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Wireless Black Box Using MEMS Accelerometer and GPS Tracking for Accidental Monitoring of Vehicles

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***Abstract*—In this work, wireless black box using MEMS accelerometer and GPS tracking system is developed for accidental monitoring. The system consists of cooperative components of an accelerometer, microcontroller unit, GPS device and GSM module. In the event of accident, this wireless device will send mobile phone short massage indicating the position of vehicle by GPS system to family member, emergency medical service (EMS) and nearest hospital. The threshold algorithm and speed of motorcycle are used to determine fall or accident in real-time. The system is compact and easy to install under rider seat. The system has been tested in real world applications using bicycles. The test results show that it can detect linear fall, non-linear fall and normal ride with high accuracy.**

I. INTRODUCTION

THE motorcycle accident is a major public problem in many countries, particularly Thailand. Despite awareness campaign, this problem is still increasing due to rider's poor behaviors such as speed driving, drunk driving, riding with no helmet protection, riding without sufficient sleep, etc. The numbers of death and disability are very high because of late assistance to people who got the accident. These cause huge social and economic burdens to people involved. Therefore, several research group and major motorcycle manufacturers including Honda have developed safety devices to protect riders from accidental injuries. However, good safety device for motorcycle is difficult to implement and very expensive.

Alternatively, intelligence schemes such as fall or incident detection with tracking system have also recently been devised to notify the accident to related people so that quickest assistance can reach people who got the accident [1]. Presently, tracking system is only installed in some high-end motorcycles [2-4] because these systems are still too expensive for most motorcycle's riders [5-6]. Thus, fall detection and accident alarm system for motorcycle has recently gained attention because these systems are expected to save life by helping riders to get medical treatment on time. In this work, wireless black box using MEMS accelerometer and GPS tracking system is developed for accidental monitoring. In the event of accident, this wireless device will send mobile phone short massage indicating the position of vehicle by GPS system to family member, emergency medical service (EMS) and nearest hospital so that they can provide ambulance and prepare treatment for the patients.

II. SYSTEM OVERVIEW

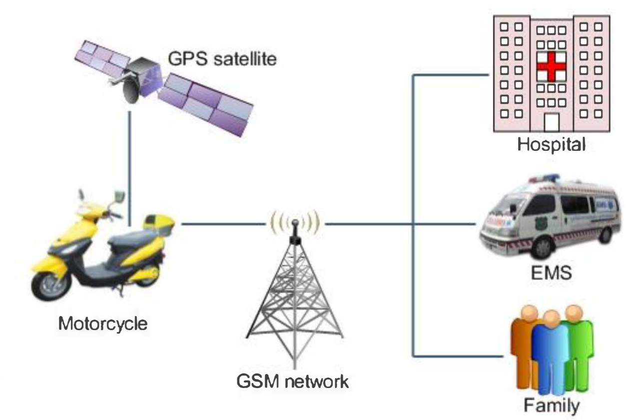

Fig. 1. System architecture.

The system consists of cooperative components of an accelerometer, microcontroller unit (MCU), GPS device and GSM module for sending a short massage. An accelerometer is applied for awareness and fall detection indicating an accident. The speed of motorcycle and threshold algorithm are used to decide a fall or accident in real-time. Mobile short massage containing position from GPS (latitude, longitude) will be sent when motorcycle accident is detected. The robust package design is implemented so that it is safe from water's spray and dust in environment. The module is aimed to be installed under the motorcycle seat.

A high performance 16 bits MCU is used to process and store real-time signal from the accelerometer. Thus, this device is analogous to a black box in airplane. The police and insurance examiner can obtain accident history to investigate accident situation from data-logger in this device. The device keeps data log of track and acceleration data for

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1 minute before and after an accident. Moreover, this device can be used to track motorcycle after it was stolen but it can't operate in real-time in this case. In this case, user can send request command with alphabet "!" to device and the device will return the position with some basic information.

