Integrated Vehicle Accident Detection and Location System

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Abstract

Many accident victim lives could have been saved if vehicle accident information could be intimated to an evergencey rescue center automatically. This paper proposes an accident detection and location system by determining the deceleration and data fusion from accelerometers and GPS. The bias, drift and noise errors of accelerometers and GPS outage limitation are overcome by integrating with Kalman filter. The test result shows the correct deceleration for accident detection and location. The proposed system will be able to overcome the limitations of GPS/IMU and save valuable human lives.

Keywords: Accident, IMU, GPS, MEMS, navigation

1. Introduction

The automobile is one of the greatest inventions that have become an essential part of our daily activities. Despite its enormous effectiveness, it can bring disaster and even can kill us through accidents. Vehicle accident is a vital problem in today's world [1]. Nearly 1.3 million people die in road crashes each year which is 3,287 deaths a day and leaving 20-50 million injured or disabled [2]. Despite various efforts by different agencies against careless driving, accidents are taking place. After an accident, many lives could have been saved if the accident victims could be rescued in time. A study shows that 4.6% of the fatalities in accidents could have been prevented only in Finland if accident information could be divulged at the right time [3]. This can be achieved by an efficient automatic accident detection and notification system with the correct location of the accident place.

Accident detection system is a widely researched topic. Real-time traffic accident prediction relates accident occurrences from various detectors such as induction loops, infrared detector, camera etc and restricted by the number of sensors, algorithms, traffic flow and weather [4]. Driver initiated incident detection system has more advantages than manual incident detection system. But driver may not be able to report at all with the severity of the accident. Chuan-zhi *et al.* proposed a freeway incident detection system by utilizing the car air bag sensor and accelerometer, Global Positioning Sensor (GPS) to locate the accident place and GSM to send the accident location [5]. However, car air bag sensors are not installed in all cars and the location may not be known due to GPS outage. A smart phone based accident detection system is proposed by White *et al.* which is based on the expensive smart phone and suffers from the possibility of false alarm [6]. An impact sensor based accident detection and wireless module based reporting system is proposed by Megalingam *et al.* which largely depends on the huge installation of wireless receiver at a very short interval [7]. A solely GPS based accident detection and location system is reported by Amin *et al.* where the speed capability of GPS is used for the accident detection and the accident location is reported from GPS position through GSM [8]. However, the proposed system is limited by the conventional GPS problems.

The GPS is a popular technology which was developed by American Department of Defense (DoD). The 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, the blockage by any obstructions affects both the amplitude and phase of the received satellite signals as the GPS requires direct line of sight signals from at least four satellites [9, 10]. This causes the receiver to lose lock on the blocked satellite, meaning that it needs to reacquire the signal and to resolve the ambiguities in the phase

measurements. Moreover, the update rate of GPS is not also sufficient to determine the sudden acceleration from the speed data.

An Inertial Measurement Unit (IMU) on the other hand provides higher update rate without any dependency to external source. The Micro Electro Mechanical Systems (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. Besides, IMU can also provide navigation information [10]. However, accuracy of the sensors degrades with the price and the performance is seriously affected by accumulated biases, scale factor variations, drifts and sensor noise errors [11]. An integration of the GPS and cheap IMU with proper filter can provide efficient navigation system [12].

This paper proposes to use the accelerometer sensor of a low cost IMU and GPS speed data to detect vehicle accident based on deceleration. Besides, the loosely coupled integration of the IMU and GPS provides accident location during a GPS outage by the Kalman filter.

2. Research Method
2.1. GPS and IMU Fusion for Acceleration

With the advancement of technology, the accuracy and 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 derived from the GPS lacks in instantaneous acceleration which is very important in determining a sudden deceleration due to accident. High data rate, continuous and instantaneous data can be acquired from the IMU as opposed to GPS.

The Razor IMU is one of the cheapest IMU with a price around 100 USD whereas the strategic grade costs around 1 million USD. However, the sensor readings are limited by accumulated bias error, drift and noise. The acceleration in the X axis of the accelerometer can be found out from (1).

$$A_x = \left(\frac{AdcAx*Vref}{Adcresolution} - VzeroG \right) / Sensitivity \tag{1}$$

where: A_x– 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.

