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An Automated System for Accident Detection

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Abstract – **Major accidents on highways, freeways and local roads can lead to huge social and economic impacts. Minor accidents may be resolved by the passengers themselves and do not require escorting to hospitals whereas major accidents where airbags are deployed require immediate attention of authorities. Automatic Smart Accident Detection (ASAD) is an auto-detection unit system that immediately notifies an Emergency Contact through a text message when an instant change in acceleration, rotation and an impact force in an end of the vehicle is detected by the system, detailing the location and time of the accident. The idea is that as soon as an accident is detected by the system, the authorities should immediately be notified to prevent further car congestion as well as allow the passengers to be escorted to the hospital in a timely fashion. The system involves the use of fuzzy logic as a decision support built into the smartphone application that analyzes the incoming data from the sensors and makes a decision based on a set of rules. The simulated results show a 98.67% accuracy of the system with failures resulting from the "gray regions" of the variable values.**

Keywords – Accident; Crash Detection; Accident Response Time; Fuzzy Logic

I. INTRODUCTION

According to the World Health Organization, approximately 3000 people die in road accidents every year while millions are injured or disabled each year [1]. The United Arab Emirates, in particular, tops the Middle Eastern region accident rates. According to the research conducted by the Chief Researcher at the Abu Dhabi Department of Economic Development, Abu Dhabi, the capital city, alone saw 116,487 vehicle crashes in 2009 [2]. In addition, the Department noted that including both direct financial measurable objective cost and the indirect socio-physical cost, the accident cost in the UAE from 2009-2011 was about AED 17 billion which is equivalent to about US $4.6 billion [3].

According to the research results, the Arab region has been classified as the most prone to car accidents, including the UAE, and especially Abu Dhabi [3]. Despite having the proper response team, the problem arises in locating the accident. The National Ambulance Company (NAC) of Abu Dhabi has 34 standby ambulances and 10 mobile hospitals ready to be dispatched [4]. The NAC has maintained an excellent record of an 86% success rate on responding to an accident within 10 minutes; however, conditions like not finding the location due to the failure of the caller to give exact address affect the response time [4].

The ideal scenario for a victim of an accident is that police and ambulances arrive on the scene immediately – but in reality victims do not always have this luxury. For instance, numerous accidents in Abu Dhabi or Dubai occur in places where no bystander or passing car is available to notify the police. Furthermore, as many accidents occur on highways, vehicles passing by at high speeds often ignore their duty to notify the police/ambulance. The response time of the police/ambulance varies due to the detection time, which is dependent on the drivers in accident, passing by drivers or bystanders' information.

As human lives are at stake, the detection and response time are crucial variables for the victim(s) of a vehicle accident as well as the governing agencies. Even a slight reduction in the response time can decrease the percentage of fatalities and economic loss by a huge margin. Using an incident detection program in the United States, a reduction in the response time from 5.2 minutes to 3 minutes would have saved 246 lives, a reduction by 11% whereas by reducing the response time to 2 minutes, 356 lives would be saved annually [5]. While it is easy to claim a reduction in lives due to reduction in response time, an actual example helps in the cementing of the argument: a reduction in accident notification time from 5.2 minutes to 4.28 minutes has led to an 18% reduction of fatalities [5].

Similarly, the cost associated with fatalities and deaths were staggering in the United States. Research shows that the monetary cost associated with non-fatal injury victim was approximately $111,870 and $708,235 for a fatal injury [5]. In addition, the comprehensive cost, which includes the loss of quality of life, was $560,018 for each injury and $2,634,551 for each fatality [5]. Therefore, an incident management system in place reducing the notification time to 3 minutes has monetary benefit of about $268 million per year while the comprehensive benefits are about $931 million per year [5].

ASAD functions as a detection and notification service that can be installed in a vehicle and in case of accident detection, requires the smartphone of the driver to send a text message to the response team. The detection of an accident is based on Mamdani fuzzy logic that evaluates, using four parameters (force, acceleration, rotation and speed) to calculate a collision index and if the threshold of the index is met, the smartphone issues and sends a notification text message. This eliminates the need of the passing by drivers or bystanders to notify the police of the accident. In addition, ASAD records the sensor data over a specific time interval (for instance 5 minutes) as a text file in

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the smartphone to be used for verification/diagnosis purposes by the police/ambulance.

The remainder of the paper is organized as follows: Section 2 lists related work and highlights the scope of the paper. Section 3 underlines the architecture of the ASAD system and highlights the components of the system. In Section 4, we present the details of system implementation and the hardware/software used in the prototyping phase. Section 5 describes the performance evaluation and provides results and graphs of test cases. Finally, section 6 concludes the paper by listing the finding and providing perspectives on the potential of ASAD.

