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Context-Aware Driver's Behaviour Monitoring System in Vehicular Ad-Hoc Network

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ABSTRACT

The number of deaths resulting from road accidents and mishaps has increased at an alarming rate over the years. Road transportation is the most popularly used means of transportation in developing countries like Nigeria and most of these road accidents are associated with reckless driving habits. Context-aware systems provide intelligent recommendations allowing digital devices to make correct and timely recommendations when required. Furthermore, in a Vehicular Ad-hoc Network (VANET), communication links between vehicles and roadside units are improved thus enabling vehicle and road safety. Hence, a non-intrusive driver behaviour detection system that incorporates context-aware monitoring features in VANET is proposed in this study. By making use of a one-dimensional highway (1D) road with one-way traffic movement and incorporating GSM technology, irregular actions (high speed, alcohol while driving, and pressure) exhibited by drivers are monitored and alerts are sent to other nearby vehicles and roadside units to avoid accidents. The proposed system adopted a real-time VANET prototype with three entities involved in the context-aware driver's behaviour monitoring system namely, the driver, vehicle, and environment. The analytical tests with actual data set indicate that, when detected, the model measures the pace of the vehicle, the level of alcohol in the breath, and the driver's heart rate in-breath per minute (BPM). Therefore, it can be used as an appropriate model for the Context-aware driver's monitoring system in VANET.

Key words: VANET, MANET, Ad-hoc networks, Intelligent transport system, Road transportation.

1. INTRODUCTION

The transportation industry provides the world with a very basic but critical service. While granting every individual the freedom to move himself and his goods at a reasonable price over vast distances, he provides the basis for establishing the fundamental economic principles of modern civilization. Unfortunately, every year, road accidents involving drivers, motorcyclists, and pedestrians cause thousands of fatalities worldwide. As reported by the Annual global road crash statistics, the deaths of over 1.35 million people are as a result of road accidents yearly, while 3,700 individuals die on roads on an average. Also, over 20-50 million people experience non-fatal accidents, sometimes resulting in long-term disabilities while over 50% of all road fatalities arise among disabled road users, that is, runners, riders, and motorcyclists [1]. The issue of sharing information between moving vehicles that ply the road has been faced with lots of challenges. Hence, ensuring road safety and consequently preventing road accidents is very important.

Very often, Road Safety officers with the use of human resources cannot monitor the driver's behaviour efficiently. In many countries, officers are unable to monitor every vehicle that moves on the road and therefore a system which is embedded in each vehicle, that monitors driver's unusual behaviours or habits, alerts the driver and sends such data from vehicles to roadside units, thus creating awareness and reducing road accidents, is required [2]. A Vehicular Ad-hoc Network (VANET) is a subcategory of the Mobile Ad hoc Network (MANET) that incorporates a Dedicated Short-Range Communication (DSRC) technology wired to a 5.9 GHz frequency as well as an Intelligent Transportation Systems (ITS), to improve communication links between vehicles or roadside units within a specified range [3]. Such functionalities decrease road mishaps or incidents while providing more secure driving conditions.

VANET's typical architecture consists of constantly moving vehicles, rapidly communicating and passing information with other vehicles along the road, and transmitting messages to specific fixed roadside units (RSUs). Increased growth in research, standardization, and development of Vehicular Ad-hoc Networks have since occurred, as it has an immense capacity to improve vehicle and road safety, road quality, and usability while ensuring both drivers and passengers alike have comfortable driving experiences. Therefore, recent work has focused much on VANET context-aware processing and communication gateways available [4]. The five means of transportation accessible in our modern world are railway, road, air, water, and pipeline. The improvement of the Nigerian transport system has a significant impact on the economic development of the nation. This is especially valid in the road transport framework which is by a wide margin the most popularly utilized means of transportation, particularly in developing countries.

