehicles have been collected and analyzed. It was verified from the analyzing process that the outputs of the detector took on very different aspects with each vehicle, so that information on not only traffic count but vehicle types could be extracted from the outputs. At final stage, experiments were done to verify effectiveness of the detector's vehicle counting algorithm in low speed congested traffic, and then traffic volumes at congested and clear traffic situation in the tested region were compared.

2. Experimental Analysis of a MR Sensor

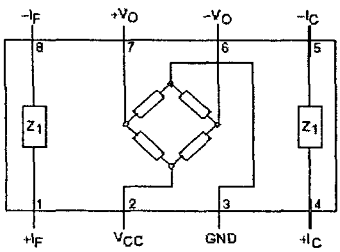
2.1 Structure of a MR Sensor[5]

The MR (Magneto-Resistive) sensor used in this research consists of six magnetically variable resistors which are made of a nickel-iron (Permalloy) thin film deposited on a silicon wafer and patterned as a resistive strip, and they are all packaged in a solid-state body as shown in Fig. 1. Biased with a dc voltage (Vcc), in the presence of an applied magnetic field, a change in the bridge resistance causes a corresponding change in voltage output (+Vo, -Vo). This change in the permalloy resistance is termed the magnetoresistive effect. Fig. 2 shows the magnetoresistive effect in permalloy. Assume that, when no external magnetic field is present, the permalloy has an internal magnetization vector, H_{in}, parallel to the current flow caused by the dc voltage. If an external magnetic field, H_{ext}, is applied, parallel to the plane of the permalloy, the internal magnetization vector of the permalloy will rotate around an angle α to be a magnetization vector, H_{tot}. As a result, the resistance of R of the permalloy will change as a function of the rotation angle α, as given below.

$$R = R_0 + \Delta R_0 \cos^2 \alpha$$

Where R_0 and ΔR_0 are material parameters.

During manufacture, the sensitive axis or easy axis (preferred direction of external magnetic field, H_{ext}) is set to one direction along the length of the permalloy film. This allows the maximum change in resistance for an applied field within the film. However, the influence of a strong magnetic field along the easy axis could upset, or flip, the polarity of film magnetization, thus changing the sensor characteristics. Following such an upset field, a strong restoring magnetic field must be applied into a resistive strip($+I_F$, $-I_F$ in Fig. 1) momentarily to restore, or set, the sensor characteristics.



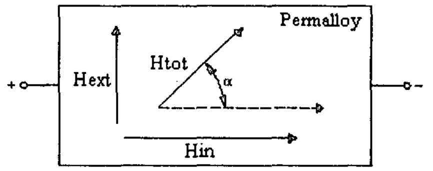
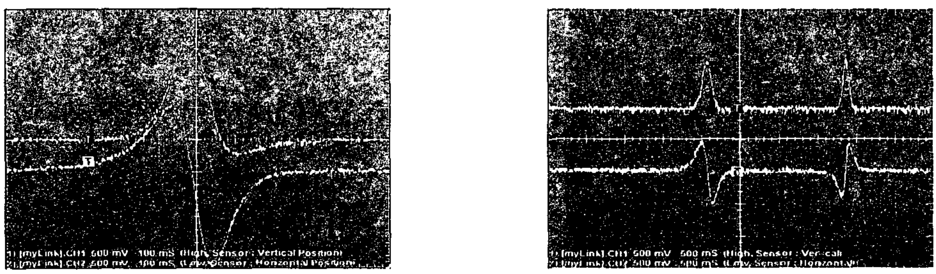


Fig. 1 Simplified Circuit Diagram of a MR Sensor Fig. 2 Magnetoresistive effect of permalloy

2.2 Experimental Analysis

Fig. 3 shows electronically magnified MR sensor's outputs for a ferromagnetic object passing over it. In Fig. 3 (a), lower curve represents a distortion to the earth's field while the ferromagnetic object moves along the sensitive axis of a MR sensor. As the object moves, sensor output increases above the initial value, and then decreases to the initial value when the object is placed above the sensor, then decreases below the initial value. But, while the object moves perpendicularly to the sensitive axis sensor outputs are quite different from the lower curve (upper curve in Fig.3 (a)). Namely, when the object is placed directly above the sensor, sensor's output increases to the maximum value and then decreases to the initial value. And, comparing the upper curve with the lower one it is shown that the upper curve increases and decreases quiet sharp than the lower one. This sharpness could have a desirable effect on discrimination of two adjacently moving objects.