II. RELATED WORK

Several researchers have been introduced in the same field of research as the ASAD system. The idea has been presented to the world at many occasions but the lack of implementation, finding the ideal location for the system or other issues have restricted the widespread uses of the idea.

The new Lexus 2014 models are equipped with a new feature called the Lexus Enform [6]. The driver, also a smartphone user, logs into the app and can use a wide range of services such as the GPS, nearby locations, assistance for directions for a phone, etc. [6]. The technology is equipped with a feature called the Safety Connect that detects an accident through a force sensor on the rear end of the vehicle or the deployment of the airbag system and sends an automatic notification to the response service center through the smartphone [6]. The problem with the Lexus Enform system is the pricing; Enform costs about $260 per year for a continued service from the second year of service and on [7].

Similarly, the OnStar Corporation, a subsidiary of General Motors Company, started the provision of accident notification service in the United States and later opened its services to Ecuador and Venezuela by the name of Chevystar [8]. It provides options such as Automatic Crash Response, Stolen Vehicle Tracking, Turn-by-Turn Navigation, and Roadside Assistance [8]. Online reviews about the system include over pricing, poor service and lack of assistance, revealing the inefficiency of the system [9]. In contrast, ASAD provides only one particular service of detection and notification. The GPS location is received through the driver's network provider and the system sends a text message through the smartphone and as there is only a one-time purchase by the user, there can be no further pricing associated with the system.

e-NOTIFY is a system that allows fast detection of traffic accidents, improving the assistance of injured passengers by reducing the response time of emergency services and the submission of relevant information on the conditions of the accident using a combination of V2V and V2I communications [10]. It uses the GPS connection of a vehicle to transmit the data, through Internet connection provided by the roadside units, to the service center that can respond immediately [10].

In [11], the author details a system of automatic accident detection and notification using the built-in sensors of the smartphone. This technology assumes the availability of a mobile wireless telecommunications system [11]. The phone is then placed in a cradle (mating stand), which has to be aligned longitudinally and transversely with the vehicle [11]. The mobile phone will then automatically send a signal without the interference of the driver [11]. The problem with this technology is that the interference of the user with the smartphone can affect the efficiency of the system. In case the driver requires using the smartphone while driving for any purpose, he is unable to pick it up from the cradle, as the acceleration will be affected. The advantage of ASAD over this system is the fact that the installation of the hardware ensures a perfect alignment of the sensors and instead of dependent upon accelerometer and gyroscope. ASAD takes force and speed into consideration when making a decision to reduce the errors (false-positives or false-negatives) of the system.

The authors in [12] implemented the ACN using a GPS sensor, an embedded wireless modem, crash sensors and an embedded microprocessor. The crash sensor detects the accident, the GPS sensor locates the vehicle and using the wireless modem and the embedded microprocessor, the data is sent to a response center [12]. The paper mentions the availability of GM Onstar being a high cost option for customers and therefore the necessity to develop a low cost option for users [12]. ASAD system uses the GPS location acquired through the network provider via the smartphone and the smartphone data network to send the text message to the response center (instead of a wireless modem).

III. ASAD SYSTEM DESIGN

Figure 1 shows an overview of the proposed ASAD system. The accelerometer, gyroscope and force sensor measures the behavior of the car and inputs the data to the embedded processor where the signals are processed. The processor then, using the Bluetooth module, sends the calibrated data to the smartphone. The fuzzy logic decision support – programmed in the mobile application – receives the processed data and makes a decision of detection or no-detection. At detection, the smartphone application, through the data network, sends a text message to the emergency contact/public safety. In addition to the response, the application stores the data over a period of last number of minutes (current implementation is set to 5 minutes) till the moment of detection for diagnosis purposes.

A. Input Module

The Input Module reads sensor data on acceleration, rotation and force and passes the collected data to the Embedded Processor. The components of the software architecture are described briefly here:

- *Accelerometer:* This 3-axial component acquires the data about the current acceleration of the car along three orthogonal axes. The accelerometer is also used to calculate the speed of the vehicle that is used in the fuzzy logic decision support component.

