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Wireless monitoring devices for regulation of vehicular events with Internet-of-Things (IoT)

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ABSTRACT

The desire of men to conveniently commute and travel is evident in the staggering increase in the production and sales of automobiles. However, this pronounced rise in the usage of vehicles also brought a proportional increase in road accidents as indicated by local and international safety agencies reports showing a surprising number of vehicle accidents which rank it among the top causes of global deaths. The study aims to create a means of providing immediate response to car drivers during vehicular accidents. The study followed the framework of development and technology research in developing a technical model for monitoring and tracking mobile vehicles in outdoor environments using the Global Positioning System (GSM), Global System for Mobile Communication (GSM), and Internet-of-Things (IoT). A drive-permission feature was also implemented to provide an anti-theft function. The system was subjected to technical functionality testing to check if the system performs its intended functions and the standard Post-Study System Usability Questionnaire (PSSUQ ver 3) to evaluate user usability. The system achieved a functionality test result of 92.5% and a PSSUQ mean of 1.78. Based on the development and results of the testing and evaluation, it was concluded that (1) the system can monitor various vehicular events such as head-on collisions of the vehicle (bump and crash), the vehicle speed, location, heading, and time, and vehicle theft attempt, (2) a high degree of system functionality in terms of the mentioned vehicular events and the integrated web application, and (3) a PSSUQ score indicating a high level of system usability.

KEYWORDS

global positioning system, internet-of-things, microcontroller, usability testing, vehicle monitoring, vehicle tracking

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INTRODUCTION

Data monitoring and recording operations have long been required in many safety-oriented applications (Johansson, 2013). This acquired data is not only valuable for determining failure mechanisms but also helpful for more purposes like maintenance, reliability, safety, and security. Automobiles like buses, vans, fleet vehicles, or private-owned vehicles are examples where data monitoring and recording are of utmost importance.

Road accidents, also called traffic collisions, are caused by humans when they overlook laid down rules and regulations governing the use of roads (Olarte, 2011). Over the years, road accidents have been proven devastating to victims and those affected. The World Health Organization (WHO) reported in their Global Status Report on Road Safety 2015 that road traffic crashes are the leading causes of deaths globally, taking 1.25 million lives per year, with one death on the road every 25 seconds (WHO, 2015). In the Philippines, with more than 7.69 million registered vehicles (LTO, 2013), there were 10,379 reported deaths caused by road accidents in 2013.

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As human dependency on transportation increases and incidents of road-related accidents rise, the need to develop a system that will track and notify owners of their vehicular events is apparent. This study intends to design a compact system that combines data monitoring and logging, security, and regulation systems. The device will provide a notification system that immediately informs the owner or family members of a car crash. The device will also integrate a regulation system that will allow the car owner to set specific controls for his car and notify him if the driver has violated the set regulation.

Most vehicle monitoring systems use wireless communication networks only to set up connections and transfer data between the vehicle and a wireless-based station and for location determination (Kuar, 2012). This setup poses a challenge in terms of reliability due to the inherent mobility of vehicles since wireless networks face limitations associated with access points when the vehicle moves out of range. The developed system will employ the latest data-transfer technology, the Internet of Things (IoT), to send location information, vehicle data, and configuration signals to and from the device and the server. The system will also integrate GPS satellite-based tracking to identify the vehicle's location, speed, and heading and relay this information to the owner's mobile device through the GSM network using Short Message Service (SMS).

Implementing these technologies will ensure an economical system with an efficient and faster data transmission rate (GSMA, 2014). Unlike other typical car monitoring devices that use GPS and GSM to identify vehicles' locations only, the system is equipped with a triple-axis accelerometer that provides continuous g-force value and various impact sensors or switches that detect head-on collisions. The g-force value generated by the accelerometer and the activation of the impact switches identify the status of the vehicle it is monitoring, either a bump or a severe crash (Majeed, 2015). These sensors will enable the device to monitor and give reports on vehicular events. The mechanism of securing the vehicle from thieves is implemented by utilizing SMS verification. Registered vehicle owners will be notified wirelessly if the vehicle shows irregularities.

