SD-IMAS: A New Slip Detection System Design for a Vehicle Using an Induction Magnetometer and an Accelerometer

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Abstract: - This paper presents a new slipping detection system design for a vehicle on a slippery road based on measuring magnetic patterns of a rotated wheel and a vehicle accelerator. Two sensors have been deployed for this propose; one is an induction magnetometer sensor and the other is an accelerometer. The data of the magnetic patterns of a rotating wheel and body-speed's data of the vehicle have been collected and hence correlated using both observation and computer-based simulation methods. The results elaborates that our new sensor is capable to provide a practical device for future ITS.

Key-Words: - ITS, sensor, induction magnetometer, accelerometer, slip

1 Introduction

An increasing demand for a safe drive on various road hazards becomes an important element in ITS (Intelligent Transportation System) platform [1][2]. Developing a detection system in a slippery road which caused by raining or snowing weather condition has being a major concern for enhancing road safety measures. A slipping vehicle happens when the force applied to a wheel exceeds the traction force to that wheel. The traction force of a tire is affected by vehicle's weight and the coefficient of the friction between road's surface and tire's surface. This coefficient depends on surface condition such as a wet or snow-covered road. In this paper, an early warning detection system has been developed to alert the driver if a slippery road condition is detected. The system consists of three components which are an induction magnetometer sensor, an accelerometer and a slip detection algorithm (*SDA*). During a wheel rotation, magnetic fields are generated in the internal wheel structure through magnetization by the geomagnetic fields. This inducted magnetic intensity can be measured by our developed induction magnetometer which placed near the wheel. Accordingly, a proportional relation between wheel rotating speed and magnetic intensity can be formulated [3]. We developed a high-sensitive induction magnetometer which is used for slip detection system and to obtain wheel-speed of the vehicle more precisely as well. Our new induction magnetometer has no mechanical parts motions involved; however, it is capable to measure the frontward speed of the vehicle properly. Another supplementary sensor that has been used to consummate our detection system is ADXL202 [1] accelerometer sensor which has been employed to determine a body-speed of the vehicle.

2 The detection system model

The detection system is based on measuring two speeds' parameters and composes of two main sensors in which the signals are collected and correlated; the first sensor is an induction magnetometer sensor (*IMS*) and the second one is an accelerometer sensor (*ACS*). These sensors detect the magnetic filed generated by wheel rotation and mean acceleration of a moving vehicle, respectively. The IMS has a tiny ferrite core bar antenna with specifications of 3x8x55mm size, the number of coil turns with N=150 and the cross section of a copper wire of 0.2mm. while ACS is well known sensor called ADXL202 sensor which has two axes direction detection system. The systematic positions of IMS and ACS sensors in the vehicle are shown in Fig.1.

During a wheel rotation, induced electromotive force detected by induction magnetometer sensor. The output signal from the induction magnetometer is amplified and passed to an anti-aliasing filter to remove the unwanted signals and noise. The speed of the wheel S_w, is based on the rotation of the wheel, can be easily calculated and converted to digital stream. Fig.2 shows the observed speed of the vehicle measured by an induction magnetometer and a current conventional speedometer. The elaborate sensors are

[1] Trademark of ANALOG DEVICES Ltd.

shown in the block diagram which includes *IMS*, *ACS* and a slip detection rate algorithm is shown in Fig.3. Unlike the current conventional speed meter system that depends on motion's parts of the vehicle's engine, the IMS doesn't require any mechanical parts contingences and its operation is based on magnetic induction only.