National Marine Electronics Association (NMEA) defines the specification of GPS receiver communication by various self contained sentences which are independent from each other. GPRMC is the most common sentence transmitted by the most GPS devices. The speed over the ground acquired from the $GPRMC contains accurate speed. The acceleration can be found from (2) by using the speed over ground.

$$a = \frac{v-u}{t} \tag{2}$$

The acceleration from the GPS is not an instantaneous acceleration despite its accuracy. It is also limited by the update rate. Moreover, during GPS outage no valid acceleration can be achieved. On the other hand, the instantaneous and continuous acceleration reading from the IMU is impaired by the noise, bias and vibration. A Kalman filter is used to reduce this impurity and predict the correct acceleration in G force with high update rates. The reading of the IMU is updated through the Kalman filter whenever GPS provides a valid acceleration. The Kalman filter is widely utilized to combine inexact forecast of a system's state with an inexact measurement of the state [13]. The prediction equations for the unknown state of the system $x[t]$ and the measurement $z[t]$ are given below.

$$\hat{x}^-[t] = \hat{x}^-[t-1] \tag{3}$$

$$P^-[t] = P[t-1] + Q \tag{4}$$

Equation (5) shows the Kalman gain. The state update is given by (6) and the covariance update is given by (7).

$$K[t] = \frac{P^-[t]}{P^-[t] + R} \tag{5}$$

$$\hat{x}^-[t] = \hat{x}^-[t] + K[t](z[t] - \hat{x}^-[t]) \tag{6}$$

$$P[t] = P^-[t](1 - K[t]) \tag{7}$$

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

2.2. Accident Detection Algorithm
The proposed system monitors the deceleration data from the GPS and IMU accelerometer sensors. These two data are integrated by the Kalman filter. Whenever the deceleration from the GPS is available, IMU deceleration is updated by the Kalman filter. The deceleration data from the IMU is considered only in GPS outage scenario. Vehicle decelerates when the brake is applied. Any deceleration more than 5Gs is considered as an accident situation by the proposed algorithm [14]. In this situation, the system would raise an alarm for the location detection module. The flowchart of the accident detection is shown in Figure 1.

2.3. GPS/IMU Integration for Accident Location
After the accident is detected, the location module determines the location of the accident place. The GPS can provide the accurate location of the accident place. However, due to various reasons GPS may not provide any location information during the outage as discussed earlier. The Razor INS can fill the gaps of GPS outage. As mentioned previously, the low cost Razor IMU suffers from bias, drift and noise error over the time. So, the IMU data are updated through the integration of the valid GPS data.
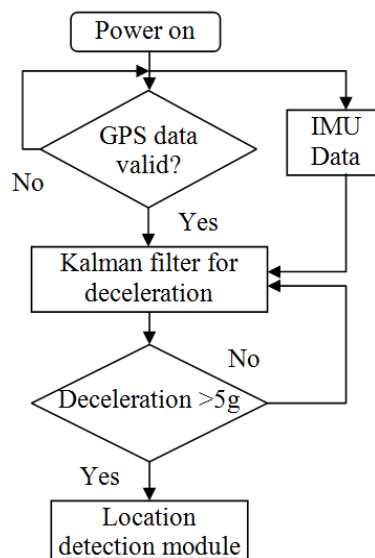

Figure 1. Accident detection algorithm

The IMU provides accelerometer, gyroscope and magnetometer reading in all three axes. The orientation of the vehicle relative to gravity can be predicted by integrating gyroscope with the accelerometer and the direction of the vehicle can be determined from the magnetometer. By integrating these three sensors in three axes, the Attitude Heading Reference System (AHRS) is first built. The Direction Cosine Matrix (DCM) described by Mahony *et al.* is used as a basis to integrate the accelerometer, gyroscope and magnetometer. This matrix is a form to represent a rotation through a $\mathbb{R}^{3X3}$ matrix. The DCM matrix described by Mahony *et al.* has been used as a basis for the IMU sensors to build the AHRS [15].