Fig. 3 (b) shows sensor's outputs in case of reversing moving direction of the object successively, left to right, then right to left with a sensor centered. When the object moves perpendicularly to the sensitive axis, the two successive sensor outputs are quite same irrelevant to moving direction (upper curve), but in the case of moving along the sensitive axis, successive sensor output is reversed according to the reversal of moving direction (lower curve).

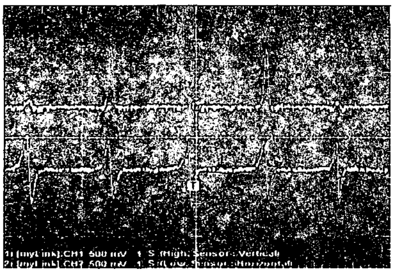


(a) Normal state waveforms (b) Reversing moving direction successively

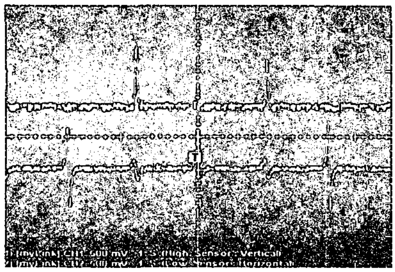
Fig.3 Comparison of outputs of sensors for a moving ferromagnetic object (upper curves : perpendicular to the sensitive axis, lower curves : along the sensitive axis)

Fig. 4 shows sensitivity characteristics of MR sensors. The curves shown in Fig. 4 were obtained while a ferromagnetic object was moving directly above the sensors, and then the same object moving apart by some centimeters from the sensors, alternately. Upper curves represent outputs of a sensor with sensitive axis perpendicular to the moving direction, and lower curves represent outputs with sensitive axis along the moving direction. It is shown from the Fig.4 (a) that, in the upper curve, the first waveform which was obtained while a ferromagnetic object was moving apart by 8cm from the sensor is much smaller than the next waveform which was obtained while a ferromagnetic object was moving directly above the sensors, whereas all waveforms in the lower curve have almost same amplitudes. Fig. 4 (b) shows results of the case when the ferromagnetic object moves apart wider, 16cm. In this case the first waveform in the upper curve was reduced to disappear.

Consequently, it can be verified from the two experimental results that sensitivity of the MR sensor according to the distance from the moving object decreases as the distance increases, much deeply when the sensor's sensitive axis perpendicular to the moving ferromagnetic object than when the axis is along the object. In multi-lane highway, a vehicle detector at a lane should not be affected with vehicles running other lanes so that the detector gives correct information. So, it is desirable for the detector which is based on MR sensor to have low sensitivity against the vehicles running other lanes, and accordingly setting up the sensitive axis of MR sensors perpendicular to a moving ferromagnetic object (a vehicle) is considered desirable.



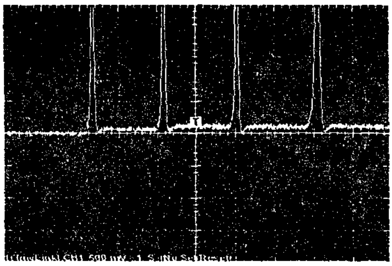
(a) Distance of 8cm



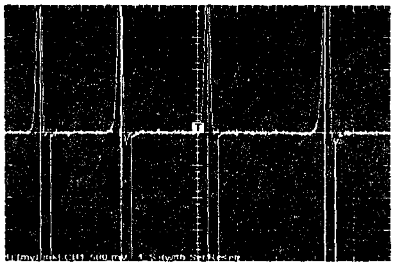
(b) Distance of 16cm

Fig.4 Comparison of sensitivity of MR sensors according to distance between a sensor and a moving ferromagnetic object

When MR sensors are exposed to a magnetic disturbing field, the sensor elements are broken up into randomly oriented magnetic domains. In this case the output voltage of the sensor would not return to its initial level accurately and has a little offset from the initial level. Fig. 5 (a) shows this offset state, that is, a little offset is produced from the second movement of a ferromagnetic object and then the offset is not reduced and somewhat magnified thereafter. This offset could be a major obstacle to stable use of MR sensor. To solve this problem, short current pulses are applied into a resistive strip of MR sensor ($+I_F$, $-I_F$ in Fig. 1), periodically from the beginning of detector's operation so that a strong magnetic field is generated which realigns the magnetic domains into the initial state, periodically. In Fig. 5 (b), the offset voltages are not shown with just voltage flashes that are caused by the current pulses and proved to have no effect on the vehicle detecting performance in this research.