More recently, with the advent of Intelligent Transport Systems, offering security and safety frameworks with smart driving conditions has been made easier. The intelligent transportation system (ITS) employs the use of sensors, control, and analysis tools and detectors in the improvement of safety and mobility [5]. Since most accidents are caused by personality, driver behaviour, and mental disorders based on logistics regression [6], this research work designed a context-aware system to monitor driver abnormal behaviours which will mitigate the number of road accident occurrences thereby reducing the mortality rate. We provide a cost-effective system that can effectively detect the major causes of a road accident and stop the vehicle from working when any of the rules is violated and support short message delivery in a case to the Road Side Unit (RSU) via GSM technology.

2. LITERATURE REVIEW

Developments in hardware, software, and even networking technology have allowed various network styles to be built and deployed in different ways and locations. VANET is a popular concept used to define the ad hoc network of self-organizing travelling vehicles [7]. In VANET, vehicles are equipped with measurement and portable advanced equipment that can communicate with each other and to devices on the roadside. These communications allow vehicles to share essential driving data such as health information (e.g., unsafe driving circumstances) and avoid mishaps or confusion (e.g., environmental conditions), tourism and traffic information) [8]. The state of the driving environment is reasoned by the accessible location information provided. For instance, in the application for intersection crash avoidance [9], the setting details of vehicles entering the intersection are obtained and analyzed, such as speed, location, and acceleration. When the chance of an impact is identified, the approaching vehicles are sent a warning to prevent the crash.

[10] developed a context-aware driver behaviour tracking system that improves driving by obtaining and evaluating situational driving data patterns, thus increasing driver consciousness while driving his / her car. The main goals were to deduce driver behaviour whilst driving. A context-conscious architecture of five layers and a modelling methodology focused on Dynamic Bayesian Networks (DBN) are provided by integrating contextual rider, vehicle, and environmental knowledge with real-time inferring four styles of driving behaviours (normal, intoxicated, careless, and fatigue). Issues with nodes that did not alter their overtime values and stayed steady.

[11], In this paper authors recommended a context-aware MAC protocol for VANETs with the simple concept of guaranteeing initially only one vehicle node access to the platform, whereas others conceal their contentious purpose. They used the hamming competitive network to determine which node would be accessing the channel according to the background post. Prediction results indicate that the suggested procedure has a relatively small probability of collision combined with rapid transmissions and little delay in accessing a dense situation.

[12]. The authors were motivated by the opportunities context-aware systems offers for software developers and end-users, by collecting context data and modifying device behaviour appropriately, they concentrated on middleware-based and context server-based systems concerning their usability in distributed systems, the authors introduced specific architectural concepts of context-conscious systems and developed a complex philosophical structure to describe the various elements of peculiar to most context-aware frameworks. Security and privacy concerns, including the security of confidential background data.

In [13], the authors concentrated on real-time drowsiness identification technologies rather than on long-term sleep/wake control prediction technology to achieve accurate and tailored driver indicators that could be used in simulators and possible actual environments, utilizing a new approach for ground-truth generation based on a controlled Karolinska Sleepiness Scale (KSS). A comprehensive indicator evaluation was performed during different driving activities, arising from trials of several study subjects on a 3rd generation simulator. The vision program didn't function properly on consumers owing to light haze and reflections.

[14] presented a context-aware driver assistance system motivated by the fact that drivers lack adequate communication with their environment which result in road accidents. The main objective was to develop such a system that creates a connection between the driver and his physical environment or surroundings to ensure safety and reduce car collision rate. The authors suggested a device design composed of various sets of modules to handle the question of the consumer and provide answers and advice as appropriate. The robots communicate with each other through Bluetooth. To demonstrate the viability of the proposed program, the

NXT Robots ecosystem is created and demonstrated. The program has minimal functionality with a limited system for pedestrian detection and parking assistance.

[15] designed a new VANET-based driver behaviour detection system that uses wireless sensors and the context sensitivity to improve road safety. Authors implemented a 3-tier framework for identification of drivers' conduct in real-time using swarm intelligence to rationalize contextual ambiguity and predict the drivers' action by detecting five driving activity types and sending out a warning when the driver is found in an unexpected condition when driving. It was implemented using network simulator-3 but with likely Issues of a bad network in underdeveloped countries.

