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Low Cost GPS/IMU Integrated Accident Detection and Location System

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Abstract

Background/Objectives: Emergency Rescue Service could save many lives if the accident location could be intimated automatically. Accident location is generally acquired from Global Positioning System (GPS). However, location cannot be determined during GPS outage. **Methods/Statistical Analysis**: This paper proposes an accident detection system by determining the deceleration from the accelerometers of a low cost Micro Electro Mechanical Systems (MEMS) based Inertial Measurement Unit (IMU). The three axes accelerometers, gyroscopes and magnetometers data of the IMU were also programmed as Attitude Heading Reference System (AHRS) to determine the orientation and the position of the vehicle during a GPS outage. Errors in positional information were corrected by a Kalman filter during the availability of GPS. A communication module was programmed to send the accident data to the base station in real time. **Findings:** The test result showed the correct accident detection. The accident location module also determined the correct accident location in GPS outage condition and sent the accident location information to the base station. **Application/Improvements:** The system will save many lives by sending the automatic accident location to Emergency Rescue Service center.

Keywords: Accident, GPS, IMU, Location, MEMS

1. Introduction

In today's world, automobile accident is a majorcrisis[1,2]. Every year, nearly 1.2 million people die in road crashes. Besides, 20-50 million people are either severely injured or disabled[3]. Accidents are happening every now-and-then, despite numerous efforts taken by various agencies. After an accident, many lives could have been saved if the accident victims could be rescued in time. In Finland, 4.6% fatalities could be avoided if accident information were conveyed at appropriate time[4]. Divulging an accident information at appropriate time can be efficiently accomplished by an automatic accident detection and notification system

Accident detection and location system has a long history which began in 1961. There are various automated accident detection systems. Some systems are offline and some systems are real time. Accident prediction in real-time relates accidents from different detectors i.e. infrared detector, induction loops, camera etc. However, the detection is constrained by weather, number of sensors, applied algorithms and traffic flow[5]. Drivers can initiate accident detection information. But the driver, at times, may not be in a physical condition to report the accident during a severe accident. Accident detection system utilizing accelerometer and airbag sensor and accident location GPS with intimation through GSM is proposed by[6]. But this system is severely constrained by the non-availability of car airbag sensors in majority of the car. It is further constrained by the non-availability of location during a GPS outage.

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Accident detection system based on smartphone is expensive and suffers from false alarm[7]. On the other hand, impact sensor based accident detection system with wireless based reporting system proposed by[8] suffers from infrastructural cost. Utilizing the speed capability of GPS, a GPS based accident detection and location intimation system is proposed by[9]. A GPS and Map-Matched accident detection and location system is reported by[10] where the speed capability of GPS and the road map database are used for the accident detection and location reporting through Global System for Mobile communications (GSM). However, the proposed systems are limited by the conventional GPS problems.

GPS receiver determines its current position and heading by comparing the time signals it receives from a number of the GPS satellites and triangulating on the known positions of each satellite. However, any obstructions of the satellite signals affects the phase and amplitude of the received signals as the GPS requires direct Line of Sight (LOS) signals from minimum four satellites[11]. The receiver loses lock during such a situation and the signal needs to be reacquired. Besides, for determining sudden acceleration from speed, the GPS update rate is not sufficient.

An IMU on the other hand provides higher update rate without any dependency to external source. The MEMS based IMUs are cheap and mostly contain accelerometer, gyroscope and magnetometer for all three axes which can provide sufficient information about a sudden acceleration, angular and heading change[12]. Besides, IMU can also provide navigation information[11]. However, accuracy of the sensors degrades with the price and the performance is seriously affected by accumulated bias, drift and sensor noise errors. An integration of the GPS and cheap IMU with proper filter can provide efficient navigation system[13].

This paper proposes to use the accelerometer sensor of a low cost IMU to detect vehicle accident depending on sudden deceleration. Besides, integration of GPS and IMU provides accident location during a GPS outage by the Kalman filter. A communication module sends the accident location to the base station of Emergency Rescue Service automatically.

