A System for Vehicle Collision and Rollover Detection

Hamdy A. Ibrahim[1,2] Ahmed K. Aly[2] Behrouz H. Far[1]
[1]Department of Electrical and Computer Engineering, University of Calgary, Canada
[2]Department of Information Systems, Faculty of Computers and Information, Menoufia University, Egypt
{hibrahi@ucalgary.ca; ahmed.157@ci.menofia.edu.eg; far@ucalgary.ca}

Abstract— **Traffic accidents negatively affect the lives of human beings. Accidents may result in deaths, severe injuries, and loss of income to the impacted families. Accident detection and prevention is a keystone in improving road safety. In this paper, a system for detecting vehicle collision and rollover is presented. The proposed system includes three key phases. Data acquisition where accelerometer and gyroscope, integrated into MPU-6050 motion sensor are used to acquire 3-axis acceleration forces and rotation angles respectively. The complementary filter is used to enable the use of the gyroscope data on the short term because it is very precise and not susceptible to external forces. On the long term, the accelerometer data is used because it does not drift. An algorithm for acquiring data using sensors, filtering and analyzing data, detecting collision and rollover is developed. Experiments are conducted to test the proposed system. Experiments show promising results.**

Keywords—Accident Detection; Vehicle collision; Vehicle rollover, Accelerometer, Gyroscope

I. INTRODUCTION

People around the world have become more dependent on transportation system. As a result of the growth of number of vehicles on roads, current transportation systems face several challenges such as traffic congestion, safety, mobility, and tremendous increase in traffic accidents especially in developing countries. Traffic accidents are one of the key causes of human death and injury in the world [1]. According to world health organization, Deaths from traffic injuries represent around 25% of deaths from all types of injury. Some of injured people during traffic accident live with permanent impairments. Average number of accidents in Egypt during 1990-2010 was 22733 accidents [2]. In Canada, 2013 statistics showed that the largest proportion of death cases and serious injuries was in vehicle drivers [3].

Immediate detection of traffic accidents, identification of accident location, efficient notification of emergency services, and warning the following cars will contribute in (1) Minimizing number of fatalities and injuries, (2) Providing medical service fast, (3) Reducing number of vehicles involved in the accident, and (4) Avoiding potential accidents as a result of the initial accident. Moreover, every minute that passes without providing emergency medical care to traffic accident victims reduces their chances to survive. For example, the analysis showed that reducing the response time to accidents 1 minute increases the number of saved lives by 6% [1]. Automatic accident notification systems are based on using sensors embedded in vehicles to detect the occurrence of an accident. In fact, most vehicles except few luxury vehicles are not equipped with automatic accident detection and notification systems. A key obstacle of using the accident notification systems is the high cost of its installation in existing vehicles and the increase in the initial cost of new vehicles.

Our research aims at developing an effective and low cost system for accident prevention and detection as well as efficiently notifying emergency services and drivers to reduce number of fatalities, injured persons, and providing medical treatment fast. This could be achieved by reducing the time between the accident occurrence time and the dispatch time of the first responders, such as medical personnel, to the accident scene.

This research paper particularly presents the overall proposed system including its key phases, hardware components, proposed algorithm, and how the proposed system works. The paper also focuses on discussing how data are acquired using accelerometer and gyroscope sensors, how the acquired data are filtered using complementary filter, how the filtered data in terms of roll, pitch, and yaw angles are calculated and used to identify vehicle collision and rollover. The calculated results (e.g. roll and pitch angles) are compared with measurements of analog and digital inclinometers.

The rest of the paper is structured as follows. Section II discusses related work. The proposed accident detection and prevention system is presented in Section III. In section IV, experimentation, system validation, and result discussion are presented. Finally, section V summarizes conclusions and future work.