[16] also presented a drunk driver detection and alert system for smart vehicles. The system design is supported by a breath-based alcohol gas sensing method, which monitors the driver's breath alcohol concentration, the sensor signal activates the alert system and the vehicle control unit when BAC equivalent to BAC crosses the current legal level limit as standardized by the countries. However, the system wasn't able to differentiate among the drunk drivers and others in the vehicle.

3. RESEARCH METHODOLOGY AND DESIGN

As presented by [10], who came up with an evaluation of the output of current rate algorithms versus context-conscious rate selection algorithm (ACARS). Although his goal was to investigate anomalous conductor behaviour, his method of analysis regarded the driver's behaviour as an unpredictable context. His system used onboard unit (OBU) integrated physical and virtual sensors including, alcohol sensors, speed sensors and GPS in each vehicle to capture four types of driving behaviour including, weariness, recklessness, intoxication, and normal behaviour and used Dynamic Bayesian Network (DBN) model with GeNIe version 2.0 software to define the network nodes and their states and to analyze and perform reasonings about uncertainties.

The following are the limitations of his research:

- The implementation is based on vehicular network applications whereby all of the system operations were carried out on a singular main server, that is, a centralized architecture.
- The implementation of the entire research was achieved using software simulators.
- The implementation solely relied on sending vehicle alarms to other moving vehicles via a wireless technology provided by VANET.

In this study, GSM technology is also incorporated for communication between the OBU and RSU. This study takes care of the limitations in the use of wireless technology if unavailable/unstable and ensures that even the roadside units are also informed of the drivers 'actions or current state per time. Furthermore, the prior study made use of software simulators in detecting normal behaviour for normal and abnormal driving. A prototype for the proposed system was developed and evaluated based on the speed and time by which abnormal behaviours such as drunkenness and reckless driving were detected.

Hence, we thereby propose a system to extend part of the achievement of (Al-sultan, et al., 2013) [10], by developing a non-invasive driver behaviour detection system using VANET context-aware monitoring system to detect abnormal behaviours (high speed, alcohol while driving and pressure) and to send alerts to other vehicles on the road to prevent accidents. Here, a one-dimensional highway (1D) road with one-way traffic movement and incorporating GSM technology was used; Irregular actions such as high speed, alcohol levels while driving, and pressure exhibited by drivers are monitored and alerts are sent to other nearby vehicles and roadside units to avoid accidents. The proposed prototype requires no electricity i.e., AC is not needed. A minimum of 3volts and a maximum of 9v battery as DC supply is enough for the Microcontroller board while exactly 5volts of a battery as DC supply is required for the LCD and alcohol sensor and a minimum of 6 volts battery as DC supply is required for the motors to be operational. Hence, the energy consumption is minimal.

3.1 System Architecture

As shown in Figure 1, the architectural diagram comprises of three (3) main parts: Input, Microcontroller, and the Output. Of which the Input part consists of an alcohol module, pressure (heartbeat) module, and speed detection module, while the microcontroller part receives an input signal from all the input modules and process them to be released as the output signal. And lastly, the Output module consists of a Liquid Crystal Display (LCD), Motors to drive the car wheels, Light Emitting Diode (LED), and the GSM module which release information from output signal in a form that can be understood by the driver and useful in the VANET system.
In this research, we adopted Arduino IDE for coding the embedded system prototype using C programming language and MATLAB R2019b software for the implementation and development of the Fuzzy Logic Model for Context-Aware Driver's Behaviour Monitoring System.

