2개의 AMR 센서를 이용한 무선 차량 검지기에 대한 현장시험 및 평가

논 문
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Field Test and Evaluation for a Wireless Vehicle Detector with Two Anisotropic Magneto-Resistive Sensors

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Abstract - This paper shows field test and evaluation results for a wireless vehicle detector with anisotropic magneto-resistive (AMR) sensors. The detector consists of two AMR sensors and mechanical and electronic apparatuses. The AMR sensor senses disturbance of the earth magnetic field caused by a vehicle moving over the sensor and then produces an output indicative of the moving vehicle. In this paper, vehicle speeds are calculated by using two AMR sensors fixed on a board, with constant distance. To test and evaluate the accuracy of the detector in real traffic situations, the detector was installed on a local highway and vehicle speeds and volumes were measured both in a free running and a highly congested traffic. The measurements from the detector are compared with the reference measurements obtained from a traffic camera with the Mean Absolute Percentage Errors (MAPE), which has proved the usefulness of the detector in the field.

Key Words : Wireless vehicle detector AMR sensor Vehicle speed, Vehicle volume, MAPE

1. Introduction

Vehicle detector is the most fundamental element of the Transportation Management Systems (TMS) which is used to collect information from moving vehicles on the road, such as traffic volumes, occupancy rates and average speeds. Among the prior state-of-the-art vehicle detectors, loop detectors have been used on the largest area due to their low cost and relatively high performance [1-3]. But, the installation of the loop requires many hours tearing up the road, and even a small shape-distortion of the loop can degrade detecting performance.

As an alternative to the loop detector, Earth Magnetic Field (EMF) detectors have been proposed and tested in the field [4-8]. These detectors are based on the magneto-resistive (MR) sensors [9-12], which sense disturbance of the EMF caused by moving vehicles over the sensor and then produce an output indicating the moving vehicles. With descriptions of the superiority of the MR sensors over the loop sensors, reference [4] proposed the method and apparatus for detecting a characteristic and a speed of a vehicle, by using the MR sensors. With the results of field tests, reference [6] showed output waves of a detector according to the various kinds of vehicles passing on the road, using anisotropic magneto-resistive (AMR) sensors, and verified the performance of AMR detector as the traffic volume counter. Recently, reference [7] showed the prototype design and the performance of wireless sensor networks for various traffic surveillance fields, using AMR sensors.

This paper shows some field test results in real traffic situations and accuracy of a wireless vehicle detector with two AMR sensors (KMZ51, Philips) [12]. Compared with conventional speed detectors which use two individually installed vehicle sensors [7], the proposed speed detector in this paper consists of two AMR sensor boards, a control board and a battery pack in a water-proof aluminum case, which needs only one installation on the road and remarkably reduces the installing time and cost in the field. The speed is calculated directly from the detector control board and wirelessly transmitted to a local data logger. The detail hardware specifications of the detector are described in the chapter 3. To evaluate the accuracy of the detector in real traffic situation, the detector was installed on a local highway, and vehicle speeds and volumes were measured both in a free running traffic and in a highly congested traffic. The measurements from the detector are compared with the reference measurements obtained from a traffic camera, and the accuracies of the proposed detector have been evaluated by the Mean Absolute Percentage Errors (MAPE) between the two measurements. The overall field

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test results have proved that the proposed vehicle detector can be effectively used in real traffic situation.

2. Preliminary tests for AMR sensors

As a laboratory test result, Fig. 1 shows the amplified outputs of two AMR sensors (KMZ51, [12]) while a ferromagnetic object (magnet) moves over the two sensors where one sensor is located with its sensitive axis horizontal to the moving direction of the magnet, (b)-(1), and the other one is located with its sensitive axis perpendicular to the moving direction, (b)-(2). From the two output waves, it can be known that the sensor output increases and decreases quite sharply with the sensitive axis perpendicular to the moving magnet than the axis positioned along the magnet. This sharpness can be a desirable effect on the discrimination of two closely and successively moving objects.