2. Methodology

2.1 Acceleration Calculation

With the advancement of technology, the accuracy and the reliability of GPS has increased with a reduction in price and size. Still, it suffers from the line of sight and poor update rate. As such, the acceleration data captured from GPS lacks in instantaneous acceleration due to the poor update rate. This is vital in determining a sudden deceleration due to accident. Continuous and instantaneous data can be acquired from the IMU at high data rate as opposed to GPS.

An accelerometer measures acceleration forces that can be a dynamic force caused by movement, vibration or the static force like the constant force of gravity. The output of an accelerometer mounted to a rigid body can be modeled as Equation (1).

$$y_a = \tfrac{1}{m}\left(F - F_g\right) \tag{1}$$

where y_a is the measured acceleration, m is the mass, F is the total forces including gravity and F_g is the force by gravity. The inexpensive MEMS accelerometers are prone to many sources of error including noise, bias, scale factor and misalignment errors. Equation presented in Equation (1) is a simple model of an accelerometer that does not include these errors which affect the accuracy of measured acceleration. Equation (2) is a more accurate model of an accelerometer.

$$a_m = M_a\left(\tfrac{1}{m} S_a(T)\left(F - F_a\right) - \beta_a(T)\right) \tag{2}$$

where M_a is the misalignment matrix, $\beta_a(T)$ is the temperature-variant vector of output biases and $S_a(T)$ is the diagonal temperature-variant accelerometer sensitivity matrix.

The acceleration in the X axis of the accelerometer can be found out from Equation (3). Digital accelerometer provides acceleration information in Serial Peripheral Interface (SPI) protocol or Inter-Integrated Circuit (I^2C). To calculate g values from the raw digital accelerometer data, the values need to be scaled. By dividing the total range with the number of bits as Equation (4), the scale is calculated where total range is denoted by a_r and number of bits is denoted by a_b. By multiplying raw digital values with the scale, acceleration in g can by calculated.

$$A_x = \left(\frac{AdcAx * Vref}{Adcresolution} - VzeroG\right) / \, Sensitivity \tag{3}$$

$$scale = \frac{a_r}{a_b} \tag{4}$$

where Ax is the acceleration in x-direction (forward direction of the vehicle), $AdcAx$ is the raw acceleration data, *Adcresolution* is the number of bit for the resolution of the ADC, *Vref* is the reference voltage of the accelerometer, *VzergoG* is the voltage for 0g and *Sensitivity* is the voltage for each *g* expressed in mV/g.

2.2 Accident Detection Algorithm

In detecting vehicle accident, the accident detection model plays a vital role. In this paper, to predict an accident, a threshold-based filtering of deceleration is used. The speed of a vehicle often decreases from its travel speed to zero in a hundred thousandths of a second in a severe crash[14]. During a crash, the frontal airbags are deployed within the 50 ms when the vehicle hits a solid barrier at 12 to 15 mph or hits another vehicle at 25 mph[15]. Deceleration more than 5g is considered as a crash situation for airbag deployment[16].

The de-noised deceleration data from the accelerometer is continuously monitored. Once declaration of more than 5g is detected, the proposed system looks for instant velocity of the vehicle. The vehicle is likely to be stopped completely in a frontal crash. The system confirms it to be an accident, if the velocity is <5Kph. Taking the errors of the accelerometer in account, 5Kph velocity was selected. The chance of false alarm is reduced by the velocity check after the deceleration. The system raises an alarm for location detection module, once the accident is detected. Figure 1 illustrates the flowchart of the accident detection algorithm.

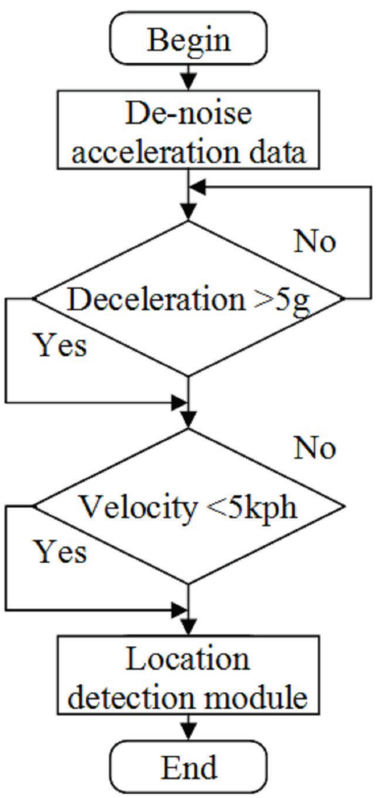

Figure 1. Accident detection algorithm.