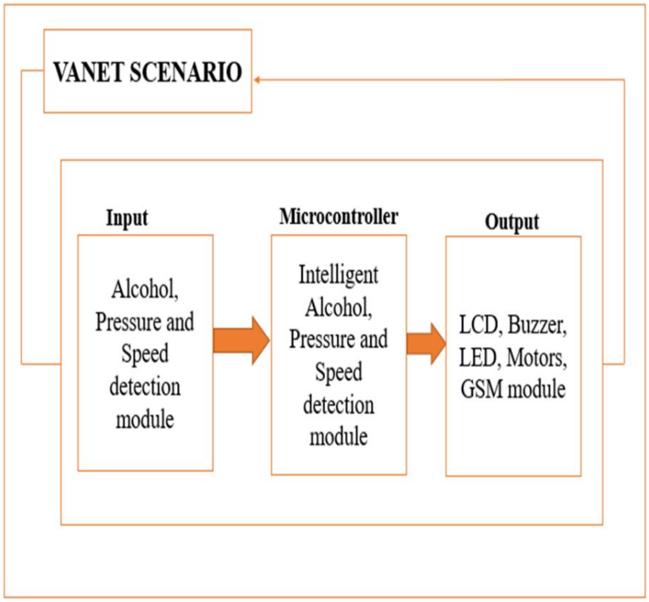

Figure 1: Architectural Diagram of Context-Aware Driver's Behaviour Monitoring System in VANET

3.2 System Implementation and Flowchart

In Figure 2, the system was designed to sense the conditions of the driver's health and sends a notification to roadside units immediately if an abnormal situation is sensed to avoid accidents. In this system, a heartbeat sensor, an alcohol sensor, and a speed sensor were interfaced to an Arduino. A Liquid Crystal Display (LCD) displays the information about the abnormal actions if it is triggered by any sensor and such information is sent to the road side units.

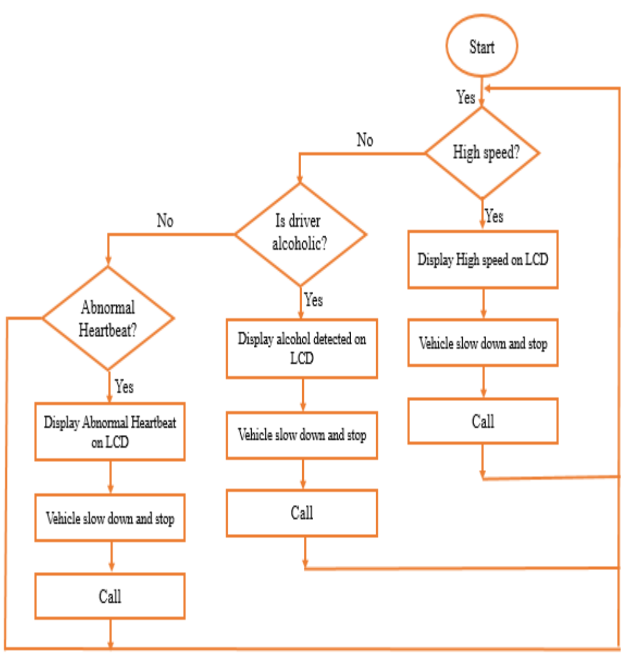

Figure 2: Flow chart of Context-Aware Driver's Behaviour Monitoring System in VANET

As shown in Figure 3, the fuzzy logic block diagram of Context-Aware Driver's Behavior Monitoring system is separated into four major categories:

i. Rule Base: This includes the collection of guidelines and the IF-THEN criteria given by the experts to control the decision-making system, based on the evidence available. Recent advances in fuzzy theory give numerous powerful methods for the construction and tuning of fuzzy rules. Some of these changes cause a decrease in the number of fuzzy rules.

ii. Fuzzification: Transforming inputs, i.e. smooth numbers, into blurry membership values is employed. Crisp inputs are essentially the same inputs determined by sensors and transmitted to the control device utilizing the conditional IF-THEN argument for processing inside the rule-base. Converting data from a pulse sensor, velocity sensor, an alcohol sensor was used in this study.

iii. Inference Engine: This calculates the relevant degree of the existing ambiguous feedback according to each rule and specifies which laws are to be shot according to the area of data. Firstly, the control actions are created from laws.

Rule Number = (Fuzzy Set Number) ^ (Input Parameter Number)

iv. Defuzzification: Used to transform the inferential fuzzy sets engine into a crisp (non-fuzzy) value. Many ways of defuzzification are possible and the most effective version is used for a particular professional program to of the mistake.