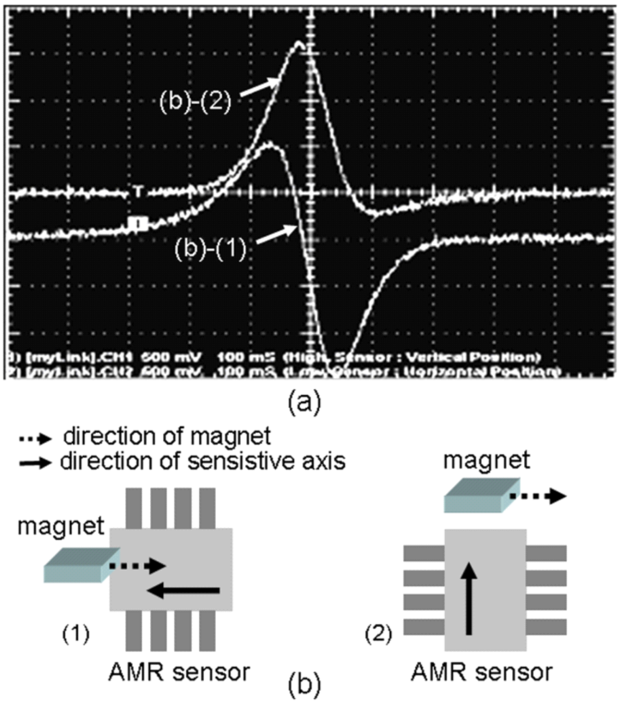

Fig. 1 (a) Amplified sensor outputs (x: 100 ms/div, y: 500 mV/div) and(b) Arrangement of a magnet and an AMR sensor for experiments.

As a field test result, Fig. 2 shows the amplified output curves of an AMR sensor according to the different types of vehicles passing over the sensor buried on a local highway. The waves in this figure give very detailed magnetic signatures of the passing vehicles and they could be used to extract various parameters for detecting vehicles. Especially, considering the voltage levels of the waves, it is shown that the AMR sensor produces voltages fluctuating over 0.3V or so for the every traveling vehicle, which gives a base level for the comparator threshold voltage, a principal design parameter of the detector circuit.

3. Configuration of the vehicle detector

Fig. 3 shows the hardware configuration of the proposed vehicle detector, and Fig. 4 shows a photograph of the detector. The detector consists of two identical AMR sensor boards, a control board, a lithium-ion battery pack, and an aluminum case. A sensor board includes sensor-output amplifiers (Amp), a flipping current generator (Fcg), a ADC, a DAC and a comparator (Com).[6] A sensor output is amplified in two stages and compared with a threshold voltage level. Assuming an average earth magnetic field of 0.5[G] is distributed over a KMZ51, a KMZ51 produces about 3[mV] by equation (1) with the typical bridge voltage of 5[V] and the sensitivity of 16$[(mV/V)(kA/m)^{-1}]$ [12]. In the tested sensor board, the bridge voltage is set to be 3[V] due to the 3.6 volt lithium-ion battery, which has preferably contributed to the low power consumption. The two stages of voltage amplifiers are adopted to increase the sensor output over 1000 times.

$$V_o = 0.07958 \times S \times V_B \times G_E \quad (1)$$

$V_o[mV]$[mV]: output voltage of a KMZ51
$S[(mV/V)(kA/m)^{-1}]$: sensitivity of a KMZ51
$V_B[V]$: bridge voltage of a KMZ51
$G_E[G]$: intensity of earth magnetic field ($1G = 79.58[A/m]$)

The control board includes a microprocessor (Atmega 168V, Atmel) and a RF module (CC1101, TI [13]). The speed of a vehicle is calculated with the microprocessor by dividing the known constant distance between the two sensors by the time difference between the two output signals from each sensor, captured sequentially while the vehicle is passing over the sensors. Once a speed calculation has finished, the RF module transmits a speed data packet to a local data logger waiting for the packet. Since the whole boards, two sensor boards and one control board, are fixed on a base panel and mounted with a battery pack in a water-proof aluminum case which is stiffly attachable on the road with an adhesive tape, the setup and installation process is very simple and takes only a few minutes.