The study answers the following research questions:

- How to design and develop a system that monitors various vehicular events that utilize SMS notifications and Internet-of-Things?
- What vehicular events will the system monitor and distinguish during operation?
- How to test the features and functions of the vehicle monitoring system?
- How can specified users use the system to achieve set goals with effectiveness, efficiency, and satisfaction in a specified context of use?

The main objective of the study was to design and develop a wireless monitoring device for the regulation of vehicular events with internet-of-things (IoT).

Specifically, this study aims to:

1. distinguish various vehicular events in terms of
   a. head-on collision status of the vehicle in terms of bump or crash,
   b. vehicle speed, location, heading, time, and
   c. car theft attempt;
2. assess the functionality of the system in terms of:
   a. crash and bump identification,
   b. vehicle status retrieval,
   c. anti-theft feature,
   d. web-program integration;
3. evaluate the usability of the system.

MATERIALS AND METHODS

Research Design

The study follows the framework of Developmental and Technology research. Upon analysis of the project design requirements, the Design and Evaluation research design was implemented as it is purposely intended for the development of a new product or process (Magallanes, 2011).

System Design

Figure 1 shows the block diagram of the system. As illustrated in the diagram, two significant components comprised the system. The hardware and the software components were developed simultaneously. The software component consists of the web program that provides the GUI for the user and the PC or mobile device. Accessing the program allows the user to view information and configure the device. The hardware component consists of the microcontroller, modules, sensors, and input and output devices. The heart of the system is the Arduino-based microcontroller, which acts as the system's primary controller. The microcontroller connects all the input, output, and communication devices.

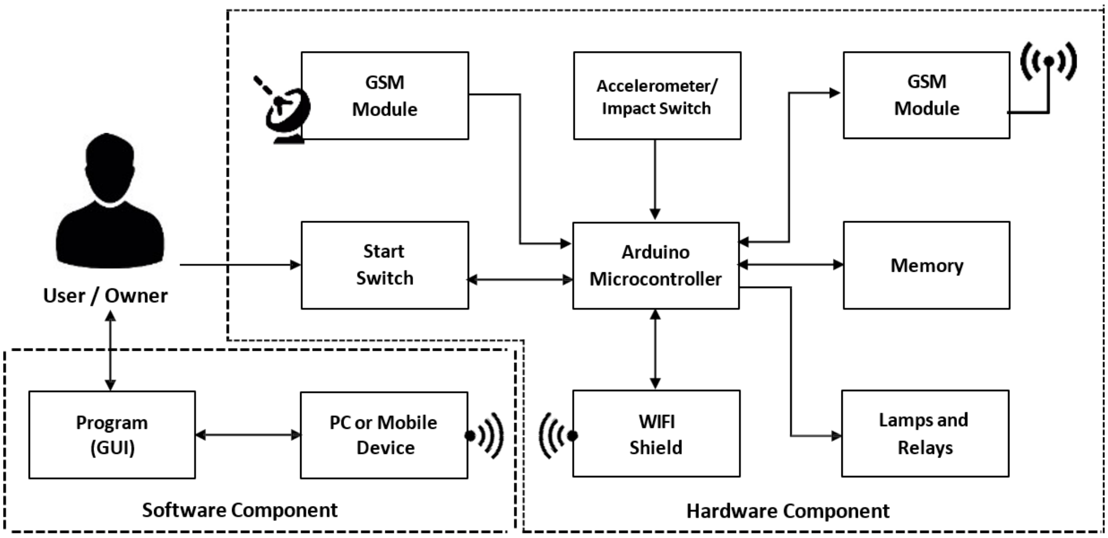

Figure 1. Block diagram of the system.

Conceptual Flow

The diagram shown in Figure 2 visualizes the process flow of the project. Two modes identify the state of the vehicle. First is the Standby mode. During standby state, the priority is the car's security since it is idle or not running. An alarm system installed in the vehicle will detect if forced entry or illegal start-up is sensed, consequently sending an SMS to the owner's mobile for verification of this entry. The system will wait for a response and interpret it to either allow driving or stall the car by cutting off the car battery's power. This mechanism implements the system's car theft feature. Once the system passes valid verification, it will change state to Monitoring mode where the vehicle is running.