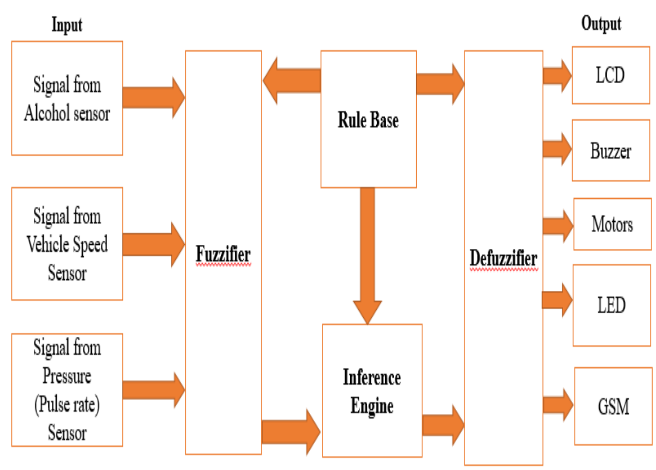

Figure 3: Fuzzy Logic Block Diagram of Context-Aware Driver's Behavior Monitoring System

3.3 Research Mathematical Model

The driver has a relatively large number of significant mental states, even though there is a likelihood of moving from one state to another. Three entities are involved in the context-aware driver's behaviour monitoring system in VANET: Driver, Vehicle, and environment. Driver's behaviour is considered normal (safe) if his or her actions associated with the current state do not lead to an accident; otherwise, it is considered anomalous (unsafe).

$$B_d - \{S_d, S_r, S_o \dots S_n\} \quad (1)$$

For 1 $\leq i \leq n$

Where B_d is the behaviour of the driver in a particular state

Four categories of the states of the driver

S_n = State of the driver at a particular time

S_d = Drunk driving state of the driver at a particular time

S_r = Heartbeat state of the driver at a particular time

S_o = Over speed state of the driver at a particular time

The driver's action is known as the present measurable condition and can be described by collecting a measurable background.

Where S_t is the state at the time (t)

C_i is the context that needs to be captured to characterize the state

$$S_i = \langle c_{i1}, c_{i2}, c_{i3}, \dots \rangle \quad (2)$$

Where $c_{ij} \in B_d$ is the context of the behaviour $\{D_n, D_a\}$ which captures the driver's status at time t

Where D_n = Normal behaviour of the driver, D_a = Abnormal behaviour of the driver

$$S = x_1A_1 + x_2A_2 + x_3A_3 + \dots + x_iA_i \quad (3)$$

Where x_1 = alcohol sensor, x_2 − speed sensor, x_3 = Heartbeat sensor

A_1 = Input signal membership function of alcohol sensor

A_2 = Input signal membership function of speed sensor

A_3 = Input signal membership function of a heartbeat sensor

A_i = the membership function signals from input components (sensors)

$$y = v + \sum_{i=1}^{m} S \quad (4)$$

Where x_i $(i = 1, 2, 3, \dots, n)$ is the input variables i.e. signals from the alcohol, speed, and heartbeat sensors

y is the output variable obtained by the fuzzy rule.

A_i = the membership function signals from input components (sensors)

v is a constant value.

The final output of the fuzzy model is inferred by a weighted average defuzzification

$$z = \frac{\sum_{i=1}^{n} w_1 y_1}{\sum_{i=1}^{n} w_1}$$

(5)

Where weight (w) is the cumulative value of the facts.

z is the final output value of the true detections from the sensors

Probability of detection (p_d) is the probability that the sensor accurately perceives the presence of either alcohol, over speeding, or fatigue.

Probability of false alarm (p_f) - Probability that the system falsely detects or perceives the presence of any of the presence of either alcohol, over speeding, or fatigue.

$$(p_f) = 1 - (p_d) \quad (6)$$

The expected result is to simulate a hardware prototype embedded in a vehicle to monitor driver behaviour while driving.