II. RELATED WORK

There are several research efforts related to accident detection and prevention and developing emergency notification systems. In [4], the sensor technologies and placement of sensors for accident detections with a focus on the rollover crash detection was reviewed. The paper also discussed sensor selection for particular crash detection based on sensors performance. The research presented in [5] aims at developing an engineering tool for evaluating technical and functional specifications of a forward looking automotive radar sensor and threat assessment algorithms for forward collision warning system. In [6], the implementation of a system which can automatically report vehicle crash to the emergency services was

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studied. The proposed system used fisheye lens camera which produces more detailed view inside the vehicle, Sensors, and Quad-Band GSM/GPRS SIM908-C module. The objective of [7] was designing and developing an economical general purpose wireless emergency event notification system for vehicles that might roll over. The proposed system used wireless channels to send necessary information to emergency services. It did not discuss the detection of vehicle rollover. Another work [8] has discussed the use of magneto-resistive and sonar sensors for detecting imminent collision in cars. Basically, the magneto-resistive sensors are used to measure the magnetic field from another vehicle in close proximity, to estimate relative position, velocity, and orientation of the vehicle from the measurements. The focus of [8] was on predicting vehicle crash not detecting it. The paper [9] described solutions to key challenges associated with using smart-phones to detect traffic accidents. It also presented the architecture of a smartphone-based accident detection system prototype and discussed how smartphone-based accident detection system can reduce overall traffic congestion and increase the preparedness of emergency responders. In [9], the ability of the proposed system to resist false positives and its capabilities for accident reconstruction were empirically analyzed. In [11], a microcontroller based system with 3-axis accelerometer sensor and discarded cell phone model to warn drivers for abnormal conditions or unsafe driving, capturing images of occurred accidents, and sending multimedia and text messages to predetermined users was presented. In [12], a real Time traffic accident detection system (RTTADS) using wireless sensor network (WSN) and radio-frequency identification (RFID) technologies was presented. It also explained the hardware prototype setup for the proposed system and the used algorithms. It is based on installing sensors in a vehicle to detect the accident's location, the vehicle's speed just before the accident and the number of passengers in the vehicle. In [13], a vision-based real time traffic accident detection method is proposed. In this method, foreground and background from video shots using the Gaussian Mixture Model (GMM) are extracted to detect vehicles. The detected vehicles are tracked based on the mean shift algorithm. Then the three traffic accident parameters including the changes of the vehicles position, acceleration, and the direction of the moving vehicles are gathered to make the final accident decision. In [14], accelerometer was used to detect dangerous driving, crash, or rollover. Another paper [1] describes how smartphones, such as the iPhone and Google Android platforms can be used to detect traffic accidents using accelerometers and acoustic data, immediately notify a central emergency dispatch server after an accident, and provide situational awareness through photographs, GPS coordinates, VOIP communication channels, and accident data recording. However, the proposed method may not able to detect all accidents such as vehicle rollover. The key drawback of the presented research is that most research papers (e.g. 6, 11, 12, 13, and 14) did not present experiments that justify the feasibility and effectiveness of the proposed system.

III. PROPOSED SYSTEM

The key phases and hardware view of the proposed system are shown in Figures 1 and 2 respectively. The main idea is acquiring data from accelerometer and gyroscope sensors. Accelerometer is used to measure 3-axis acceleration forces. Vehicle crash will impact acceleration forces measured by accelerometer. The direction of the vehicle collision determines which acceleration force (i.e. X-axis, Y-axis, or Z-axis) is impacted. Large variation in acceleration forces particularly X-axis and Y-axis within a very short time period means a possible vehicle collision.

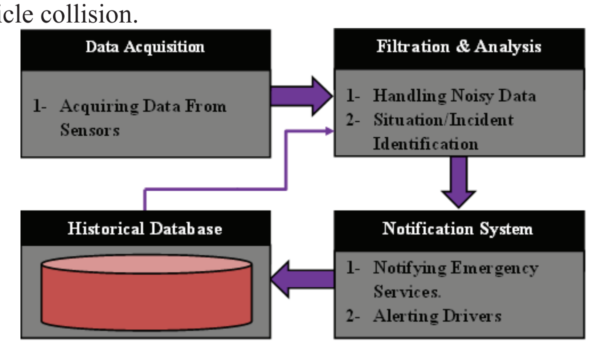

Fig. 1. Proposed System: Key Phases

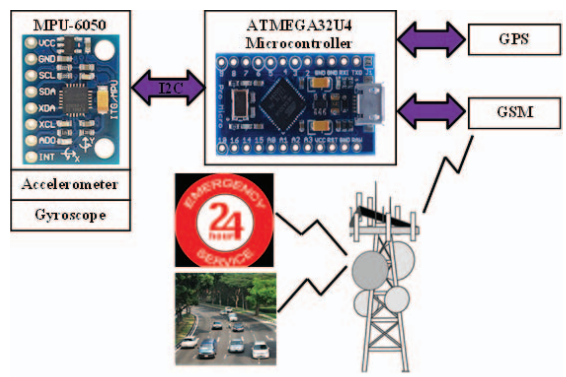

Fig. 2. Proposed System: Hardware View

However, gyroscope is used to measure 3-axis rotation angles: (1) X-axis rotation angle called roll angle, (2) Y-axis rotation angle called pitch angle, and (3) Z-axis rotation angle called yaw angle. Vehicle rollover can be identified by analyzing roll and pitch angles. The following subsections discuss the system phases with the focus on data acquisition, filtration, and analysis.