III. METHODOLOGY OF DETECTION

Our signal processing goal is to classify the original data into two classes, fall and not fall. In this system, the input data from 3 axis accelerometer was kept and processed in real-time with sampling rate of 60 Hz or higher. The signal from MEMs accelerometer was converted by 10 bits ADC into integer range between 0 and 1023. The sensor was embedded in a motorcycle seat to fix the accelerometers axis so that the response of acceleration data is well defined. The classification of the fall detection utilized the 3-axis acceleration signal from MEMs accelerometer and the ground speed from GPS module. In general, motorcycle fall can be classified as linear fall and non-linear fall. The linear fall is concerned about fall without external force, which is free falling condition that only z-axis acceleration changes. The non-linear fall occurs by the external force. The non-linear fall detection is decided by all 3-axis acceleration data from accelerometer and the ground speed from GPS module.

To determine the accelerometer output, two frames of acceleration data, which include 3-axis acceleration at present time (t) and prior time (t-1), are used for analysis. For a linear fall, the z-axis acceleration follows free falling condition which is given by

$$|A_z| \geq 9.7 \text{ m/s2} \qquad (1)$$

where the Az is the z-axis acceleration. In a non-linear fall, two frames of acceleration data are used. From non-linear fall experiments under most likely situations, we found that the change of acceleration between two consecutive frames should be more than 15.5 m/s2. Thus, the non-linear fall condition is given by

$$|A_{n,t} - A_{n,t-1}| \geq 15.5 \text{ m/s2} \qquad (2)$$

Where the An t is acceleration from x, y or z coordinate at the present time frame and An t-1 is acceleration parameter from x, y or z coordinate in the previous time frame. From equation, if the difference of acceleration in two time frames is more than 15.5 m/s2, the first condition of non-linear fall accident of motorcycle is met. The ground speed from GPS module then used to decide whether actual non-linear fall accident occurs. If ground speed becomes zero after detection of large acceleration change as indicated in equation (2), non-linear fall detection in motorcycle is detected and fall alert message will be sent. However, false detection may occur in case of a severe brake because data are not kept and processed over a long time frame. Normally, there is noise in z-axis while motorcycle rides over knotty surface. The noise is filtered by averaging acceleration data all of three axes over five time frames.

The fall detection and alarm system for motorcycle accident operates according to the flowchart as shown in Fig. 2. After system start, microcontroller periodically gets 3-axis acceleration data from the accelerometer. If acceleration in z-axis satisfies the free falling condition in equation (1), a linear fall is identified. If the system detects a linear fall, the position of accidental place will be saved and sent via SMS. If the condition of linear fall is not met, the system will check for non-linear fall from 3-axis acceleration data. If data from each axis is in line with equation (2), speed from GPS module and posture of motorcycle will be monitored. If motorcycle is still running (ground speed is more than zero) after 10 seconds or posture are not lying down on the ground, no motorcycle accident is assumed. Otherwise, nonlinear fall is detected and position data from GPS module will be sent via SMS. While no fall condition is met, the system will always return to starting point of the program.

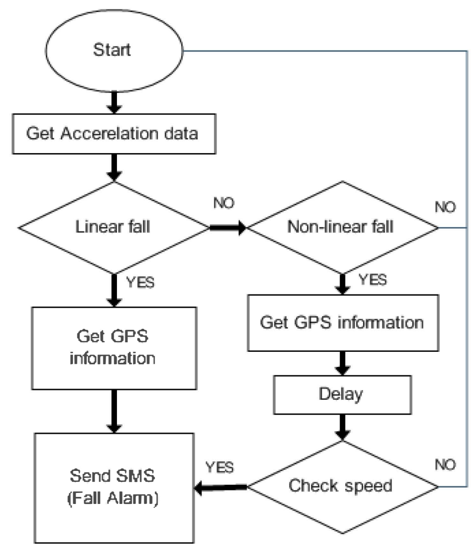


Fig. 2. Flowchart of motorcycle fall and accidental alarm system.