(a) Without current pulses

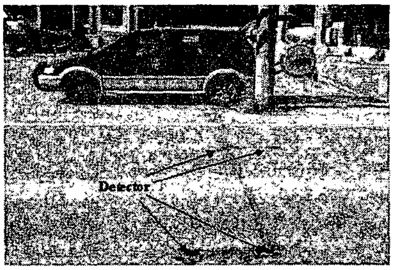


(b) With current pulses

Fig.5 Comparison of outputs of MR sensors according to current pulses

3. Field Experiment

The developed detector has been tested on a local highway between Mishiryong and Sokcho in Korea. Fig. 6 shows the photograph of experimental site and equipments.



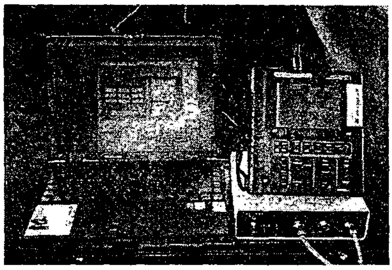
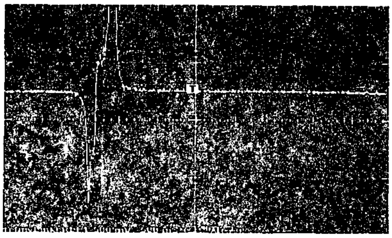


Fig. 6 Photograph of experimental site and equipments

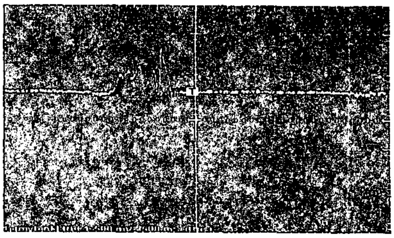
Field tests were set-up, firstly to measure the detector's output voltage waveforms for different passing vehicles. Fig. 7 shows detector's output waveforms according to various vehicles driving over the detector on the highway. When a vehicle passes over the magnetic sensor within the detector, the sensor detects earth field variations caused by all the different dipole moments of the various parts of the vehicle. Namely, this field variation will reveal a very detailed magnetic signature of the vehicle.

From the curves of (a)~(f) in Fig. 7, it is shown that the field variations are generally and substantially different from each other according to the passing vehicles and could give essential traffic information on not only traffic count but vehicle types, such as, for example, sedans, vans, trucks, buses and special trucks.

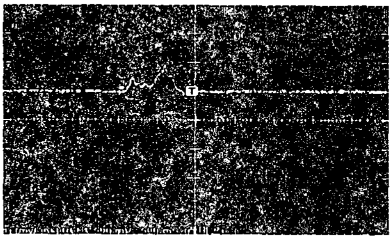
But on the other hand, it should be noted that, as shown in the waveforms of (g), (h), very different magnetic field variations could be generated although two vehicles are similar in shape. Two facts that two vehicles similar in shape could have different internal structures and parts, and accordingly different magnetic arrangement and that relative position and/or distance between a detector and a vehicle passing over it vary every time, contribute to the differences of the detector's output waveforms as a whole.



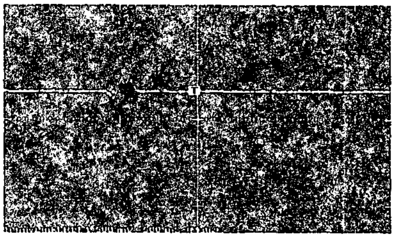
(a) A large size sedan (Grandeur old)



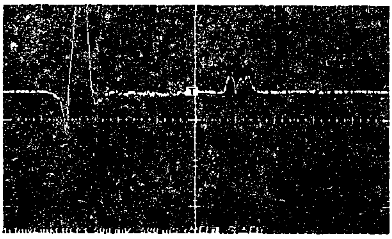
(b) A bus



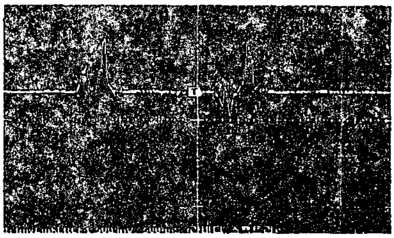
(c) A special truck (Remicon)