A. Data Acquisition

In this phase, a low cost MPU-6050 motion sensor and a low cost Atmega32U4 microcontroller are used to acquire and process data. MPU-6050 combines Micro-Electro-Mechanical Systems (MEMS) accelerometer, gyroscope, and a digital motion processor. 3-axis acceleration forces data are acquired using the accelerometer. However, 3-axis rotation angles data are collected using the gyroscope. Moreover, Atmega32U4 microcontroller applies the proposed algorithm to process the acquired data to determine the current incident (e.g. vehicle collision or rollover). MPU-6050 and Atmega32U4 are communicated using Inter-Integrated Circuit (I2C) communication protocol.

Data acquisition includes three keys steps shown in Figure 3 and Figure 4 shows the designed hardware. Figure 5 shows the algorithn used in the proposed system.

Fig. 3. Data Acquisition Steps

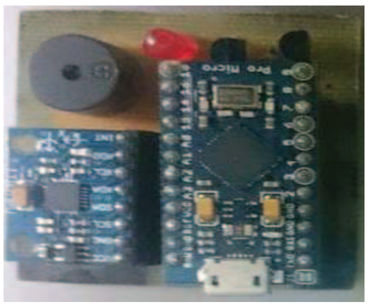

Fig. 4. System Hardware

The following steps summarize the acquisition key steps.

1. Data acquisition starts with initializing and configuring Atmega32U4 microcontroller to communicate with the MPU-6050 inertial measurement unit through Inter Integrated Circuit (I2C) protocol. I2C protocol is a simple, powerful, and flexible communication protocol. It supports master-slave operation and enables up to 400 KHz data transfer rate.
2. MPU-6050 is configured to communicate with Atmega32U4 microcontroller. This step also includes:
   a. Setting registers 13 to 16 to be sensor self-test registers to test accelerometer and gyroscope sensors and making sure they are working properly.
   b. Setting output data rate of the sensor to 100Hz. 100Hz output data rate is appropriate to the proposed system because data will be acquired every 55.55 centimeter at 200 Km/h. If the vehicle speed is less than 200 Km/h, data will be acquired at shorter distance.
   c. Setting gyroscope configuration register 27 to ±500 degree/second. This is appropriate to a moving vehicle because it is impossible for a vehicle to drift twice in less than one second and moving objects usually use ±250 degree/second.
   d. Setting accelerometer configuration register 28 to ±8g because it is impossible for a vehicle to accelerate or decelerate more than space shuttle acceleration.
   e. Enabling FIFO register. FIFO register allows decreasing the microcontroller interaction with the sensor and therefore allows system power savings. FIFO register also helps in acquiring data without overflow.
3. Finally, accelerometer and gyroscope data are streamed. Accelerometer measurements are written to registers 59 to 64. Gyroscope measurements are written to registers 67 to 72 at the sample rate defined in register 25. Figure 5 shows a sample of accelerometer and gyroscope measurements.