The AHRS data gets corrupted with the time due to noise, drift, bias and the presence of hard and soft irons. The AHRS data is fused with the GPS data by the Kalman filter following the procedure described by Li *et al.* [16]. The block diagram of the AHRS and GPS integration is shown in Figure 2.
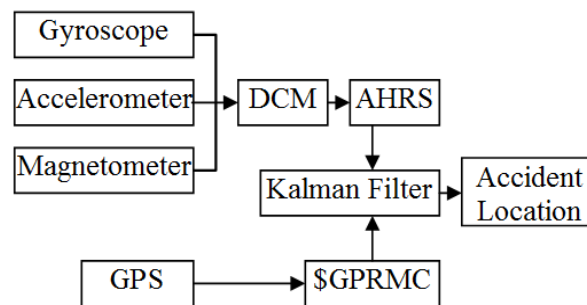

Figure 2. Block diagram of fusion filter for accident location

3. Experimental Setup and Results

An ultra high sensitive HI-204III of Haicom Electronics Corporation GPS receiver is used in the experiment. The receiver provides accurate satellite positioning data with a continuous tracking of all satellites in view. Its 4000 search bins and 20 parallel channels provide quick satellite signal acquisition and takes less than 40 seconds in cold start and 8 seconds in hot start. With -159dBm tracking sensitivity, it offers good navigation performance in urban areas and limited sky view with 1Hz update rate.

The IMU sensor is the 9DoF Razor IMU from Sparkfun Electronics. It incorporates a triple-axis gyro (ITG-3200), a triple-axis accelerometer (ADXL345) and a triple-axis magnetometer (HMC5883L) in a single board. 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 [14]. The outputs of all sensors are processed by the on-board ATmega328 microprocessor with 13-bit resolution over a serial interface at a maximum 57,600bps.

The Razor IMU was rigidly fixed inside in the test vehicle. It was calibrated following the procedure described in [17]. The GPS was installed on the dashboard for a better line of sight. With a driving around the university premises, data was recorded from the IMU and the GPS. The test vehicle was driven at various speed to attain high acceleration and stopped suddenly to achieve a sudden deceleration.

The accelerometer data along the X-axis (direction of the vehicle movement) was plotted without the fusion algorithm. The acceleration from the GPS was also plotted. These two data were then fused with the developed algorithm and plotted. The fused data plotted in Figure 3 shows the sudden deceleration and acceleration. It is evident that the fusion algorithm provides more accurate acceleration/deceleration than the individual sensor. The accident detection situation could not be achieved as it requires a deceleration of 5Gs. However, it is clear from Figure 3 that the system could detect sudden deceleration and the system would be able to detect a sudden deceleration of 5Gs also.
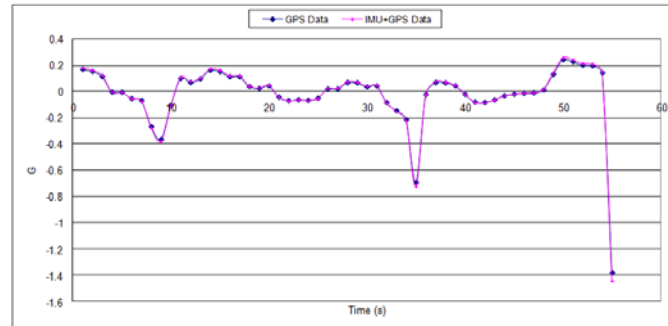
Figure 3. Acceleration derived from GPS and GPS/IMU fusion

To test the accident location module, the threshold of the accident was reduced to 1G. With a sudden stop, the vehicle could achieve 1G deceleration. During this time, the GPS and IMU fused data could provide the location of the simulated accident place. The GPS/IMU integrated location of the accident was entered in the web based Google map application and it depicted the correct accident location as shown in Figure 4.

Figure 4. GPS/IMU integrated location of the accident place

4. Conclusion

A GPS and IMU based acceleration fusion system is developed to determine the deceleration for accident detection purpose. The higher rate of IMU's accelerometer data can detect any instantaneous deceleration and also can fill the gap during GPS outage. The accident location module was also developed by integrating the IMU based AHRS with the GPS by utilizing Kalman filter. The test result shows that the system can detect the accident location efficiently. This will save many lives by sending the automatic and correct accident location to an appropriate agency.

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