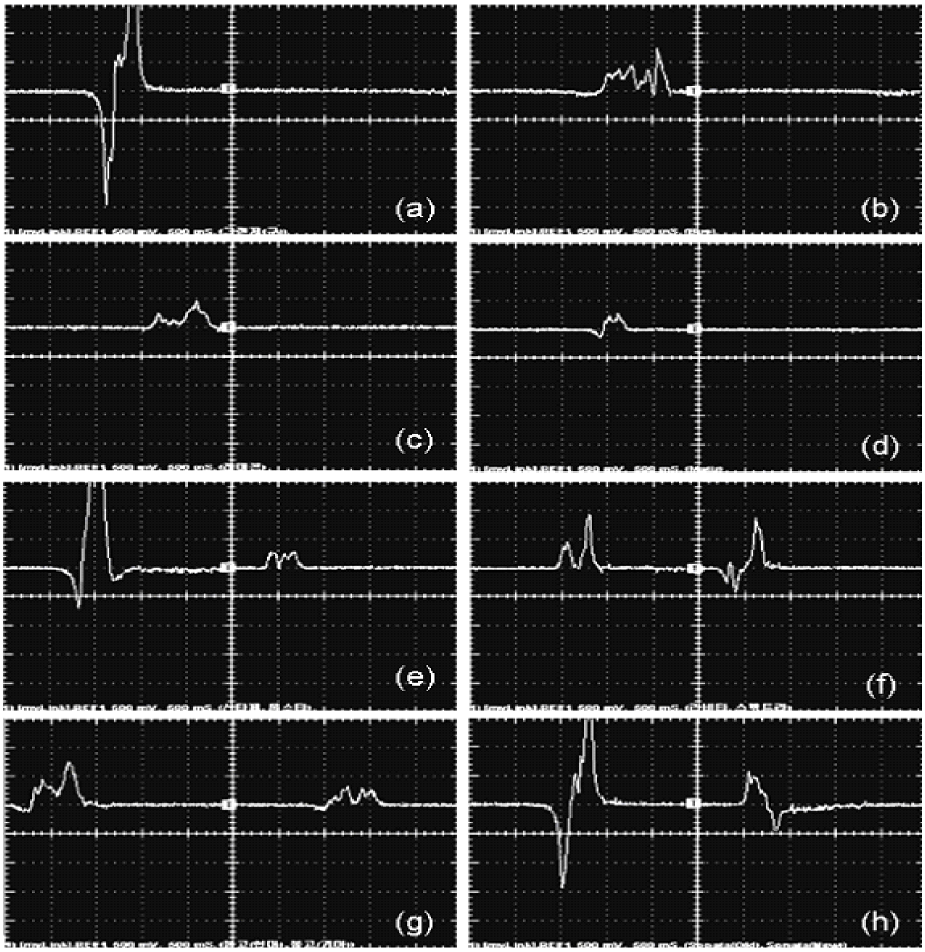

Fig. 2 utput curves of an AMR detector according to various vehicles traveling over the detector on a highway (a) a large size sedan, (b) a bus, (c) a special truck (remicon), (d) a light-weight passenger car, (e) two RVs(van and jeep), (f) a small size passenger car(hatchback) and a small size sedan, (g) two 1-ton trucks, and (h) two medium size sedans(old and new version) (x:500 ms/div, y:500 mV/div).

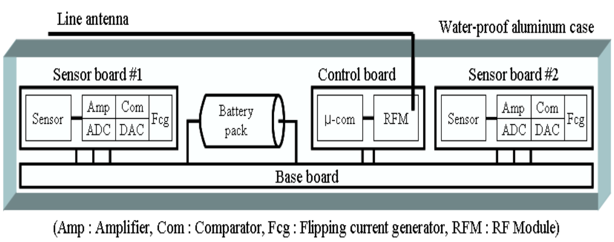

Fig. 3 ardware configuration of a detector.

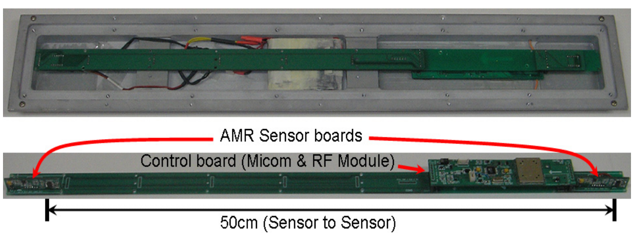

Fig. 4 hotograph of a detector.