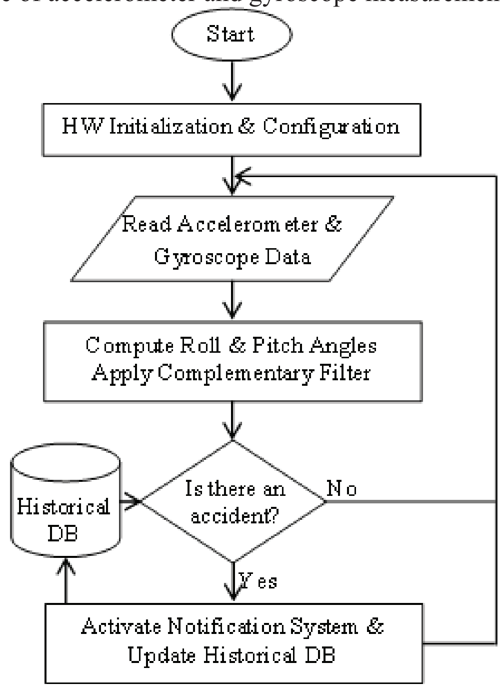

Fig. 5. Algorithm used in the Proposed System

Accelerometer			Gyroscope		
Ax	Ay	Az	Gx	Gy	Gz
12060	-3934	11096	1.69	-5.44	6.61
-3464	-12634	-12206	-56.23	-183.48	158.17
-6668	-10120	-11928	7.02	-102.38	121.8
-7226	-9668	-10610	18.29	9.94	-7.04
-5028	-11382	-9432	65.04	71.37	-98.44
1958	-14690	-9554	227.88	99.97	-141.71
4374	-15624	1472	223.37	9.56	-136.05
8936	-9324	6214	248.9	-37.08	-209.88
11968	-4426	9226	179.57	14.99	-191.77
15162	1976	11142	148.7	20.75	-251.1
5354	15062	8856	137.54	35.25	-286.64
4830	15772	9572	47.16	10.26	-91.56
10460	9600	13170	-16.37	-0.12	79.5
11736	15784	7546	-24.26	33.59	268.49

Fig. 6. Accelerometer & Gyroscope Data Sample

B. *Data Filtration and Analysis*

The algorithm, shown in Figure 5, shows all steps starting with initializing and configuring system hardware and ending with activating notification system. Identifying whether the incident is a vehicle collision or rollover depends on calculating the angular position of the vehicle. The angular position of a vehicle can be calculated using accelerometer or gyroscope data. In case of using gyroscope data, the angular position is calculated by integrating the angular velocity over time. However, calculating the angular position using the accelerometer data requires determining the position of the gravity vector (i.e. g-force) which is always visible on the accelerometer. This can be done by using an ATAN2 function. In both cases, there are some issues making the acquired raw data noisy and very hard to use without filtration.

1. Gyroscope provides accurate measurements that are not subject or susceptible to external forces. However, when the system returns back to its original position, there is a tendency to drift and not returning to zero. This is because of the integration over time. Therefore, gyroscope data are reliable only on the short term because it begins to drift on the long term. Equations 1-3 are used to calculate roll, pitch, and yaw angles using gyroscope data.

$$Roll = Roll + G_X \ / \ Frequency \tag{1}$$

$$Pitch = Pitch - G_Y \ / \ Frequency \tag{2}$$

$$Yaw = Yaw + G_Z \ / \ Frequency \tag{3}$$

2. Accelerometer measures all forces impacting the vehicle. Every small force impacting the vehicle will completely disturb the accelerometer measurement and lead to noisy data. The accelerometer data are reliable only on the long term. Therefore, a low- pass filter has to be used. Equations 4 and 5 are used to calculate roll and pitch angles using accelerometer data.

$$Roll = ATAN2(A_X, \sqrt{{A_Y}^2 + {A_Z}^2}) * 180 / \Pi \tag{4}$$

$$Pitch = ATAN2(A_Y, \sqrt{{A_X}^2 + {A_Z}^2}) * 180 / \Pi \tag{5}$$

3. Third option is using accelerometer and gyroscope data together to determine the angular position of the vehicle. This gives more precise angular values.

Kalman filter is a well-known filter that can be used to filter acquired data. However, complementary filter is used in this research since Kalman filter is very hard, if not impossible, to implement on certain hardware (e.g. Atmega32U4 microcontroller). The complementary filter facilitates the use of the gyroscope data on the short term because it is very precise and not susceptible to external forces and on the long term, the accelerometer data are used because it does not drift. Equation 6 shows the simplest form of the complementary filter.

Basically, the complementary filter is used to fuse the accelerometer and gyroscope data. This is done by passing the accelerometer data through a 1st-order low pass and the gyroscope data through a 1st-order high pass filter and adding the outputs.

$$Angle = \alpha * (Angle_{Gyro} * dt) + (1 - \alpha) * Angle_{Acc} \tag{6}$$

Where:

***α* :** floating value between 0 and 1. It is typically ranged from 0.9 to almost 1, depending on how much you can trust your gyroscope and accelerometer. It is used to tune the filter.