(a) (b)

Fig. 3. (a) Robust case and (b) device embedded under motorcycle seat

IV. ROBUST SYSTEM DESIGN

The system for motorcycle fall detection using a tri axial accelerometer is shown in Fig.3a. The system was packed in robust aluminum case and embedded under motorcycle seat as illustrated in Fig. 3b. The basic concept of the proposed system is to detect motorcycle accident from motorcycle fall or from collision with another car or motorcycle.

The motorcycle fall detection system is based on a tri-axial accelerometer. The accelerometer provides analog acceleration output in three axes (x, y and z). The acceleration sensor was positioned so that its z axis was aligned vertically and the coordinate was fixed when installed under motorcycle seat. A high performance 16 bits MCU was chosen as a control unit. The MCU processed real-time motorcycle fall detection using A/D signal converted from accelerometer output at 60 Hz sampling rate. U-blox (LEA-5S) was GPS module that provided the location of accident. MCU received data from GPS module operated at refresh rate of 1 Hz with UART interface and the GPS module communicated with 20 satellites to obtain geographic information. The data was decoded from GPRMC package using NMEA protocol, GPRMC or minimum recommended data consisted of basic GPS parameters including latitude (north or south), longitude (east or west), ground speed, current date and time, course over ground and magnetic variation. GSM module (GM862) was used to send short message to hospital or family member to help patients in case of accident. The GSM module is quad band 800, 900, 1800 and 1900 MHz and it was controlled by AT-command from microcontroller. The basic AT-command was used to send instant massage, check signal strength and get system commands and basic GSM parameters. The short massage shows position of motorcycle, time of accident and type of accident (fall by themselves of crashed by other person). The whole system was packed in aluminum box with Li-ion backup battery. The power from backup battery was periodically charged from motorcycle battery. In case of accident, backup battery may operate alone and its backup power is enough for signal processing and short message service.

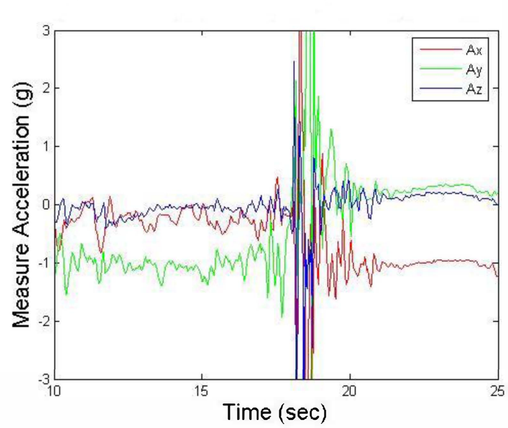


Fig. 4.Typical acceleration data for a linear fall case.

V. Results

The scenarios of fall or accident in motorcycle are mainly divided into two groups including fall by themselves and crash by other objects. Thus, the device may be tested with a limited number of situations of accidents. The motorcycle fall detection using MEMS accelerometer has been implemented and tested by using bicycle instead of motorcycle because it is less dangerous and the basic structure is like motorcycle. However, some parameters such as mass of rider and motorcycle were ignored in this experiment. Typical data for motorcycle fall without external force or linear fall is shown in Fig 4. For linear fall, only acceleration on z-coordinate is used to determine the accident.

Fig 5 shows typical experimental results of a non-linear fall obtained from accelerometer with 60 Hz sampling rate. The condition of non-linear fall according to equation (2) can be met on some axes or all three axes. The results of nonlinear fall can be divided into two parts, first crashing and second ground hitting.