4. Field test and evaluation

4.1. Vehicle detecting sequence

The speed of a vehicle is calculated by dividing the known constant distance (d) between the two sensors by the time difference (Δt_s) between two output signals from each sensor, captured sequentially while the vehicle is passing over the sensors. After power-on of the detector, an initial adjusting process is carried out to make the amplified output voltages of the two sensors constant (V_c), irrelevant to the various local magnetic conditions adjacent to the detector. At the end of the initial process, the microprocessor reads the local magnetic level (V_i) with an ADC and stores it. After the initialization the microprocessor waits in sleep mode until an interrupt signal is activated by the first sensor. If the output voltage of the first sensor (V_o) is excited and goes over a threshold level ($V_{th} = V_c \pm \Delta V_{th}$) by a vehicle, a comparator on the sensor board activates the interrupt signal. At this point the microprocessor starts a timer and waits for the second interrupt signal from the second sensor. At the time the second interrupt signal is activated by the vehicle continually passing over the detector, the microprocessor captures the timer output (Δt_s) and calculates the speed of the vehicle, and increments the vehicle volume count by one. Afterwards, if the output voltage of the detector recovers from the excited level (V_o) to the initial level (V_i) within a range ($|V_o - V_i| \le \Delta V_{oi}$) and continually remains in that range for a time (t_r), the vehicle is considered to have gone away out of the detector. Lastly, the microprocessor transmits a speed and volume data packet to a data logger and goes into the sleep mode again waiting for the second vehicle. Fig. 5 shows the flow chart of the detecting sequence and Table 1 shows the detector parameters with their values.

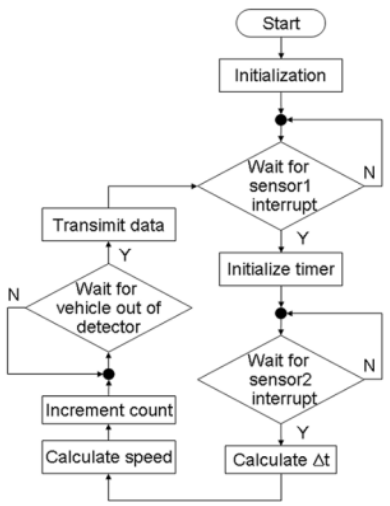

Fig. 5 Flow chart of a vehicle detecting sequence.

Table 1 Detector parameter values.

Parameters	Values
d	50.0[cm]
V_c	1.50[V]
ΔV_{th}	0.25[V]
ΔV_{oi}	0.25[V]
t_r	0.50[sec]

4.2. Test results and evaluation

Performance of the vehicle detector is verified on the basis of the field tests carried both under a low-speed congested traffic and under a free running traffic on a local highway in Korea, the entrance of Hongjimoon tunnel in Seoul. To evaluate the accuracy of the detector, vehicle speeds and volumes were measured and compared with the reference measurements obtained from a traffic camera, where the MAPE between the AMR detector measurements and the reference camera measurements are calculated with the equation (2) and (3). Fig. 6 is a photograph of the tested local highway, showing an AMR detector attached on a lane and a reference camera.

$$\text{MAPE [\%] (for speed)}: \frac{100}{n}\sum_{i=1}^{n}\frac{|\overline{f_{CAM,i}}-\overline{f_{AMR,i}}|}{\overline{f_{CAM,i}}} \qquad (2)$$

$$\text{MAPE [\%] (for volume)}: \frac{100}{n}\sum_{i=1}^{n}\frac{|f_{CAM,i}-f_{AMR,i}|}{f_{CAM,i}} \qquad (3)$$

n: Number of time intervals

$\overline{f_{CAM,i}}$, $\overline{f_{AMR,i}}$: Average values of measurements of a camera and an AMR detector for the i-th time interval

$f_{CAM,i}$, $f_{AMR,i}$: Summations of measurements of a camera and an AMR detector for the i-th time interval

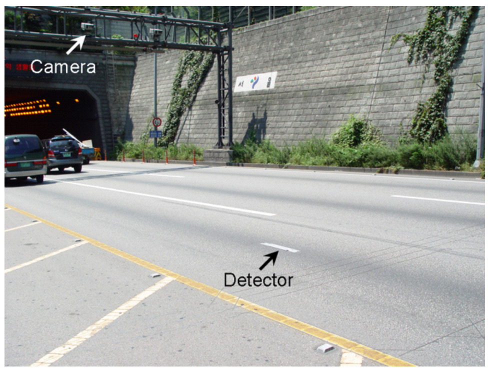

Fig. 6 hotograph of the detector under test on a local highway (Hongjimoon tunnel).