4. IMPLEMENTATION AND RESULTS

As shown in Figure 4, the On-Board Unit (OBU) hardware consists of Microcontroller board, three input sensors; Alcohol sensor, Speed sensor, Heartbeat / Pressure sensor, four output components which are GSM module, Liquid Crystal Display (LCD) screen, motors and Light Emitting Diode (LED). The entire system is powered by connecting 3 - 12volts Direct Current (DC) power supply to the microcontroller board, while both inputs and output components tap their powerful energies to function directly from the microcontroller board. The microcontroller board consists of the ATMega328p microcontroller chip which is the heart of the entire system.

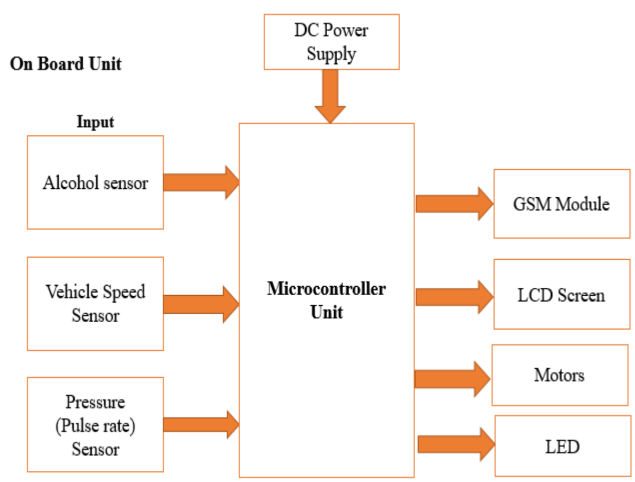

Figure 4: Hardware Prototype Block Diagram

4.1 Implementation

A prototype of the proposed context-aware driver's behaviour monitoring in VANET was designed and tested. It takes a maximum of one second for all the sensors used to detect the abnormal behaviour of the driver while driving and sends the signal to the microcontroller for the appropriate action to be taken. During testing, the context-aware driver's behaviour monitoring system was connected to the computer using COM port 21, which varies on other systems due to the port availability. Figure 5 shows screenshots of the experimental setup while Figure 6 shows the LCD of a high-speed detection by the speed sensor.

The device was programmed to detect alcohol from the driver's band display on the LCD. Normal heartbeat occurred at 80 - 120 Beat Per Minute (BPM). While heartbeat above the mentioned range happened as a result of pressure and it was captured from the serial monitor of the Arduino IDE. As shown in figure 7, the value 233 is way too high beyond a normal heartbeat rate, such value is read by the heartbeat sensor whenever the driver is under pressure.

Figure 5: Hardware Prototype Experimental Setup

Figure 6: Liquid Crystal Display (LCD) of High-Speed Detection

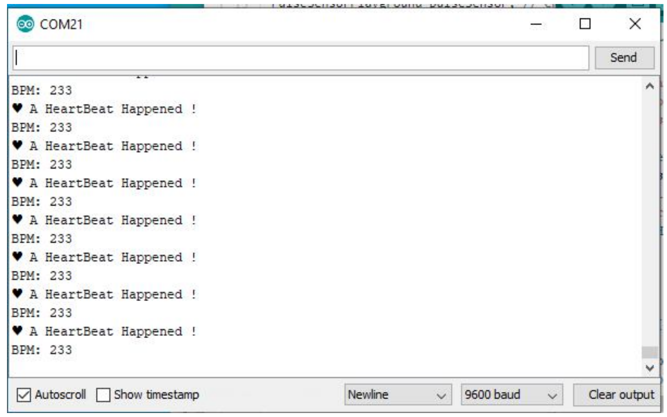

Figure 7: Detection of Heartbeat

4.2 Simulation

Figure 8 shows a screenshot of the context-aware driver's behaviour monitoring system before the simulation using Fuzzy Logic Designer in MATLAB. Fuzzy rules editor was used in constructing the crisp logic for our model. There are a total of twelve rules consisting of premises and consequents. This was achieved by representing the linguistic variables using fuzzy sets. Picking randomly, from the 1st rule we have the following:

IF (Heartbeat is Low) or (Alcohol is Low) or (Speed is Low) then (DetectedDriverBehaviour is Low) (0)

From the 9th rule we have the following:

IF (Heartbeat is High) or (Alcohol is High) or (Speed is High) then (DetectedDriverBehaviour is (High) (1)

The input and output variables range are defined as follows:

- Normal Driver Pulse: (low, medium, high) between (0, 80, 120 BPM)
- Abnormal Driver Pulse: (low, medium, high) between (0, 121, 350 BPM)
- Level of Alcohol: (low, medium, high) between (0, 1023)
- Vehicle Speed: (10 m/mSec to 255m/mSec)

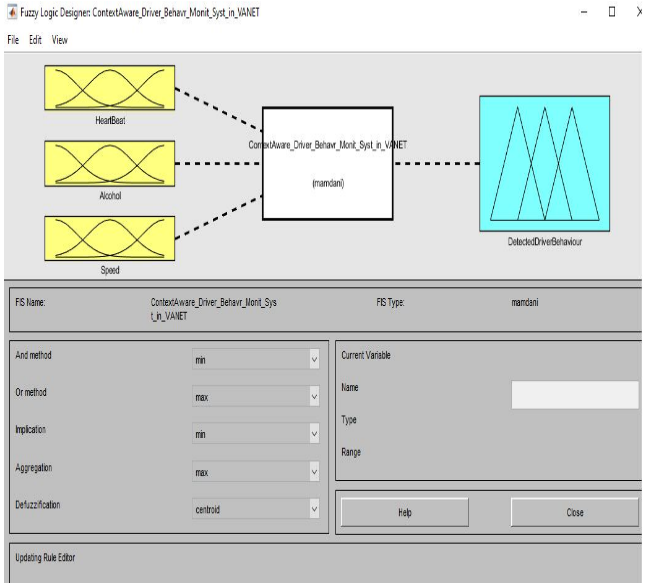

Figure 8: Fuzzy Logic Design of Context-Aware Driver's Behaviour Monitoring System

The input and output variables range are defined as follows:

- Normal Driver Pulse: (low, medium, high) between (0, 80, 120 BPM)
- Abnormal Driver Pulse: (low, medium, high) between (0, 121, 350 BPM)
- Level of Alcohol: (low, medium, high) between (0, 1023)
- Vehicle Speed: (10 m/mSec to 255m/mSec)

As shown in Figure 9, the membership functions indicate the ranges of the abnormal pulse rate of a driver. Considering the medium and High membership functions which indicate the range of abnormal pulse rate between 120 – 350 BPM and 250-350 BPM respectively. The speed was calibrated from 0 – 250, the speed is between 0 – 50 m/mSec, we considered it to be low speed, 25 – 220 m/mSec was considered to be medium speed while 150 – 250 m/s was considered to be high speed.

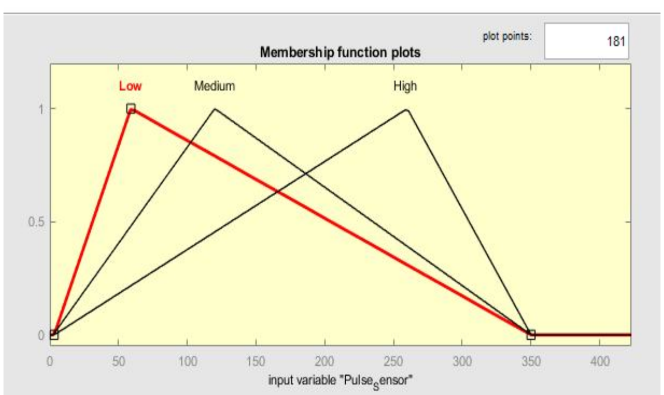

Figure 9: Membership Function of the Input variable (pulse) for abnormal behaviour

4.3 Performance Evaluation

Figure 10 shows the representation of the signal received against time (mSec) from the pulse rate sensor when the rate of the heartbeat was high. In Figure 11, we have the representation of the signal received against time (mSec) when alcohol was detected in the breath of a driver.