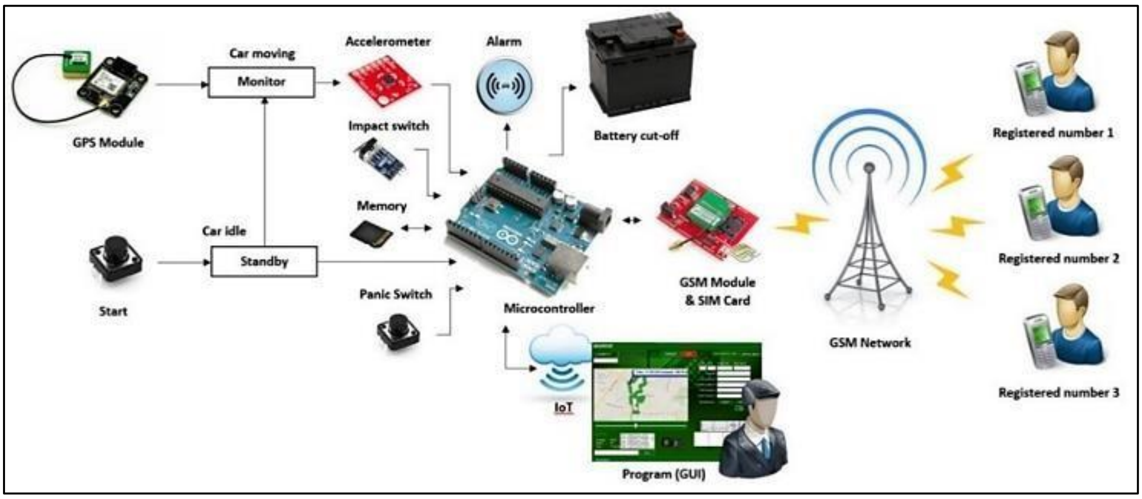

Figure 2 Conceptual flow of the Wireless Monitoring Device for Regulation and Information of Vehicular Event.

During Monitoring mode, the triple-axis accelerometer and the impact sensors mounted in front of the vehicle are set to detect sudden stops and head-on collisions. Suppose the accelerometer and impact sensors simultaneously sense a sudden stop or impact; the value of the g-force acquired by the accelerometer will be compared to the three-set values in the microcontroller. Three levels of g-force will correspond to three levels of car collisions: normal drive (0-4g), bump (4-20g), or crash conditions (above 20g with all impact sensors activated). Suppose, based on the received values, the triple-axis accelerometer senses a collision; the device will contact the first registered cellular number through SMS, indicating the geographical location (acquired from the GPS receiver module), bearing, heading, and degree of the car collision. After receiving the SMS message from the device, the receiver is required to reply to the message. Informing the system that the first registered cellular number has received, read the SMS message, and understood it. After a specific time, interval that the first registered user fails to reply, the device will send an SMS message to the second registered cellular number. If the second registered user fails to respond, a similar SMS message will be sent to the third up to the last registered number until an acknowledgment is received. Modes automatically change as soon as SMS acknowledgment is received. The driver needs to activate the emergency panic button to indicate his need for assistance.

Test Procedures

The device is subjected to various testing and assessments to verify if the system coincides with the design criteria and user requirements. This will ensure that the system provides its desired features and functions and satisfies its intended users' needs.

A User Acceptance Test (UAT) Plan was developed based on the IEEE Std. 829 – 2008 Standard for Software and System Test Documentation. The plan evaluates the system and consists of risk management, testing features, standards used during testing, test items, schedule, and approvals. This document aims to outline the UAT process to make the testing of the device more manageable. The plan consists of risk management, testing features, standards used during testing, test items, schedule, and approvals.

The following are the assessment procedures stipulated in the UAT Plan:

(a) Functionality Test

To ensure that the product's functions and features, Functionality testing was carried out. The process required a series of tests that performed a feature-by-feature validation of behavior using a wide range of standard and erroneous input data. The parameters tested for functionality are:

a. the head-on collision status of the vehicle in terms of Bump or Crash;
b. the vehicle speed, location, heading, and time;
c. the car theft attempt

(b) Usability Test

Usability testing assesses how specified users can use a product to achieve set goals with effectiveness, efficiency, and satisfaction in a specified context of use (Lewis and Sauro, 2012).