$Angle_{Gyro}$: Angle calculated using gyroscope data

$Angle_{Acc}$: Angle calculated using accelerometer data

As shown in equation 6, the calculated angle using gyroscope data are combined with the angle calculated using accelerometer data. In our research, different values of α are used. However, the highest accuracy has been reached by setting these α to 0.98.

Once roll, pitch, and yaw angles are calculated using data acquired from accelerometer and gyroscope, these angles along with the vehicle speed are analyzed to determine whether the incident is a vehicle collission or rollover. There are two cases:

1. ***Vehicle Rollover:*** Vehicle usually starts rollover at 46 degrees or more and at -46 degrees or less. However, these threshold values can be set to different angle degrees to warn drivers and early notify emergency services. The threshold value of roll and pitch angles represents a point from which the weight of the vehicle may contribute to the vehicle rollover. Therefore, if roll or pitch angle exceeds 46 degrees or is less than -46, then a rollover is detected, notification system will be activated, and vehicle rollover will be reported to the emergency services.

2. ***Vehicle Collision:*** during a collision, the speed of at least one vehicle that is involved in the collision usually decreases dramatically. Collision will impact acceleration forces measured by accelerometer. The direction of the vehicle collision determines which acceleration force (i.e., X-axis or Y-axis acceleration force) is impacted. Furthermore, large variation in acceleration forces associated with huge degradation in the vehicle speed within a very short time period means a possible vehicle collision. Consequently, the proposed system detects a collision by calculating the difference between two consecutive A_X or A_Y readings and compared to a specific threshold value (e.g. 2000). Additionally, vehicle speed is determined using GPS and the system check if there is degradation in the speed or not. Collision is detected when the variation in acceleration force exceeds the threshold value (e.g. 2000) and speed is degraded. Consequently, notification system is activated and collision will be reported to emergency services.

C. Notification System & Historical Database

Notification system aims at reporting the occurrence of vehicle roll over and collision to emergency services and drivers who are in or close to the scene of the traffic incident. For the purpose of testing key system components, buzzer is integrated into the system and used as indicator for detecting an incident.

Historical database is used to keep track of incident information for future use and reference. Details of notification system and historical database are out of the paper scope and will be considered as a part of future work.

IV. Experiments and Results Discussion

Identifying whether the incident is a vehicle collision or rollover depends on the validity of roll, pitch, and yaw angles calculations. A number of experiments have been conducted to test the designed hardware system and proposed algorithm. These experiments have two objectives:

- ***Confirming the validity of calculating roll, pitch, and yaw angles using the designed system.***

  In the first experiment, the angles, calculated by the proposed algorithm, are compared with the angles measured by two inclinometer devices:
  (1) Sabia's Scoliometer which is an analog inclinometer device with the ability to measure up to 90 degrees ranging from -45 and 45 degrees.
  (2) Saunders' digital inclinometer which is able to measure up to 180 degrees ranging from 0 to 180 degrees. In both cases, the designed system is installed or mounted on both inclinometer devices. In Figure 7, the proposed system is mounted on Saunders.

Fig. 7. Proposed System Mounted on Saunders' Digital Inclinometer

Afterward, Sabia or Saunders inclinometer with the proposed system is inclined in X-axis to measure roll angle and in Y-axis to measure pitch. The measured angle is compared with the calculated angles. 100 experiments are conducted. In each experiment, measurements of the proposed system and inclinometer devices are recorded and compared. Finally, the accuracy of the proposed system is calculated. The accuracy refers to the degree to which the value of angles calculated by the proposed system conforms to the value of angles measured by inclinometer devices. Figure 8 shows the accuracy of the proposed system. The accuracy of the proposed system is 100% and 97% with respect to Sabia and Saunders inclinometers respectively. The case of mounting the proposed system on Saunders inclinometer has accuracy lower than the case of mounting the system on Sabia because the system printed circuit board (PCB) is manually fabricated by us. PCB edges were not even and homogenous and system PCB perfectly fits with Sabia. A professional fabrication of system PCB will contribute in improving the accuracy.