2.3 GPS/IMU Integration for Accident Location

The location module determines the location of the accident place. GPS can provide the accurate location of the accident place. However, GPS may not provide any location information during the outage as discussed earlier. An IMU can be used to fill the gaps of GPS outage. IMU provides accelerometer, gyroscope and magnetometer reading in all three axes which can be used to build an AHRS system. An AHRS can provide roll and pitch angles of the vehicle relative to the earth gravity vector and heading angle relative to North. The attitude information from AHRS can be integrated to estimate velocity and the position can be estimated by further integration. The heading information can provide direction of the vehicle.

Accelerometers measure both the gravitational force and force due to the gravity. The tilt angles against the gravitation force can be found by comparing the outputs of three orthogonal accelerometers of the IMU with the gravity. Gravity measured by accelerometers in sensor frame (*b*-frame) and gravity expressed in inertial frame (*i*frame) are expressed as A_b and A_i, respectively and defined by Equation (5) where a_x, a_y and a_z are the acceleration measured in x, y and z axis[17]. The relationship between A_b and A_i is defined by Equation (6) where C_i^b is orientation transformation matrix from *i*frame to *b*frame expressed by Equation (7).

$$A_b = \left(a_x, a_y, a_z\right)^T \tag{5}$$

$$A_i = \left(0,0,-g\right)^T \tag{6}$$

$$A_b = C_i^b A_i \tag{7}$$

The orientation transformation matrix from *i* frame to *b* frame is expressed by Equation (8) and C_1, C_2 and C_3 are defined by Equations (9), (10) and (11) where γ, θ and ϕ represent roll, pitch and heading, respectively.

$$C_i^b = [C_1 \quad C_3 \quad C_3] \tag{8}$$

$$C_1 = \begin{bmatrix} \cos\theta\cos\phi \\ -\cos\gamma\sin\phi + \sin\gamma\sin\theta\cos\phi \\ \sin\gamma\sin\phi + \cos\gamma\sin\theta\cos\phi \end{bmatrix} \tag{9}$$

$$C_2 = \begin{bmatrix} \cos\theta\sin\phi \\ \cos\gamma\cos\phi + \sin\gamma\sin\theta\sin\phi \\ -\sin\gamma\cos\phi + \cos\gamma\sin\theta\sin\phi \end{bmatrix} \tag{10}$$

$$C_3 = \begin{bmatrix} -\sin\theta \\ \sin\gamma\cos\theta \\ \cos\gamma\cos\theta \end{bmatrix} \tag{11}$$

The roll and pith angle is derived as Equations (12) and (13) from Equations (5), (6) and (8).

$$\theta = \arcsin(a_x / g) \tag{12}$$

$$\gamma = \arctan(a_y / a_z) \tag{13}$$

Headings can be found from the geomagnetic measurements of a magnetometer. The horizontal components of the geomagnetism X_h and Y_h in the i frame are expressed by Equation (14) and (15) where m_x,m_y and m_z are the geomagnetism components in the b frame. From Equation (14) and (15), the heading can be found by Equation (16).

$$X_h = m_x\cos\theta + m_y\sin\gamma\sin\theta + m_z\cos\gamma\sin\theta \tag{14}$$

$$Y_h = m_y\cos\gamma\sin\theta - m_z\sin\gamma \tag{15}$$

$$\phi = -\arctan(Y_h / X_h) \tag{16}$$

The gyroscope measures angular velocity in radians. A three axis gyroscope measures the rate of angular change in *b*frame in *x*, *y* and *z* axis which can be expressed by Equation (17). The measurements from the three axes gyroscope can be used to measure the orientation by integrating the angular velocity with a known orientation. The angular position θ from a single axis gyroscope can be found by Equation (18).