The study used the standardized Post-Study System Usability Questionnaire (PSSUQ) to measure the system's usability. The PSSUQ standardized questionnaire was developed by the International Business Machine (IBM) and widely used to measure users' perceived satisfaction with a website, software, system, or product at the end of a study (Garcia, 2014). The 16-item PSSUQ survey questionnaire measures the overall user satisfaction with the device. The standard survey questionnaire further identifies the usability in terms of,

a. System Quality
b. Information Quality
c. Interface Quality
d. Overall Usability

Data Treatment

Using PSSUQ, the overall system usability score is obtained by getting the mean of the sub-scales of System Quality (items 1-6), Information Quality (items 7-12), and Interface Quality (items 13-16). The mean score is normalized and compared to the PSSUQ-3 Norms. The comparison will determine if the average usability score is above or below the commonly accepted standard.

RESULTS AND DISCUSSIONS

The result and significant findings observed in the development of the vehicular monitoring system, identification of essential features, testing of its different parts and functions, and the evaluation of its usability are discussed in this section.

Technical Testing

(a) Global Positioning System Map

This process tested if the system provided accurate GPS location during a car accident and even during car travel. The device's tracking ability was pilot-tested by mounting it inside a vehicle and letting it travel in two locations. A mobile device with Google mapping capability was used to provide reference location.

Figure 3 shows the route where the car has traveled. The GUI shows point per point, the vehicle's compass orientation, and the date and time of the vehicle's location at a certain point.

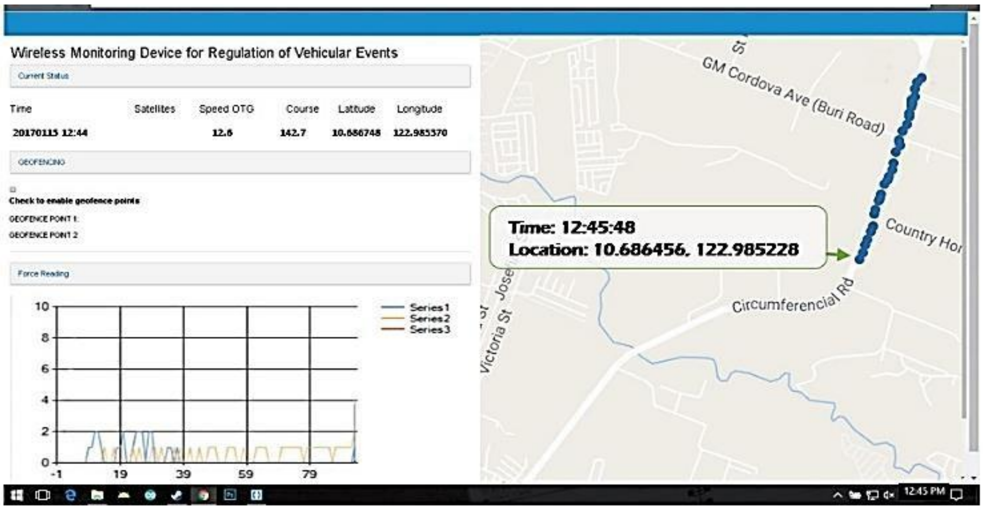

Figure 3. Sample interface implementing geolocation function.

(b) Accelerometer

The triple-axis accelerometer was used to monitor the head-on collision event of the system. The running prototype was first tested in a controlled area and was forced to collide on the wall to simulate a vehicle crash or collision event. This situation allowed the accelerometer to gather data regarding the force of impact, g-force, to be compared to the actual and expected value of g. The g-force value is dependent on the speed and acceleration of the vehicle during a collision. The g-force is a unit of acceleration (Allain, 2012) and is represented by the formula in equation (1)

$$g - force\ (in\ g's) = \frac{|F_{net} - mg|}{mg} \qquad (1)$$

where F_{net} is the object's net force, m is the mass of the object subjected to impact, and g is the gravitational force equal to 9.8 m/s^2.