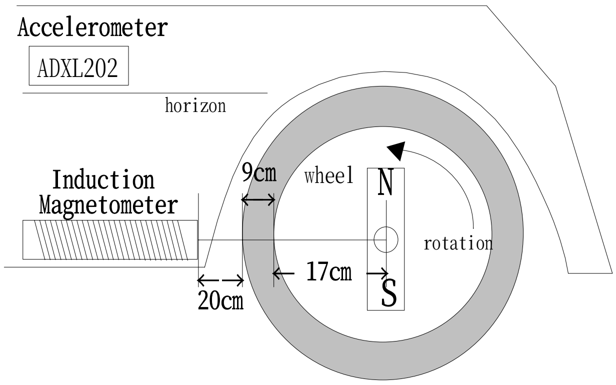

Fig. 1 The sensors positions in the vehicle

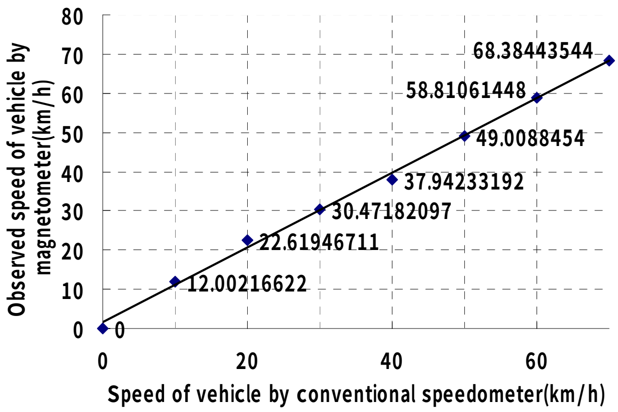

Fig. 2 Observed speed of the vehicle using induction magnetometer

The *ACS* measures the level of the acceleration in volts; it means that the mean acceleration of the vehicle has proportional relationship with the output voltage of the accelerometer, Therefore, the sensor output is voltage scale, and the acceleration of the vehicle (α) is easily obtained by the following relation

$$\alpha = g \times \frac{V}{\xi} \tag{1}$$

where g denotes the acceleration due to gravity, V the output voltage from *ACS*, and ζ the detection sensitivity output (312mv/g).

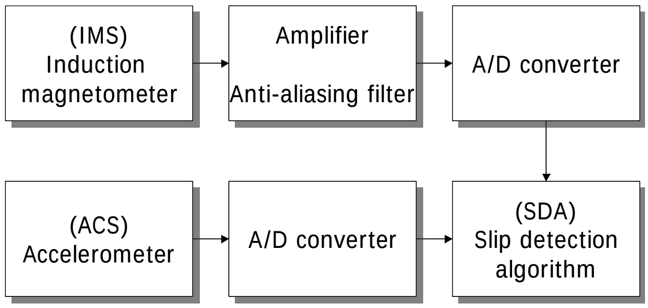

Fig. 3 Block Diagram of the System

Fig. 4 shows the observed output data from *ACS* and we need to find the body-speed S_b of the vehicle. From the Figure, as the vehicle start moving, the initial time that the body-speed starts is t_i, and suppose that the vehicle is moved to t_j then the mean acceleration of the body-speed is the constrained area between t_i and t_j which has proportional relationship with the output voltage of the accelerometer.

The body-speed S_b of the vehicle at time t_j can be easily calculated using the following relation;

$$S_b = \int_{t_i}^{t_j} \alpha(t)dt + S_0 \tag{2}$$

where S_0 denotes initial speed at t_i. The S_b is the encompassed area between t_i and t_j. From above relation we can obtain the speed of the vehicle at any point in the illustrated curve as shown in Fig.4. The obtained results from *ACS* are converted to digital stream which is used together with S_w to obtain slip rate.

As we mentioned above that the induction magnetometer sensor IMS is designed to measure a wheel's speed S_w. During the wheel rotation, magnetic field will be detected in IMS and the output from IMS is voltage scale, as shown in Fig. 5. During wheel rotation, a periodic signal of period T_w will be generated, where T_w represents a time period between two signal's peaks in which the speed of the wheel can be determined precisely. As the speed of the wheel becomes irregular, the output signal from IMS will be a periodic pattern through which the period T_w will have different values. When the speed S_w of the wheel increases then the period T_w will be short and vice versa. The S_w can be calculated from the relation $S_w = \pi D / T_w$, where D is a diameter of the tire.