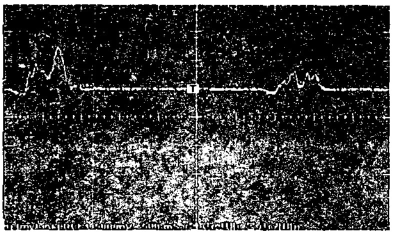
(d) A light-weight passenger car (Matiz)



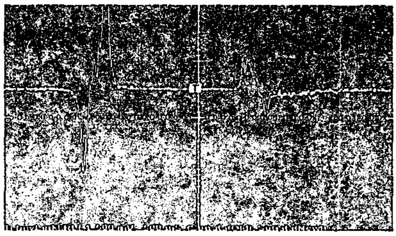
(e) Two RVs (Santafe(van) and Rockstar(jeep))



(f) A small size passenger car (hatchback) and a small size sedan (Labita and Spectra)



(g) Two 1-ton trucks

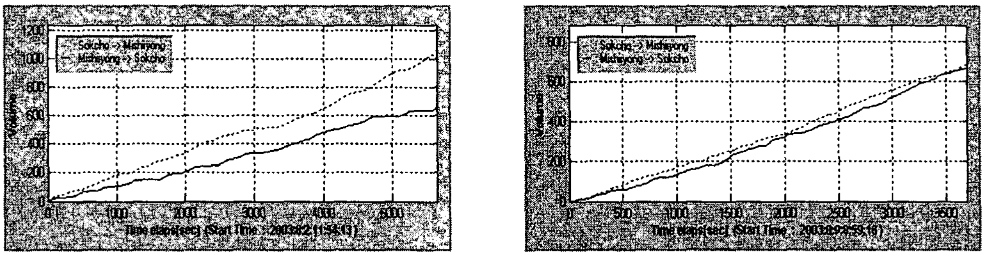


(h) Two medium size sedans (Sonata old and new)

Fig. 7 Detector's output waveforms according to vehicles driving over the detect

When amplified sensor output, that is detector's output voltage, goes over (below) the upper (lower) boundary a vehicle is detected and traffic counter is incremented by one after checking procedure for vehicle's passing away. The updated vehicle count is saved in memory and then sent to a notebook pc along with detector's identification (ID) via a RS-485 communication port.

Fig. 8 shows experimental results that compare traffic volumes between congested and clear traffic situation. The solid line in each figure represents the number of driving vehicles on a lane, Mishiryong to Sokcho, according to time elapse, and the dotted line shows result on the opposite lane, Sokcho to Mishiryong. From those two figures it could be inferred that the lane, Mishiryong to Sokcho, is far more congested than the opposite lane at holiday, and that in a low speed congested traffic, the number of vehicles on the lane, Mishiryong to Sokcho, is getting smaller than that of the opposite lane. On the other hand, there is no notable difference during clear traffic situation.



(a) Congested traffic (b) Clear traffic

Fig. 8 Comparison of traffic volumes between congested and clear traffic

4. Conclusion

This paper proposed a new type of vehicle detector based on a MR sensor and addressed its characteristics on the basis of experimental results.

Laboratory analyses for characteristics of the sensor were done thoroughly and therefrom validity of the proposed compensation circuits and algorithms were confirmed, preliminarily. Proposed detector has been tested on a local highway between Mishiryong and Sokcho in Korea. Through extensive field tests, the outputs of the detector in response to various kinds of passing vehicles have been collected and analyzed. And it is verified from the analyses that the outputs of the detector take on very different aspects with each vehicle, so that information on not only traffic count but vehicle types could be extracted from the outputs. Lastly, an experiment was done to compare traffic volumes between congested and clear traffic situation in the tested region. From experimental results it was found out that the lane, Mishiryong to Sokcho, is far more congested than the opposite lane at holiday, and that in a low speed congested traffic, the number of vehicles on the lane, Mishiryong to Sokcho, is getting smaller than that of the opposite lane. On the other hand, there is no notable difference during clear traffic situation.

For the moment, proposed vehicle detector counts the number of passing vehicles. Future research will be focused on measuring occupancy time and vehicle speed.

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