As shown in Table 1, consistent low G readings were generated from the accelerometer logs. Distance from the Impact column indicates the distance the test vehicle is away from the impact point (concrete wall). The Accelerator readings g-force (g) values were taken from the accelerator readings mounted in the vehicle. The average from three Trials taken from every distance the vehicle is away from impact is indicated in the Table. The vehicle started its acceleration from a distance of seven (7) meters from the impact point. The device generates an average of 0.3 g at this location, indicating minimal acceleration. At the point of impact (0 m), the vehicle experienced a surge in g-force, indicating a collision. As the vehicle approached the wall, its momentum and acceleration abruptly changed, causing a sudden increase in g-force (average of 8.0 g from three trials). The highest g-force value was recorded at the point where the car had a collision with the wall (9g in Trial 1).

Accelerator readings at different trials taken at different distances from impact.

Distance from Impact (m)	Accelerator readings g-force *(g)*			
	Trial 1	Trial 2	Trial 3	Average
7	1	0	0	0.3
6	0	1	1	0.6
5	1	1	1	1.3
4	1	1	1	1.3
3	1	1	1	1.3
0	9	8	7	8.0

(c) GSM module

The GSM module was also tested to assess the reliability of the mobile messaging features of the device. From the mobile unit, a Google map was used to compare the coordinates taken from the mobile application and the prototype. A GSM text message was sent from the device to relatives or friends of the person driving the car, providing the status of what happened to the vehicle while it was on the road. In addition, the GPS coordinates embedded in the text message allowed them to identify the vehicle's location.

Functionality and Usability Testing Result

(a) Functionality Testing

Once the system was developed, selected users were requested to evaluate it based on its functionality and usability. Guidelines for conducting these tests are outlined in the UAT Plan created for the system.

The Functionality Test allowed the user to check the various functions and features of the device. The users were requested to fill out the Functionality Test Form based on their perception of the accuracy of the tasks the device performed and the correctness of its output.

To test these functions, a prototype vehicle where the system is mounted was subjected to various controlled situations that simulate different vehicular events. Messages sent via SMS to registered users' mobile devices and data from the integrated software are then recorded and verified if the system monitors or shows accurate events.

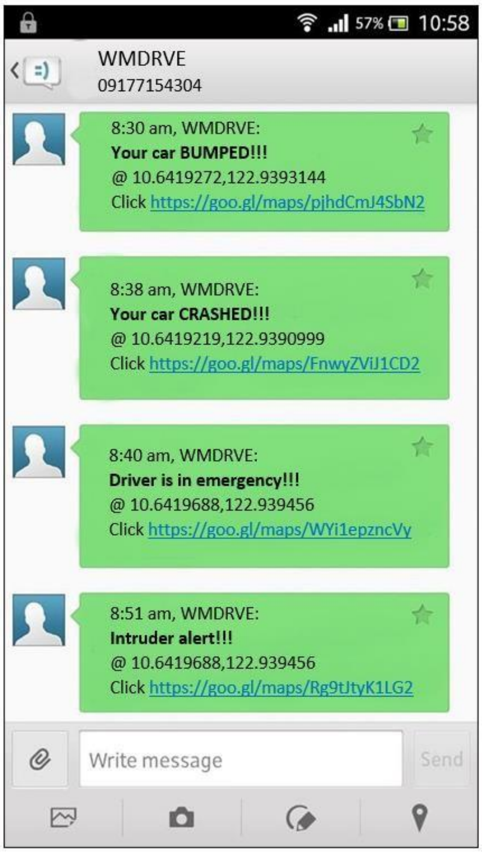

Figure 4. Sample SMS messages reporting different vehicle events.

As seen on the sample SMS text messages (Fig. 46) sent from the device, registered relatives or friends of the person driving the car will be prompted on what happened to the vehicle while it was on the road. The first three SMS messages show the different status of the vehicle during a collision, while the last message indicates vehicle intrusion when the system was subjected to Car Theft testing. In addition, the GPS coordinates embedded in the text message allowed them to identify the location of the vehicle.