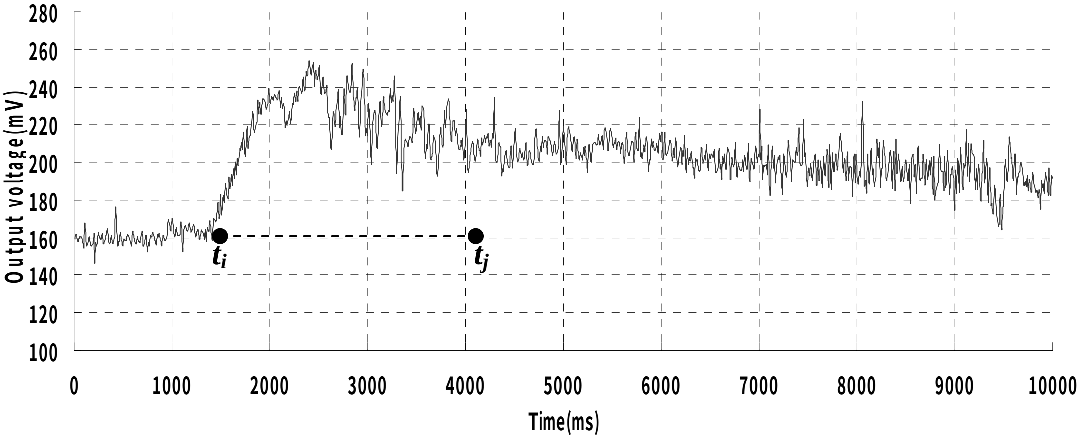

Fig. 4 Observation data of accelerometer

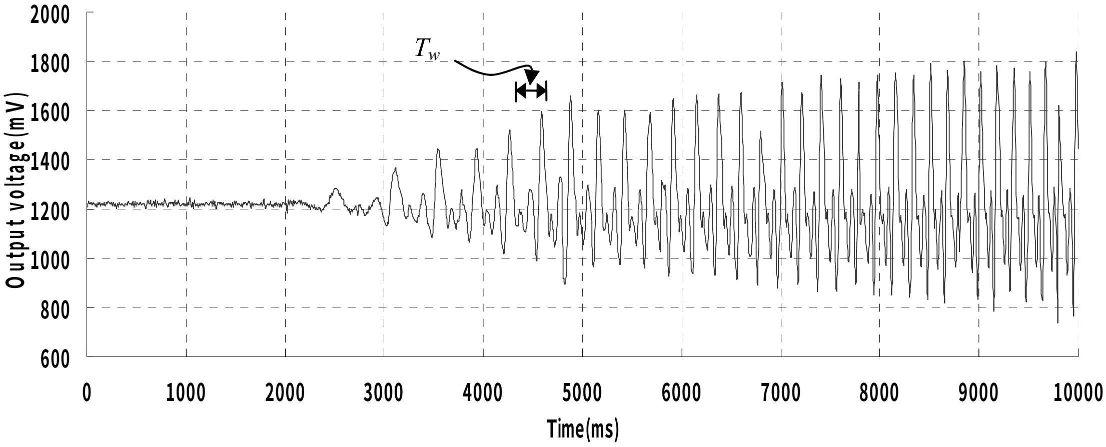

Fig. 5 Observation data of induction magnetometer

The data that has been collected from *IMS* and *ACS* is converted to digital streams to calculate S_w and S_b. This task is done by a slip detection algorithm (*SDA*) which is predicated on computer programming in C++. Another task that *SDA* perform is correlating S_w and S_b signals to obtain a slip rate and makes an appropriate decision to send warning signals if the rate reaches to a value outside a specific rate boundary that will be described in the next section.

A slip of a vehicle is occurred when there is a difference between two speeds S_w and S_b. The relationship between two speeds is defined as a wheel slip rate η and can be written as;

$$\eta = [(S_b - S_w) / S_b] \times 100\% \tag{3}$$

In case of η=0% in equation (3), the body-speed S_b and the wheel speed S_w are equal and there is no a slippery condition on the road, however, in this condition, it is difficult for the vehicle to drive on curved roads. The wheel slip rate becomes higher value when the body-speed of the vehicle exceeds the wheel speed i.e. $S_b > S_w$. An example for this condition, on a slippery road when a driver makes a sudden break which stanches the rotation of the wheel, the body-speed S_b remains close to its speed. In this case, the wheel slip rate η positive and the best drive condition for the vehicle when the slip rate is positioned within a specific boundary value which is detailed in the next section. If a vehicle drives on a glacial road, where $S_w > S_b$, the slip rate will have a negative value. For certain values of the slip rate that are detected the system will give an advanced warning signal alerting a driver to drive with caution or to slow down to a speed that coincides with existing slippery road conditions.