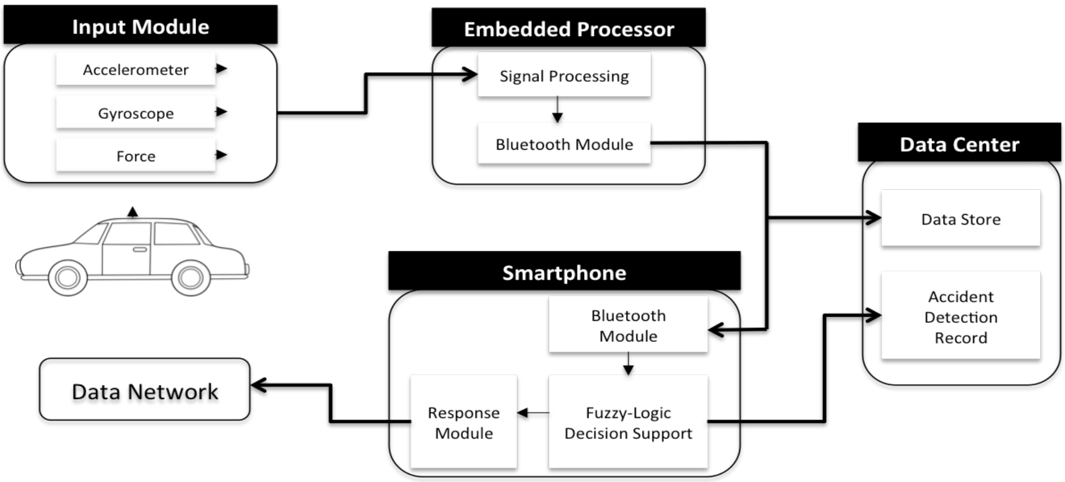

Figure 1 - Architecture for Automated Smart Accident Detection

- *Gyroscope:* The Gyroscope senses the rotation/tilt of the car and reads the data after processing in degrees per second. This rate of rotation is used for evaluating if the car has rotated to its side or flipped completely.
- *Force Sensor:* The four force sensors located at each side of the car detect the impact force of the accident.

B. Embedded Processor

The Embedded Processor plays the role of a translator. It includes a signal-processing module that samples the calibrated data every second, and a Bluetooth module that sends the calibrated data to the smartphone. In addition, using the readings of the accelerometer, the speed of the vehicle is calculated and used by the decision support component in the smartphone.

- *Signal Conditioning and Processing:* This component minimizes the noise and information damage that severely deteriorate the readings. Additionally, the accelerometer readings are converted from its raw values to g's while the gyroscope readings are converted to degrees/second. Using the third kinematic equation and the accelerometer readings, the speed of the vehicle is calculated for context purposes.
- *Bluetooth Module:* The Bluetooth module in the processor receives the data from the microprocessor and transmits the processed data (acceleration, rotation, speed, force and timestamp) to the smartphone.

C. Smartphone

The smartphone application acts as the decision support as well as the means to reach out for help. It is composed of a Bluetooth Module, the fuzzy logic decision support and the response module that enables sharing of information with a third party (an emergency contact, police or ambulance service).

- *Bluetooth Module:* The Bluetooth module of the smartphone is responsible for communicating data with the microprocessor.
- *Fuzzy Logic Decision Support:* The decision support is based on Mamdani Fuzzy Logic that uses four input variables (accelerometer, gyroscope, force and speed) to evaluate whether an accident has occurred or not. Each variable is composed of three ranges; low, medium and high. This creates 81 different combinations of inputs that are used by the decision support to evaluate a detection scenario.
- *Response Module:* The response module is responsible for receiving a green light from the decision support to send a text message to a third party (emergency contact/public safety). The text message includes the GPS location, the time and the date of accident. The text messages can be used to verify the data of the storage.

D. Data Center

The Data Center is hosted by a web server that is managed by a third party (such as the police department) and made readily accessible by end users. It is implemented as a MySQL database.

- *Data Store:* The Data Store saves the processed readings of acceleration, rotation, force and speed over the past time interval. In addition, it saves contextual information that can be used by the police in accident records. It tables the following information for each user:
  - ✓ Accelerometer readings
  - ✓ Gyroscope readings
  - ✓ Force readings
  - ✓ Speed of vehicle
  - ✓ GPS location
  - ✓ Time
  - ✓ Date
- *Accident Detection Record:* The Accident Detection Record stores the user profile along with the history of accidents that have been previously detected by the system. The police and the licensing department use this record to keep track of the behavior of the vehicle/driver.

E. Fuzzy Logic Decision Support

The fuzzy logic decision support is part of the smartphone application responsible for evaluating whether an accident has occurred or not. Instead of using fixed threshold values, fuzzy logic uses statistical reasoning, especially when dealing with borderline values. It takes in account all variables and the combinatorial outputs and bases its decision on the criteria that are met. Table 1 shows a sample of the different combinations of the fuzzy logic (a total of 81 combinations):

Figure 2 and 3 show the membership functions implemented in the fuzzy logic for the force data and accident index, respectively. The force membership function (Figure 2) is a combination of triangular and trapezoidal functions. The three other variables have similar membership functions with different ranges. Figure 3, on the other hand, shows the membership function of the collision index, the output variable.