$$W_b = (\omega_x, \omega_y, \omega_z)^T \tag{17}$$

$$\theta(t) = \int_0^t \dot{\theta}(t)dt \tag{18}$$

An AHRS is built by using the readings from the IMU sensors. The reading from MEMS IMU suffers from bias, drift and other noise errors. The drift rate of the gyroscope can reach several degrees per second over the time. On the other hand, orientation calculated from accelerometer suffers from short term large errors. Thus, the reading from the accelerometer is periodically used to restrain the drift of gyroscope and a better orientation is achieved. The heading estimated from the gyroscope is corrected by the magnetometer reading. Despite this correction, the orientation information from the AHRS suffers from accumulated errors which can seriously affect the positional information obtained by the double integration of the AHRS information. Thus, the GPS is used to correct the positional information. The Direction Cosine Matrix (DCM) is used as a basis to integrate the accelerometer, gyroscope and magnetometer[18]. The block diagram of the proposed AHRS and GPS integration is shown in Figure 2.

National Marine Electronics Association (NMEA) defines the specification of GPS receiver communication by various self contained sentences which are independent from each other. Most of the GPS devices transmit data in GPRMC sentence. The time, latitude, longitude, speed over ground and heading information from the GPRMC sentence are used to correct the accident location by the Kalman filter. The Kalman filter is widely utilized to com-

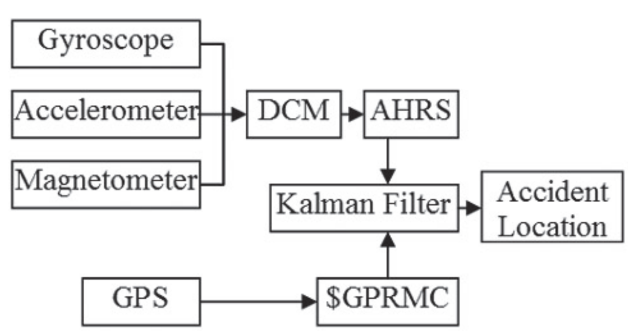

Figure 2. Block diagram of the AHRS and GPS integration for accident location.

bine inexact forecast of a system's state with an inexact measurement of the state[19]. The AHRS data is fused with the GPS data by the Kalman filter following the procedure described in[20]. The reading of the AHRS is updated through the Kalman filter whenever GPS provides a valid acceleration. The orientation differences of the accelerometer and magnetometer from the gyroscope is used as observations in Kalman filtering to estimate orientation errors and the gyro drifts. The differences in the positional data integrated from the AHRS and the GPS is used as the observation in a separate Kalman filter to determine the correct positional information from the AHRS and also to provide positional information during GPS outage. The prediction equations for the unknown state of the system $x[t]$ and the measurement $z[t]$ are given below.

$$\hat{x}^-[t] = \hat{x}^-[t-1] \tag{19}$$

$$P^-[t] = P[t-1] + Q \tag{20}$$

Equation (21) shows the Kalman gain. The state update is given by Equation (22) and the covariance update is given by Equation (23).

$$K[t] = \frac{P^-[t]}{P^-[t] + R} \tag{21}$$

$$\hat{x}^-[t] = \hat{x}^-[t] + K[t](z[t] - \hat{x}^-[t]) \tag{22}$$

$$P[t] = P^-[t](1 - K[t]) \tag{23}$$

where, predicted state estimate at time t is $\hat{x}[t]$, predicted covariance estimate at t is $P^-[t]$, process noise covariance is Q, Kalman gain at t is $K[t]$, measurement noise variance is R, measurement value at t is $z[t]$, posteriori state estimate at t is $\hat{x}\,[t]$ and posteriori covariance estimate at t is $P[t]$.

2.4 Communication to Base Station

The accident information needs to be communicated to an emergency rescue center in real time for the recovery of the accident victims at the earliest. GSM is a digital mobile communication system that is widely used nowadays. A GSM modem is used in the communication module. The accident information is sent as a General Packet Radio Service (GPRS) data and Short Message Service (SMS) text through the GSM modem. The data contains the latitude and longitude of the accident place detected by the accident location module. The data also contains deceleration information which can indicate the severity of the accident. Additionally, the accident data contains the time stamp of the accident and the phone number for identifying the vehicle. The ID, latitude, longitude, deceleration and time stamp information are delimited by comma for the easier extraction of the information by the base station.