3 Experiment and Observation results

An experiment has been conducted on a vehicle that had the following features; the radius of the tire was 26cm without Antilock Brake System (*ABS*). The structure of the wheel was steel. On board sensors and detection system were installed to collect real time data and to calculate S_w, S_b and slip rate simultaneously. Fig. 6 shows relation between the two speeds and also shows that they are equal at a time of about 3500*ms* from commencement moving of the vehicle, at this point, the slip rate η is zero. There is a divergence of speeds between S_w and S_b as the speed of the vehicle becomes higher, henceforth, the slip rate η is positive and the slip road condition is existent.

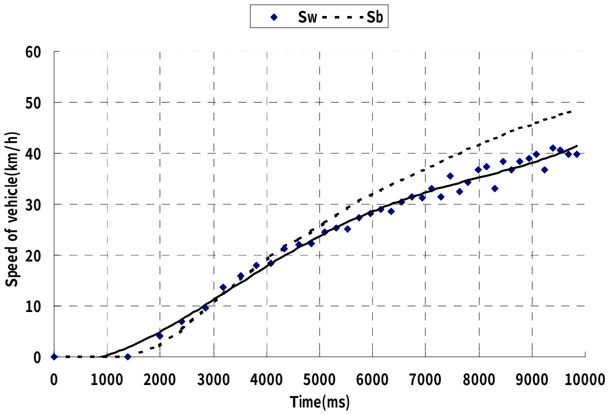

Fig. 6 Experiment results: a vehicle's body-speed and a wheel speed

The correlation of S_w and S_b has been preformed by means of the slip rate that is presented in Equation (3). Fig. 7 shows the slip rate with various speeds of S_w and S_b. In our experiment, we found that a perfect drive condition, which the driver can completely control the vehicle and the vehicle is in best drive condition, occurs when the values of the slip rates are ranging of 10% to 30%.

This boundary ratio (10% to 30%) is called a stable driving rate (*SDR*) boundary, in which a steering control and the coefficient of friction are inherent. Thus, if the slip rate value is out of this boundary the risks of a slippery road will be high. Indeed, the slip detection algorithm (*SDA*) will make a decision to send a warning signal to the driver. The system operation provides an effective mechanism for reducing road accidents.

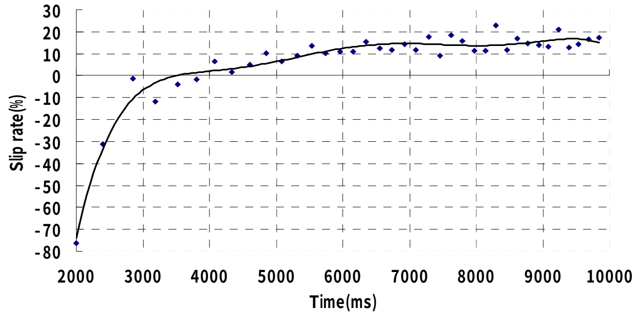

Fig. 7. Experimental record of slip rate factors (η)

4 Discussions and Future Work

The new slip detection system for a vehicle on a slippery road has been presented We have designed a high sensitive, a very low cost and a tiny induction magnetometer sensor in which numerous applications can be constructed.

The slip detection system presented in this paper gives an exceptional means of facilitating safe drive conditions on hazard roads such as slippery roads and it has the potential to provide efficient system for early warning and speed control for an emerging intelligent transportation system technology platform.

This is part of our on going work in attempting to design detection system based on RISC (Reduction Instruction Set Computer), by which the collected data from multi-sensors can be processed expeditiously.

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