- ***Confirming the ability of the algorithm to correctly detect the current incident (e.g. vehicle rollover)***

Two experiments are conducted to check the correctness of the proposed algorithm. In the first experiment, roll and pitch angles calculated by the proposed system in the above experiment are processed by the algorithm to identify the corresponding incident (e.g. rollover or collision). In the second experiment, the system PCB is mounted on an object and rollover is simulated by rolling over the object. More than 225 trials was run. In each trial, the object was inclined to different angles that may lead (i.e. roll or pitch angles satisfy rollover condition defined in the algorithm) or may not lead (i.e. roll or pitch angle does not satisfy rollover condition defined in the algorithm) to rollover.

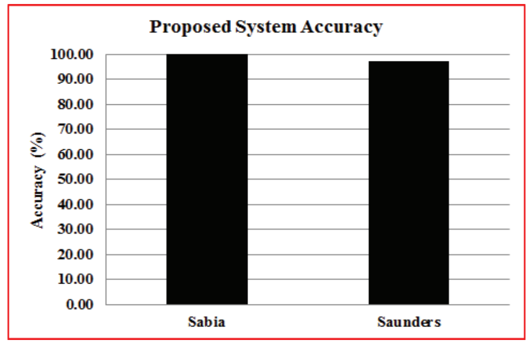

Fig. 8. Proposed System Accuracy with respect to Sabia & Saunders

Whenever the proposed system detected rollover incident, buzzer was activated and state variable,a variable declared and used to keep track incident type, was set to 1. Moreover, buzzer was not activated and the state variable was set to zero in case of the incident is not rollover. Figure 9 shows the state variable with repect to 225 trials. As shown in Figure 9, the value of state variable is 0 for trials 1-53 because roll or pitch angles do not satisfy rollover condition. This mean these incidents are not rollover. The value of state variable is 1 for trials 54-60 because roll or pitch angles satisfy rollover condition. This means these incidents are rollover. Vehicle collision is also simulated and variation in 3-axis acceleration forces are monitored.

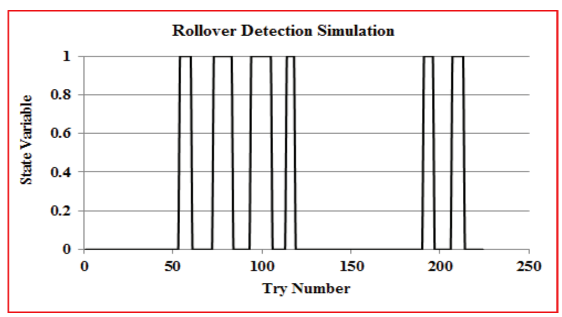

Fig. 9. Rollover Simulation: Value of State Variable in 225 Trials

Figure 10 shows the state variable with respect to 225 trials. For trials 114-128, there is a fast fluctuation (see Figure 10) of the state variable from 0 to 1 and vice versa. This is because we rapidly changed the object from collision status to normal status and vice versa to check the fast response of the proposed system. In conclusion, the proposed system shows its ability to accurately calculate roll, pitch, and yaw angles. Moreover, it shows a promising capability of fast and accurate detection of collision and rollover.

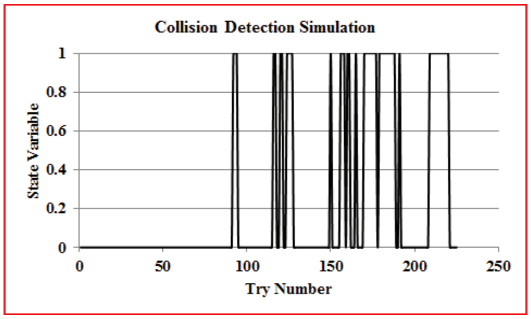

Fig. 10. Collision Simulation: Value of State Variable in 225 Trials

V. Conclusion and Future Work

In this paper, we proposed a system for detecting vehicle collision and rollover. Detecting vehicle rollover and collision and immediate notification of emergency services will facilitate fast assistance to injured occupants. The proposed system consists of three phases: (1) Data Acquisition, (2) Data Filtration and analysis, (3) Notification. A hardware system and algorithm have been designed to implement the intended functionality of the proposed system. Experimentation with the proposed system shows promising results. The accuracy of calculating roll and pitch with respect to Sabia and Saunders' inclinometer was 100% and 97% respectively.