The GSM modem is accessed via AT commands. The AT commands are used to send both the SMS and GPRS data. At startup, the GSM modem is set in text mode by the 'AT+CMGF=1' command for SMS and GPRS connection is established by 'AT+CGATT', 'AT+SAPBR' and 'AT+HTTPINIT' commands. The 'AT+CMGS' command is used to send the accident information to the desired number of Emergency Rescue Center. The 'AT+HTTPPARA' and 'AT+HTTPACTION' commands are used to send the data in GPRS in HTTP protocol. After the SMS and GPRS data is sent, a voice call is initiated to Emergency Rescue Service Center. It will allow the vehicle occupants to express the emergency situation if they are in a situation to do so. The flow diagram of the communication module for sending accident location is illustrated in Figure 3.

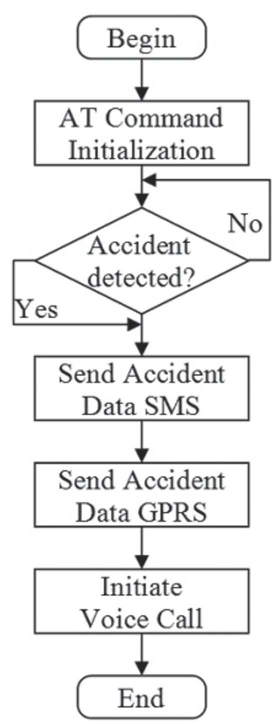

Figure 3. Flow chart of the communication module for sending accident information.

The server at the Emergency Rescue Service Centre is connected by a GSM modem. The modem works as the gateway for receiving the information from the emergency vehicles. The system waits for any incoming accident data. Once the accident information is received, the data is separated to latitude, longitude, deceleration, time and phone number using the comma delimiter and stored in a database. The vehicle ID is retrieved against the phone number. The location is then plotted in the map of the Quantum Geographical Information System (QGIS). Under the Genuinely Not Unix (GNU) General Public License (GPL), it is a free Open Source System (OSS). The Open Street Map plugin is modified for the plotting purpose. Once the location is portrayed on QGIS, Emergency Rescue Service Centre can direct a rescue team to the accident place. The team can assess the severity of the accident and can be prepared accordingly from the deceleration information. Besides, the automatic call initiated from the accident detection system with the Emergency Rescue Service Centre can also help to assess the severity of the accident.

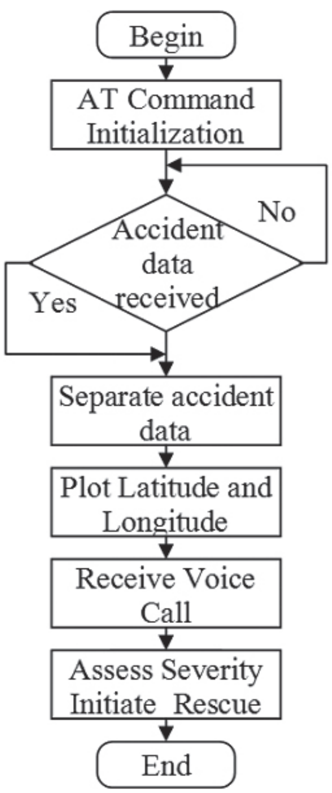

Figure 4. Flow chart of the communication module at the base station.

3. Results and Discussion

The IMU sensor used in the experiment is the 9 Degree of Freedom (DoF) Razor IMU from Sparkfun Electronics. The IMU consists of a three axis accelerometer (ADXL345), magnetometer (HMC5883L) and gyro (ITG-3200). The accelerometers are capable of providing ±16g acceleration and gyros are capable of providing ±2000°/sec second which are sufficient to provide any sudden acceleration for detecting vehicle accident. The outputs are processed by the on-board AT mega 328 microprocessor. 13-bit resolution over a serial interface at a maximum 57,600bps is used.

