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EARLY DEVELOPMENT OF EMBEDDED FATIGUE MONITORING SYSTEM BASED ON HEART RATE

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ABSTRACT

The seriousness of road traffic injuries had been aware by public since the past decades. Nevertheless, it is very difficult to avoid driver fatigue or drowsy driving while fatigue is suspected to be the primary cause in more than 20% of road fatalities. In this article, an embedded based detection system is proposed to alert the driver when drowsiness or driver fatigue is detected. The conducted statistical analyses in this study show that the normal heart rate of a person is significant difference when he/she falls in fatigue. Thus, the framework of the proposed system uses heart rate as the classification feature for the fatigue detection. In overall, the proposed system consists of an Arduino UNO microcontroller integrated with a pulse sensor, GPS module, and GSM module. The measured heart rate from the pulse sensor is further processed with programmed Artificial Neural Network (ANN) algorithm and a warning SMS is sent with current GPS location when fatigue was detected. From several conducted testing and evaluations, the functionality of the developed system is verified and the mean accuracy achieved for the recognition of fatigue is 94%. In summary, the study reveals that besides of vision solutions, classification based on biometric signal can be an alternative approach for fatigue detection and the proposed framework has a potential to reduce the occurrence of road crashes due to drowsy driving.

Keywords: artificial neural network, fatigue monitoring system, embedded system.

INTRODUCTION

Similar with the drink driving behaviour, fatigue has a huge negative impact on the driving performance. In fact, driver fatigue or drowsy driving will cause a driver to have slower reaction times and thus it is difficult to avoid road crashes occurred accidentally. Moreover, the lack of concentration while driving results in errors in calculating speed and distance due to poor judgement [1]. These kinds of behaviour are very critical while driving and the situation become worse where the law against fatigue are proving to be difficult for authorities to enforce.

Attention has recently been drawn to tackle and solve the aforementioned problem. With recent advances in advanced driver assistance system (ADAS), several techniques and approaches had been reported to detect and monitor the driver fatigue. Among the reported works, vision solution has always been proposed to deal with the issues. The concepts of Percent Eye Closure (PERCLOS) had been discussed in several published studies [2]. In this technique, the percentage of total time where the detected eyelid is closed more than 80% is calculated and the result is used to determine whether the driver falls in fatigue or not. Besides of PERCLOS that is capable to relate the eye blinking rates with the fatigue, there are some other work studies on yawning detection [3]. Typically, the detection is based on the analysis on the changing pattern of mouth feature using image processing techniques and intelligence algorithms.

Although the reported achievements sound could be a prominent solution for detecting driver drowsiness, there are also some encountered problem and drawbacks. For example, long time of eye exposures under the image acquisition hardware which normally consists of near infra -red (IR) illuminator and camera is likely to damage the eye internal tissues. In addition, the algorithms built have difficulty to adapt the variance in different shapes and size of eyes and mouths. In fact, it is not easy to implement a real-time vision solution on hardware platform since it involves lot of intensive computations and consumes more hardware resources.

In this article, the development of an embedded fatigue monitoring system based on biometric feature is presented. The highlights of the article are listed as follows:

(1) The conducted investigations and statistical analyses verify the decrement of heart rate when a person falls in fatigue.
(2) The design and the architecture of the entire fatigue monitoring system based on Arduino microcontroller are presented in details.

In the subsequent sections, the data collections for statistical analyses and the developed prototype system are described in details. The results of t-test analyses and the functionality test of the complete system are presented accordingly.

SYSTEM ARCHITECTURE

The prototype system developed for the detection of fatigue behaviour in this study is based on the concept of Artificial Neural Network (ANN) classification system. The system is capable of producing a digital fingerprint from the sensors and classifying the produced pattern into different groups.