Future research may include:

1- Expanding the functionality of the proposed system to avoid the occurrence of an accident and detect dangerous driving.
2- Modeling and simulating vehicle collision and rollover incidents and using the developed model to test and assess the performance of the proposed system.
3- Testing and evaluating the performance of the proposed system in a realistic environment.
4- Developing a mobile-based notification system that is able to report an occurrence of traffic incident to emergency services and warn drivers in case of careless driving.
5- Designing the historical database with the ability to record traffic incident information and post-incident assistance. Moreover, investigating how vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication can be used to expand and facilitate the communication between vehicles in the accident scene and emergency services.

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References

[1] JulesWhite, Chris Thompson, Hamilton Turner, Brian Dougherty, and Douglas C. Schmidt,"WreckWatch: Automatic Traffic Accident Detection and Notification with Smartphones," Mobile Netw Appl, Vol. 16, pp. 285–303, 2011.

[2] P. Puvanachandra, C. Hoe C, H. F. El-Sayed, R. Saad, N. Al-Gasseer, M. Bakr, and A. A. Hyder AA, "Road Traffic Injuries and Data Systems in Egypt: Addressing the Challenges,"Traffic Injury Prevention," Vol. 13(S1), pp. 44–56, 2012.

[3] Transport Canada, "Canadian Motor Vehicle Traffic Collision Statistics," 2013, available at https://www.tc.gc.ca/media/documents/roadsafety/cmvtcs2012_eng.pdf.

[4] Silvere Bonnabel and Erwan Salaun, "Design and prototyping of a low-cost vehicle localization system with guaranteed convergence properties," Control Engineering Practice, Vol. 19, pp. 591-601, 2011.

[5] K. Saadeddin, M.F. Abdel-Hafez, and M. A. Jarrah, " Low-Cost. High-Accuracy, State Estimation for Vehicle Collision Prevention System," 8th Int. Symposium on Mechatronics and its Applications, pp. 1-11, April 10-12, 2012.

[6] Md. Syedul Amin, Salwa Sheikh Nasir, Mamun Bin Ibne Reaz, Mohd. Alauddin Mohd. Ali, and Tae-Gyu Chang "Preferences and Placement of Vehicle Crash Sensors," Technical Gazette, Vol.21 (4), August 2014.

[7] P. Björkholm, L. Lande n, J. Stigwall, P. Johannisson,, S. Södermalm, P. Andersson, and C. Johnsson, "Navigation in Vehicle Crash Test using MEMS-based IMU," 2010 IEEE/ION Position Location and Navigation Symposium (PLANS), pp. 27 – 31, 4-6 May 2010.

[8] Shih-Ken Chen and J. S. Parikh,"Developing a forward collision warning system simulation," Proc. Of IEEE Symposium on Intelligent Vehicles (IV 2000), pp. 338-343, Oct 3-5, 2000

[9] R. Manoharan, G. Balamurugan, and B. Rajmohan, "Enhanced Automated Crash Reporting System in Vehicles based on SMS & MMS with Fish Eye CAM Camera," Proc. Of Inter. Conference on Radar, Communication and Computing (ICRCC 2012), pp. 307 – 311, December 21-22, 2012.

[10] D. Acharya, V. Kumar, and G. M. Gaddis, "A Mobile System for Detecting and Notifying Vehicle Rollover Events," Proc. Of 2007 Int. Conference on Advanced Computing and Communications (ADCOM 2007), pp. 268 – 275, December 18-21, 2007.

[11] S. Taghvaeeyan and R. Rajamani, "Two-Dimensional Sensor System for Automotive Crash Prediction," IEEE Transactions on Intelligent Transportation Systems, Vol. 15 (1), pp. 178 – 190, September 23, 2013.

[12] Chris Thompson , Jules White , Brian Dougherty , Adam Albright and Douglas C. Schmidt, "Using Smartphones to Detect Car Accidents and Provide Situational Awareness to Emergency Responders," Mobile Wireless Middleware, Operating Systems, and Applications Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering Vol. 48, pp. 29-42, 2010.

[13] Seongjin Yim, "Design of a Preview Controller for Vehicle Rollover Prevention," IEEE Transactions on Vehicular Technology, VOL. 60 (9), pp. 4217-4225, November 2011.

[14] Vasif Ahmed and Naresh P. Jawarkar, " Design of Low Cost Versatile Microcontroller based System using Cell Phone for Accident Detection and Prevention," Proc. Of the 6th Int. Conference on Emerging Trends in Engineering and Technology, pp. 73-77, December 16-18, 2013.