Table 1 - Fuzzy Logic Rules

Inputs				Output
Force	**Accel.**	**Gyro.**	**Speed**	**CI**
L	L	H	M	M
L	H	M	H	H
M	L	H	L	L
M	H	H	H	H
H	L	H	L	M
H	H	L	M	H

L = Low, Medium = M, H = High

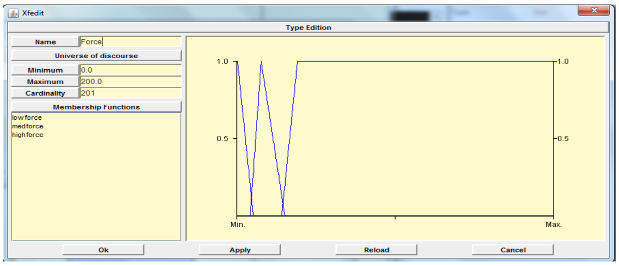

Figure 2 - Membership Function (Force)

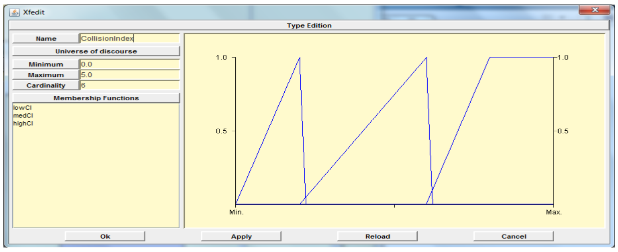

Figure 3 - Membership Function (Collision Index - Output)

IV. ASAD SYSTEM IMPLEMENTATION

The implementation architecture, as shown in Figure 4, is composed of an MPU-6050 triple axis accelerometer and gyro breakout to measure the acceleration and rotation of the car, four Force Sensitive Resistors (FSR) that are attached at the 4 ends of the vehicle to detect impact force of accident, a Bluetooth Module to send data to smartphone, an Arduino Pro Mini microprocessor to read the sensor data, power the Bluetooth module to send data to smartphone, condition and process the sensor data and calculate the speed of the vehicle. It also comprises of a smartphone that runs an application to provide the GPS coordinates through the Network Provider and send a text message in case of detection of an accident.

The hardware of ASAD system is composed of the following components:

- 1 MPU-6050 triple axis accelerometer and gyro breakout
- 1 Arduino Mini Pro
- 4 FSR – Long
- 1 Bluetooth Module BT Board V1.2 JY-MCU INEX
- 1 battery

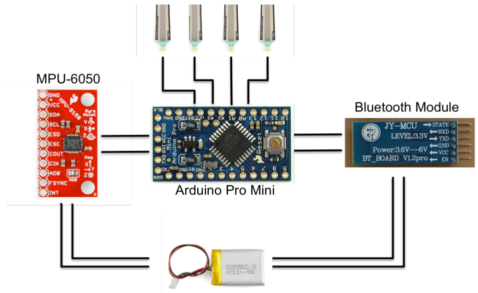

Figure 4 - Implementation Architecture

As for the software development, the following components were used: (1) Arduino IDE, (2) Eclipse IDE, (3) Processing, and (4) xFuzzy 3.0.

V. PERFORMANCE EVALUATION

The objective of this study is to explore the reliability and usability of the ASAD system to detect and report accidents (by measuring false positives/negatives). Due to safety issues, crash testing of vehicles was replaced by simulated testing of the system. 150 test cases (randomly generated values of each input variable) were adopted and the intended results were compared to the actual result of the system. For example, a test sample values (83N, 0.67g, 81.75^0/s, 72.81km/h) result in a Collision Index Output of 4.50, which is greater than the threshold value of 3, hence an accident is detected. This is compared to the intended output of high force, low acceleration, high rotation and speed that is supposed to result in an accident, and hence the test passes. Out of the 150 test cases that were performed, 2 failed, resulting in a 98.67% accuracy of the system. The data was plotted on a graph to get a better understanding of the failed cases.