In this study, the entire architecture of the system is decomposed into four main components: pulse sensor, GPS sensor, GSM module and microcontroller. The heart rate obtained from the pulse sensor is further investigated using statistical analyses and ANN. The built ANN model on microcontroller will perform the classification task to determine whether the presented sensor data is the normal

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heart rate or heart rate in fatigue condition. If fatigue is reported, a warning SMS will be sent to the related parties through GSM module. The contents of the SMS include the fatigue message and the current location detected by the integrated GPS sensor. The overall design of the proposed system is illustrated in Figure-1.

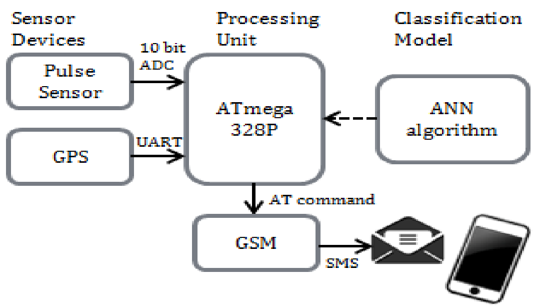

Figure-1. Block diagram of the system architecture.

All the hardware components mentioned above are interfaced with a microcontroller. In the present study, 8-bit microcontroller named ATmega 328P acts as the processing unit and the brain of entire system. The device receives all the data from the input devices, process and analyze the data before transmit the results to the output devices. For the developed prototype, the operations handled by the microcontroller include:

(1) Data acquisition from the pulse sensor.
(2) Recognition tasks through implementation of ANN.
(3) Display the ANN results and activate SMS service if fatigue detected.

PULSE SENSOR

In the proposed system, pulse sensor was used to detect the heart rate of a subject based on the examination of photoplethysmograh (PPG) waveform. The sensor is able to monitor the changes of blood volumes via the integrated light detector that gives responds relative to the changes of light intensity. High blood volume results in less reflected light and vice versa. In fact, the changes of blood volume are synchronous to the pumping action of heart [4]. Thus the interval time between the two detected peak values of blood volumes by the sensor can be used to represents the heart rate.

The pulse sensor integrated in the proposed system operates at 5V DC. Since the output is in analog form, the output pin of the sensor in connected to pin A0 of the ATmega 328P that capable to perform analog-to-digital (ADC) conversion. In order to verify the accuracy of the detected heart rate, the output readings of the pulse sensor is compared to a commercial medical device called Medisana MTC. The device is capable to detect the pulse ranges from 30-180 beats/min with a maximum tolerance of +/-5%. From several investigations, the deviation of the detected heart rate is less than 4 beats/min or +/-3%. Thus, the sensor is considered suitable to be implemented in this study.

GPS MODULE

In the proposed system, a GPS module is integrated to get the exact location of the driver when he or she falls into fatigue. This information is included in the warning SMS that will be sent out when fatigue detected. The GPS module called Skylab GPS Module MT3329 SKM53 is selected in this study. The device can provide the latitude and longitude of a specific location with the accuracy of +/-10m. The modules communicate with the processing unit via Universal Asynchronous Receiver Transmitter (UART) serial protocol. The transmitted data from the GPS module is in the form of NMEA, thus a library called TinyGPS.h is included in the software development of ATmega controller. The library is capable to extract all the information from NMEA, such as position, altitude, speed, date, and time. In this study, the information of location is extracted and represented in the format of latitude and longitude.

GSM MODULE

In the present study, a GSM module called GPRS Shield from Seed Studio is implemented in the prototype system. The main function of the shield is to activate SMS service and send a warning text to driver's close friends or family members, so that the recipients can call and alert the driver when he/she fall in fatigue. The shield requires an active SIM card to activate the SMS service. The device operates at 5V DC and the controller is able to control the operation of GSM module via AT command. The UART protocol is set at 9600 baud rate for the communications between the controller and the GSM module. In general, there are two important AT commands need to be issued by controller prior content of message. First, the controller need to write "AT+CMGF=1" to set the GSM in text mode, and the next transmitted word to GSM module is "AT+CMGS=phone number" to define the number of message recipients. After these two commands, the controller can write the content of message sent through GSM. In this case of study, the message starts with the number of car plate and warning text followed by the current location of the driver. The example of the message sent is look likes below:

AEEE 7642 DRIVER FATIGUE DETECTED
Latitude: 5.1519770
Longitude: 100.4950180

SYSTEM INTEGRATION

In the present study, almost the entire processing operations are controlled by the software programmed on ATmega controller. The use of C language is emphasized for the programming of ATmega and the source code is written and compiled in Arduino IDE.