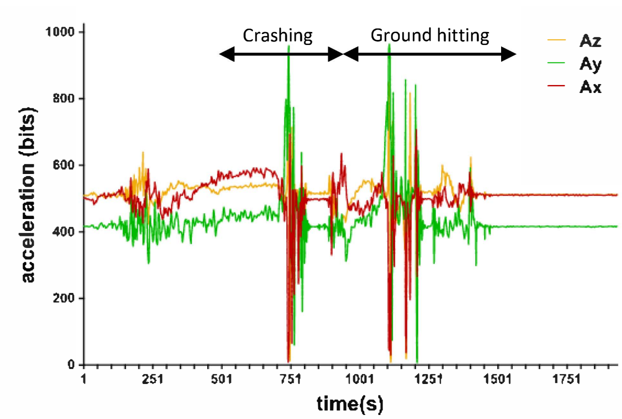


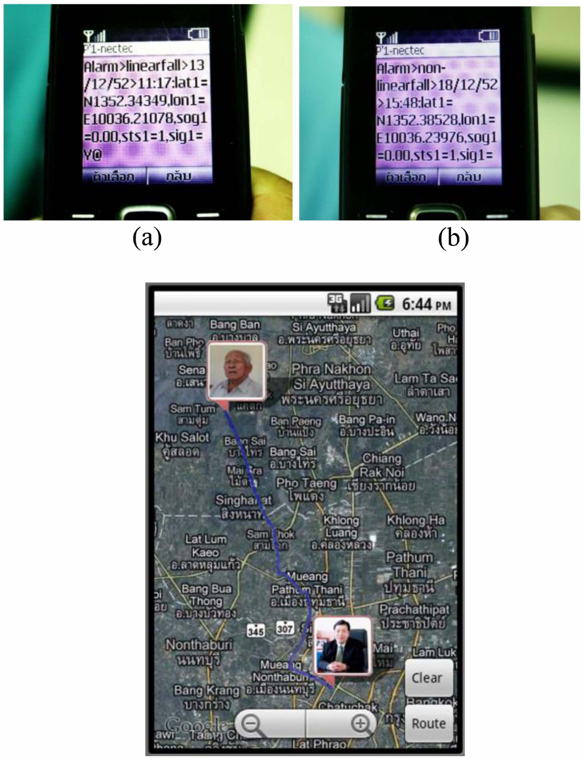
Fig. 5. Non-linear fall situation was tested with bicycle.

After initial system characterization to classify fall types and to separate fall from not-fall, it was tested in real situation with bicycles. Five scenarios including, linear fall, non-linear fall, normal ride, knobbed surface and brake suddenly were each tested for 100 times and the results are listed in table I.

TABLE I Test results for fall experiments using bicycles.

Task	Test times	Alarm	Not alarm
Linear fall	100	100	0
Non-linear fall	100	99	1
Normal ride	50	0	50
Bumpy surface	50	0	50
Brake suddenly	50	1	49

An accidental alarm system in motorcycle was tested over 100 times. In case of linear fall, no false alarm occurred while 1 miss alarm happened in non-linear fall. For normal ride cases, riding in various condition such as riding over bumpy road surface or riding on shaky vehicle were tested and false alarms were also not found. The last scenario was test in badly brake in suddenly situation and found 1 false alarm in this case. Thus, the accuracy of the system is considered satisfactory.



(a) (b)

(c)

Fig. 6. Short massage mobile phone from black box device: *(a)* linear *(b)* non-linear *(c)* tracking.

According to Figure 6*(a)*, massage was received when motorcycle falls. Figure 6*(b)*, shows massage from non-linear fall condition from the device. In addition, motorcycle's owner or police can access and tracking motorcycle in case of stolen by sending alphabet '!' to device phone number, but the phone allows only member accessible only. The short massage mobile phone from wireless black box using MEMS accelerometer and GPS tracking device are consist of geographic position (latitude and longitude), time of accident, type of accident, ground speed, status of backup battery and signal status from GPS module and GSM module. Figure 6*(c)*, show some tracking feature from Android smartphone when getting GPS data from alarm message.

VI. Conclusion

In conclusion, an innovative wireless black box using MEMS accelerometer and GPS tracking system has been developed for motorcycle accidental monitoring. The system can detect type of accident (linear and nonlinear fall) from accelerometer signal using threshold algorithm, posture after crashing of motorcycle and GPS ground speed. After accident is detected, short alarm massage data (alarm massage and position of accident) will be sent via GSM network. The system has been tested in real world applications using bicycles. The test results show that it can detect linear fall, non-linear fall and normal ride with no false alarm

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