Fig. 7 ~ Fig. 9 show the plots of the average speeds and the volumes obtained from the measurements of the AMR detector and the reference camera, where each average speed was calculated by averaging all of the speed measurements during a time interval and each volume was calculated by accumulating the total counts during the same time interval. The distances (d) used to calculate the speed of a vehicle are 50[cm] and 1200[cm] for the AMR detector and the camera, respectively.

Fig. 7 and Fig. 8 show the test results obtained in a highly congested traffic condition for 20 minutes while the total average speed was about 17[km/h]. In Fig. 7, subplots (a) and (b) show respectively the average speed and the volume consistencies between a tested AMR detector and a reference video camera, where the MAPE of 30-seconds time interval between the two detectors is 12.46[%] for the average speed accuracy while the MAPE for the volume accuracy is 1.67[%]. Subplots (a) and (b) in the Fig. 8 show the results with the same measurements as Fig. 7, but the time interval is

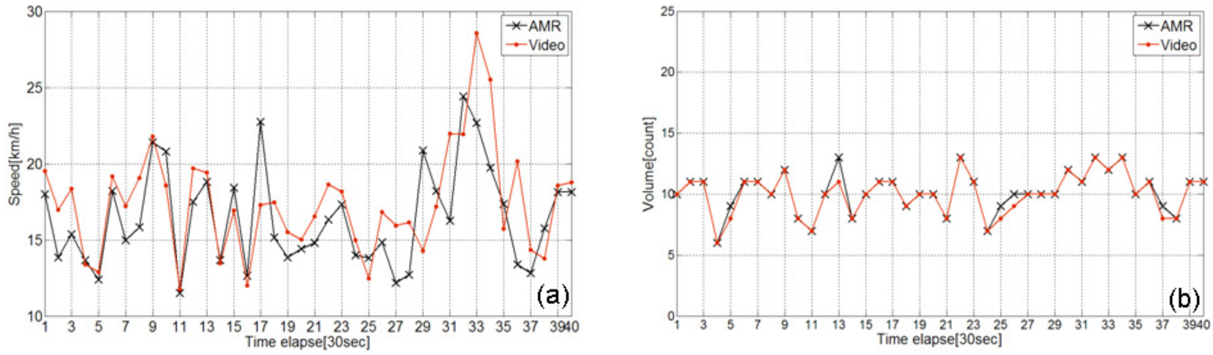

Fig. 7 Comparison of average speeds (a) and volumes (b) from an AMR detector and a camera (start time:19:00:27, time interval:30[sec], MAPE(speed):12.46[%], MAPE(volume):1.67[%], total average speed:17[km/h]).

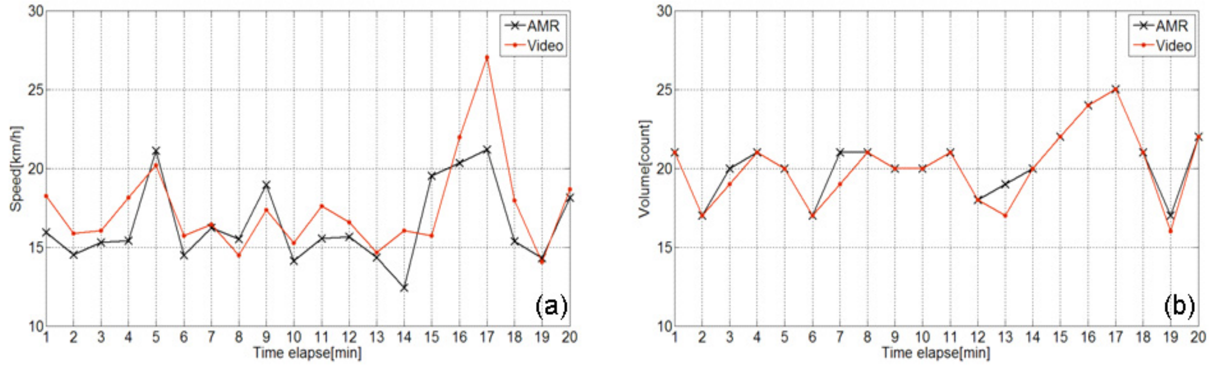

Fig. 8 Comparison of average speeds (a) and volumes (b) from an AMR detector and a camera (start time:19:00:59, time interval:60[sec], MAPE(speed):9.61[%], MAPE(volume):1.69[%], total average speed:17[km/h]).