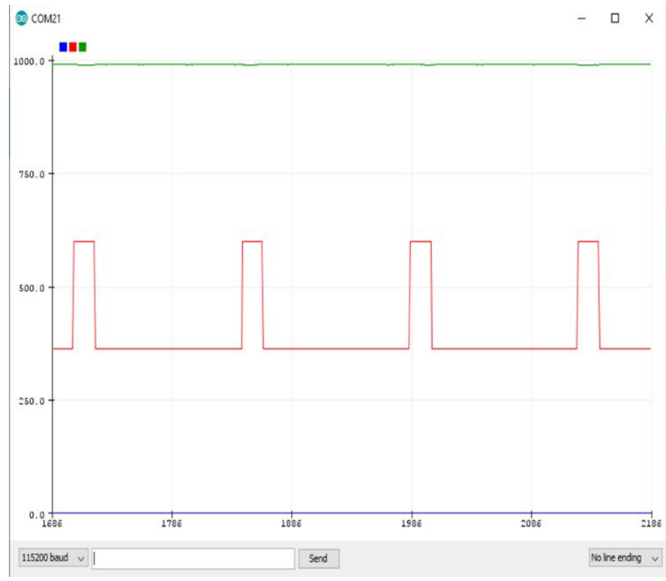

Figure 10: Performance of Abnormal Heartbeat rate of Driver (BPM) against time (mSec)

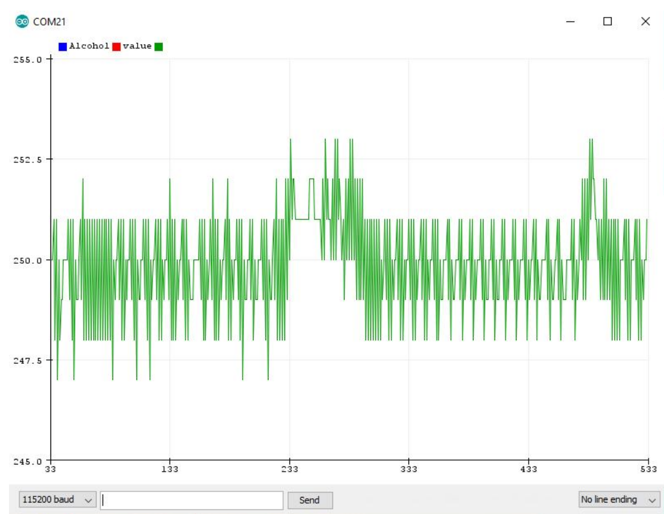

Figure 11: Performance of Alcolmeter against time (mSec) for alcohol detection in Driver's breath

Given the system's operation, we carried out the evaluation using the following metrics:

- Efficiency: The system offers effectiveness in the accident mitigation and avoidance and detection of high pulse rate, alcohol in the breath of a driver, and over-speeding.
- Response: System response time gives assurance of reliability, most especially during the detection of alcohol, high pulse rate, and over-speeding.

• Road safety: The program supports road safety, protection, and its activities by being able to minimize collisions and save lives on the highways by early detection.
• Automation: The device is capable of remotely tracking and identifying driving and over-speed without human interference. That, in effect, protects traffic officers from the health hazards of operating in extreme weather conditions as well as the safety threats from being in contact with an airborne disease such as Corona Virus and so on.

5. CONCLUSION

In this research work, a context-aware driver behaviour monitoring system was designed, constructed, and tested. We developed a cost-effective system that can effectively detect the major causes of road accidents and stop the vehicle from working when any of the rules is violated and support short message delivery in a case to the Road Side Unit (RSU) via GSM technology. A fuzzy model was used to monitor driver's behaviours such as drunkenness, over speeding, and abnormal. The key objective was to create fuzzy relationship models articulated via a series of fuzzy linguistic propositions extracted from expert experience.

The proposed model was tested on experimental data from a set of hardware prototypes. The analytical tests with actual data set indicate that, when detected, the model measures the pace of the vehicle, the level of alcohol in the breath, and the driver's heart rate in-breath per minute (BPM). Therefore, it can be used as an appropriate model for the Context-aware driver's monitoring system in VANET. In future research, more works may include designing a neuro-fuzzy system to detect and compute the level of alcohol in the system of a driver.

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