The GPS/GPRS/GSM shield embedded with SIM908 chip from DF Robot is used as the communication module. The Quad-band GSM/GPRS engine supports the EGSM 900MHz/DCS 1800MHz and GSM850 MHz/PCS 1900MHz frequencies. It can be controlled via GSM07.07 AT commands for both the SMS and GPRS. This shield also contains a 42 channel GPS receiver. It offers good navigation performance at 1Hz update rate with <2.5m CEP and 160dBm tracking sensitivity in urban areas.

Arduino Mega 2560 microcontroller board based on AT mega 2560 is utilized for the sensor fusion. The board is equipped with 16 analog inputs, 54 digital input/output pins, a 16 MHz crystal oscillator, 4 UARTs (hardware serial ports), a power jack, a USB connection, a reset button and an ICSP header. The board is suitable for the experiment with16MHz clock speed and 256KB of memory. The GPS/GPRS/GSM module contains the compatible pin connectors to be fitted over it. The IMU module is connected to the third serial port of the board.

The razor IMU was calibrated following the procedure described in[21]. Then the board was fixed inside in the test vehicle. For a better line of sight, the GPS was installed on the dashboard. The test vehicle was driven at various speed to attain high acceleration and stopped suddenly to achieve a sudden deceleration.

The X-axis (forward direction of the vehicle movement) accelerometer data of the IMU was used for the accident detection. Using Equation (4), raw accelerometer data were scaled to determine acceleration in *g* value. With an acceleration range of ±8g, the scale was found 0.015625 and data were captured at 10bits. After the scaling, the raw value was multiplied by *g* value (9.80665 m/s^2). A low pass filter was used to smooth the accelerometer data.

The deceleration above 5g is considered as accident situation in the proposed accident detection algorithm which is not achievable without an accident. To test the accident detection, the threshold was reduced to 0.9g. The vehicle achieved 0.9g deceleration, as illustrated in Figure 5, at around 5100th sample time. However, the vehicle started to accelerate again without a dead stop. As the vehicle started moving >5kph even after the achieving the 0.9g deceleration, the accident was not confirmed by the system. At around 5800th sample time, the vehicle again achieved a deceleration more than 0.9g. The vehicle was completely stopped after that time and the system detected the situation as accident. Thus, the system could detect sudden deceleration. Besides, it could also differentiate a false accident situation.

The location module provides the position of the vehicle, once the accident is detected. The location module provides AHRS and GPS derived fused position. During the test drive, the GPS coverage was intentionally denied several times to check positional availability during GPS outage. These position gaps were compensated by the Kalman filtered AHRS positions. With the filled up Kalman filtered positions, Figure 6 illustrates the GPS outage positions. Once the vehicle completely stopped, the GPS signals were required to check the position. As evident from Figure 6 the AHRS based position almost coincided.

The system sends the accident location to the base station. After the simulated accident was detected, the system sent position information through the communication module. The system successfully sent in both SMS and GPRS. A computer was considered as the server of the base station. The information received by the server

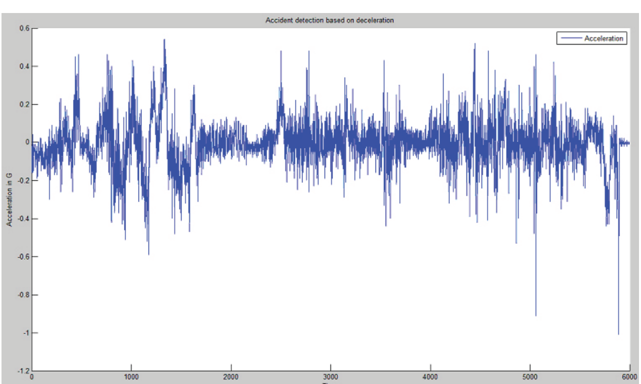

Figure 5. Deceleration based accident detection.