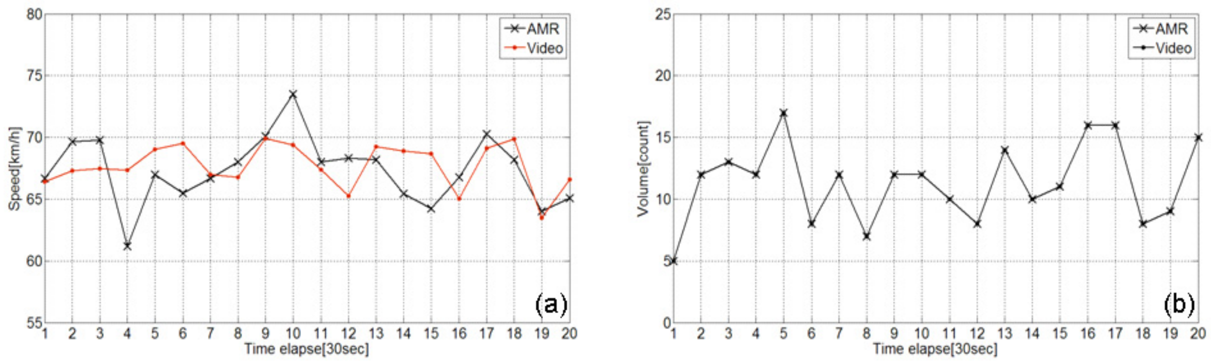

Fig. 9 Comparison of average speeds (a) and volumes (b) from an AMR detector and a camera (start time:17:35:29, time interval:30[sec], MAPE(speed):3.11[%], MAPE(volume):0.00[%], total average speed:68[km/h]).

increased to 60-seconds and each MAPE for the average speed and the volume is recalculated with this new time interval. In this case, each MAPE for the average speed and the volume is 9.61[%] and 1.69[%], respectively. From this results, it has proved that the AMR detector is nearly equal to the reference detector for the volume accuracy, within 2[%], while the average speed accuracy is not as good as the volume accuracy in a highly congested traffic but could be increased with increasing the time interval. In the meantime, in a highly congested traffic where the vehicle speeds are very slow and easily changeable with repeated stops and goes, there can be considerable differences between the detectors in the speed measurements. Namely, because the longer the detecting distance (d) is, the bigger the possible speed change within the distance is, the difference of the average speeds shown in the Fig. 7 and Fig. 8 can be, in some extent, due to the difference of the detecting distances (d) between the AMR detector and the camera.

Fig. 9 shows test results obtained in a free running traffic condition for 10 minutes while the total average speed was about 68[km/h]. Two subplots (a) and (b) in the Fig. 9 show the average speed and volume consistencies between the tested AMR detector and the camera. For the average speed accuracy, the MAPE of 30-seconds intervals between the two detectors is 3.11[%] and for the volume, the MAPE is 0[%]. This results show that the volume accuracy of the AMR detector agrees perfectly with the camera and the average speed accuracy agrees with the reference detector within 3[%]. Consequently, the AMR detector has shown very high accuracies in the free running traffic condition. Table 2 summarizes the entire field test results.

Table 2 Test results.

Average speed [km/h] (Video/AMR)	Total volumes [count] (Video/AMR)	MAPE [%]		
		Speed	Volume	Time interval[sec]
17.4/16.4	401/406	12.46	1.67	30
17.4/16.4	401/406	9.61	1.69	60
67.7/67.3	227/227	3.11	0	30

5. Conclusion

This paper shows field test and evaluation results for a wireless vehicle detector with two AMR sensors. Field test was carried both under a low-speed congested traffic and under a free running traffic condition on a local highway in Korea. To evaluate the accuracy of the detector, vehicle speeds and volumes were measured with the detector and with a reference traffic camera, and the measurements have been compared by using the MAPE. In a congested traffic, each MAPE for the average speeds and the volumes has been calculated as about 10[%] and 2[%], respectively, while in a free running traffic they have been calculated as 3.11[%] and 0 [%], respectively. As conclusion, the proposed vehicle detector has given good accuracies for both speeds and volumes. Future research will be focused on increasing the speed accuracy, especially in the low-speed traffic condition.

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