Table 2 presents the collated and computed mean of the system features. Based on the values given in Table 2, it is evident that all of the tested users strongly agree that all of the features/ functions tested are functional. The overall average usability figure indicates that 92.5% of the users strongly agree that the whole system is functional, and 7.5% do not. The result denotes a high-level functionality.

Summary of the Functionality Test

ID #	Features/ Functions	Number of Responses		Percentage (%)	
		Passed	Failed	Passed	Failed
1	Crash and bump identification	10	0	100	0
2	Vehicle status retrieval	10	0	100	0
3	Anti-theft features	8	2	80	20
4	Web program integration	9	1	90	10
	Average	9.25	0.75	92.5	7.5

(b) Usability Testing - PSSUQ

The industry-accepted Post-Study System Usability Test Questionnaires (PSSUQ version 3) were distributed to test participants to evaluate the system's usability. The participants or respondents of the study consisted of eight subjects purposively sampled from persons who own a vehicle, drivers, operators, and IT and engineering experts. They rated the system using a 7-point Likert scale and based their answer on their agreement with the 16 stated criteria. The PSSUQ scale was further divided into subscales that measured System Quality (SysQual), Information Quality (InfoQual), and Interface Quality (IntQual).

Shown in Table 3 is the overall system's usability level and its subscales. Based on Table 3, the system achieved an End-User Satisfaction Level of 1.78 (on a scale of 1 – 7 and 1 being the highest). Another evidence that will support the high user usability rate towards the system is when normalizing the data and comparing the achieved value to the PSSUQ Norm. The PSSUQ Norm is a database of PSSUQ Mean scores compiled from other systems.

This PSSUQ Norm compared the system under study to see if their product is comparable or better than the rest (with a Confidence interval of 99%). Comparing the mean values for each criterion over the Mean values of the PSSUQ-3 Norm demonstrated that the system achieved a better Mean in all criteria (Lewis, (2002). Based on the PSSUQ-3 Norms (Means and 99% Confidence Interval), the figure is better than the industry standard of 2.82 (a smaller value is better), signifying a high level of system usability.

Table 3. Mean of every subscale and overall Usability of the system using PSSUQ version 3.

Subscales	**Criteria covered in PSSUQ-3**	**Average (mean)**
System Quality (SysQual)	Items 1 to 6	1.63
Information Quality (InfoQual)	Items 7 - 12	2.10
Interface Quality (IntQual)	Items 13 - 15	1.73
Overall End-User Satisfaction	All items	1.78

Based on the development and results of the testing and evaluation process, the following conclusions are drawn:

1. The developed system can monitor various vehicular events that utilize SMS notifications and Internet- of-Things. The developed system can distinguish various vehicular events in terms of:
    a. Head-on collision of the vehicle: Bump and Crash;
    b. Vehicle speed, location, heading, and time;
    c. Attempt of vehicle theft.

2. The result of the test indicates a high degree of system functionality in terms of:
    a. crash and bump head-on collision identification,
    b. vehicle status retrieval,
    c. anti-theft feature,
    d. web-program integration.

3. the system has a high level of usability.

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ETHICAL DECLARATION

The author of the manuscript entitled: “Wireless monitoring devices for regulation of vehicular events with Internet-of-Things (IoT)” hereby declare that the above-mentioned manuscript which is submitted for publication in VJSTI is NOT under consideration elsewhere. The manuscript is NOT published already in whole (except in the form of an abstract) in any journal or magazine for private or public circulation. I am fully aware of what plagiarism is. No part of this manuscript has been copied verbatim. I do not have any conflict of interest (financial or other) other than those declared. I have read the final version of the manuscript and am responsible for what is said in it. The work described in the manuscript is my own and my contribution to this work is significant enough to qualify for authorship. No one who has contributed significantly to the work has been denied authorship and those who helped have been duly acknowledged.

CONFLICT OF INTEREST

The author of the manuscript entitled “Wireless monitoring devices for regulation of vehicular events with Internet-of-Things (IoT)” and whose name is indicated immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers’ bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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