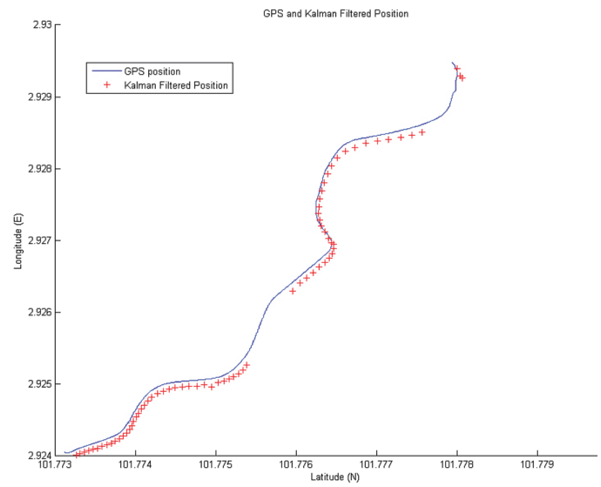

Figure 6. Kalman filtered AHRS positions during GPS outage.

was interpreted correctly as ID, time, latitude, longitude and deceleration in *g*. The simulated plotted accident location shown in Figure 7 depicts the correct location of the accident place.

4. Conclusion

An accident detection system is developed based on the deceleration from an accelerometer of a low cost IMU. The accident location module is also developed by integrating the IMU based AHRS with the GPS utilizing Kalman filter. A communication module is also developed to send the accident information automatically. The system is able to detect an accident correctly. It is also able to locate the accident information in GPS outage condition and send the accident information to a base station. The system will save many lives by sending the automatic accident location to Emergency Rescue Service center.

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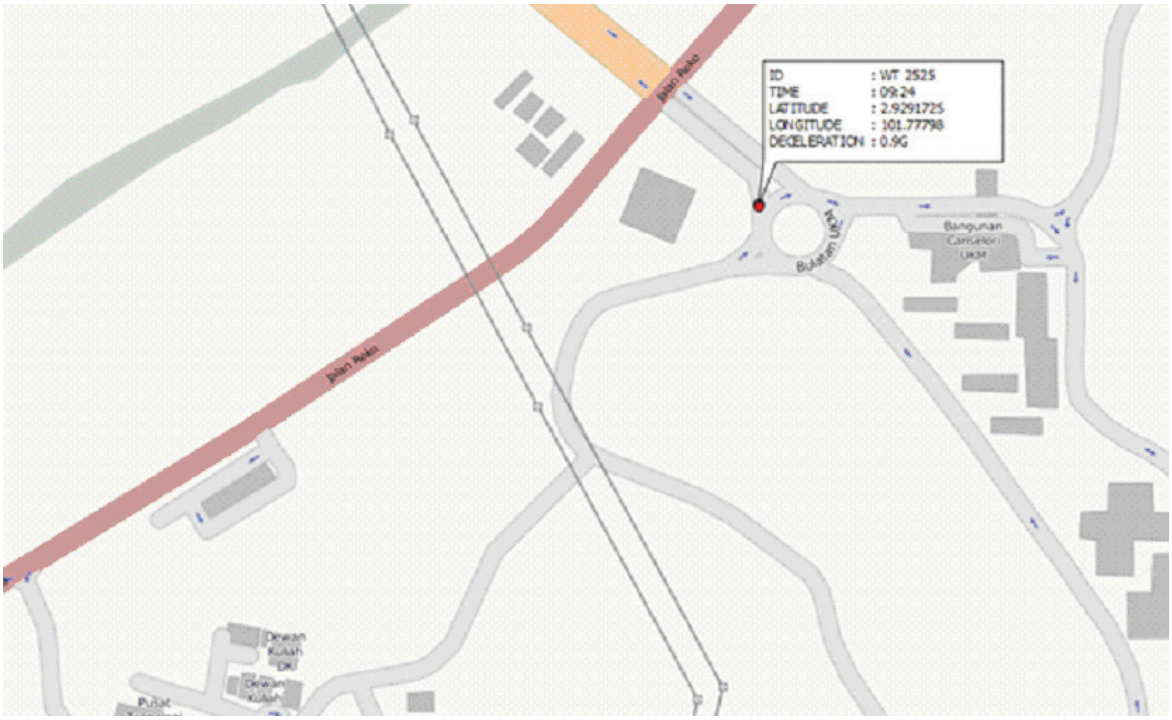

Figure 7. Accident location plotted in QGIS from the communication module.

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