Figure 5 shows the test cases data plotted. The red lines highlight the two failed cases and as 3.0 is the threshold for the Collision Index, the two cases fail by a very close margin. The reason for the failure is the “gray region” of the fuzzy logic. Due to the overlap of the three ranges (e.g. Acceleration: 0 < Low < 1.23, 1.20 < Medium < 2.00, High > 1.90) in each of the variable, if the value of each of the four variable lies between these overlapped ranges, then the fuzzy logic gives the Collision Index output of about 2.9. The system can be calibrated to optimize the threshold so that all the accidents will be detected. The other possibility is to calibrate the membership functions.

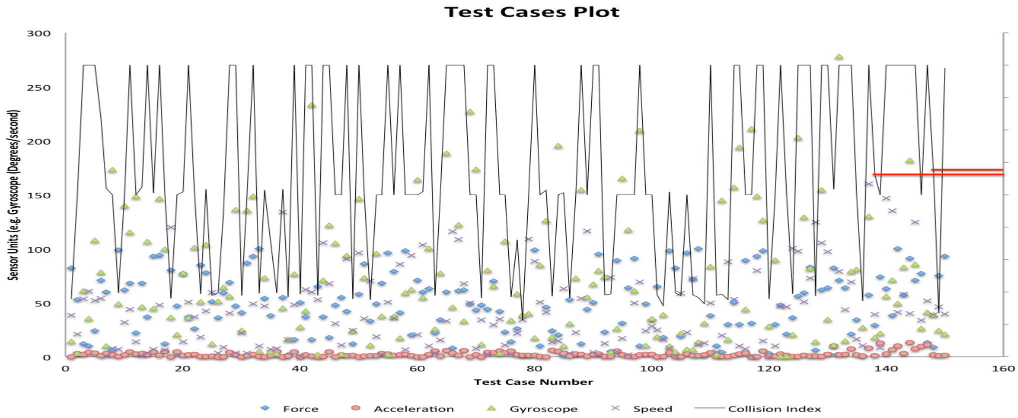

Figure 5 - Test Cases Plot (Red Lines Show Failed Cases)

As part of the usability evaluation, questionnaires were given to 42 participants. The four questions were: Q1: What in your opinion is the most important factor of the device that would make you want to buy ASAD? Q2: Would you buy the system at affordable price? Q3: Do you think the device compromises user privacy? And Q4: Would you feel safer with such a device installed in your vehicle?

As shown in Figure 6 and Table 2, the results are promising. Figure 6 shows that 31.86% of the subjects emphasized the importance of reliability, 21.24% highlighted the importance of price while 16.81% preferred user-friendliness. 97.6% confirmed that they would be willing to buy the system at affordable prices. In addition, a third of the subjects raised an issue of privacy due to the GPS location. Finally, about 93% of the subjects confirmed that with a system like ASAD, they would feel safer driving a car.

Table 2 - Survey Statistics

Response/Question	**Q2**	**Q3**	**Q4**
Yes (%)	97.6	33.3	92.9
No (%)	2.4	66.7	7.1

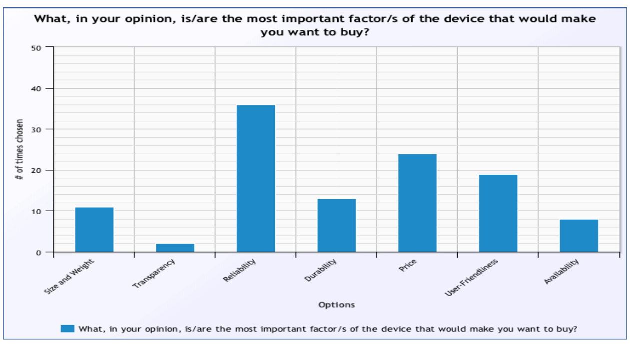

Figure 6 - Question 1 Response Statistics

VI. CONCLUSION

This paper presented ASAD system – an automated notification service that allows authorities to be immediately aware of any accidents that occur in the their respective cities to allow them to take immediate action and prevent as much damage as possible, both human and economic. The system has demonstrated its efficiency through a 98.67% accuracy while the 1.33% can be corrected by adjusting the system's threshold. Furthermore, user surveys have indicated a keen interest in ASAD while a few raised concerns about privacy.

Moving forward from the prototyping and testing phase, further improvements can be made to the system. The hardware can be optimized to be more compact to be installed into a vehicle. The smartphone application can be updated to accommodate sending a text message to more than one contact (for example, simultaneous text messages to an emergency contact, the police and the ambulance service). We plan to add neural networks component to enable online, self-tuning system. A bigger step will be having crash testing facility to update the system values and thresholds along with the membership functions of the fuzzy logic. Finally, a more detailed survey can be done with more questions and a larger population in order to understand customer needs better and complete a system that satisfies the needs of the majority.

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