Besides of the interfacing between the controller and the integrated devices mentioned above, the hardware implementation of ANN algorithm as the classifier to detect the fatigue behaviour is also emphasized in the design. In general, ANN has shown good performance in solving some problems related with the object recognition

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[5]. Typically, the development of ANN model consists of 3 stages, which start with data assembly and follow by model training and testing.

Out of the thousand sets of collected heart rate data in this study, 70% of the data is used for ANN training, while the remaining 30% served for the testing. The ANN model is constructed and trained in Matlab. Based on the back propagation theory, the ANN model is trained with numerous data to modify the values of weight and bias until the minimum feedback error between the predicted and obtained results is achieved [5].

Among the different architecture of ANN model, a fully connected 2-3-1 feed forward ANN is adopted and implemented in this study. The adopted model is selected based on the factorial design analyses on different ANN parameters, e.g. the number of hidden neuron, activation function and learning algorithm in this case.

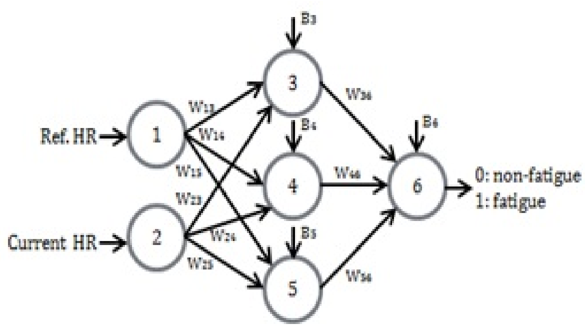

Figure-2. Architecture of 3-2-1 ANN model.

From the conducted factorial design analyses, the optimum training success rate achieved when Levenberg-Marquardt is selected as the training algorithm together with sigmoid activation function, regardless of the amount of hidden neurons (either 3 or 5).

The final ANN model implemented on the ATmega is illustrated in Figure-2. The input layer of the ANN consists of 2 neurons, which represent the reference heart rate and the current heart rate. In real application, the reference heart rate is taken at the first 2 minutes before the driver started to drive, and the current hear rate is measured and compared with the reference heart rate from time to time. The reason to include the reference heart rate is to eliminate the effect of variations of different heart rate possessed by different people. The output neuron represents detection results, either fatigue if value of 1 obtained or non-fatigue if the output is equal to 0. The computation steps of ANN are shown in Figure-3, and the procedure of the entire software embedded on the ATmega for fatigue detection application is described in Figure-4.

ANN Implementation Module
Input: Ref. HR; Current HR; W_{13}, W_{14}, W_{15}, W_{23}, W_{24}, W_{25}, W_{36}, W_{46}, W_{56}; B_3, B_4, B_5

1. Input to neuron 3, $I_3 = I_1*W_{13} + I_2*W_{23} + B_3$;
2. Output of neuron 3, $O_3 = f(I_3)$;
3. Input to neuron 4, $I_4 = I_1*W_{14} + I_2*W_{24} + B_4$;
4. Output of neuron 3, $O_4 = f(I_4)$;
5. Input to neuron 5, $I_5 = I_1*W_{15} + I_2*W_{25} + B_5$;
6. Output of neuron 3, $O_5 = f(I_5)$;
7. Input to neuron 6, $I_6 = O_3*W_{36} + O_4*W_{46} + O_5*W_{56} + B_6$;
8. Output of neuron 3, $O_6 = f(I_6)$;
9. **if** ($O_6 > 0.5$) **do**
10. Result = 1; //Indicate fatigue detected
11. **else do**
12. Result = 0; //Non-fatigue detected
Notes: f (I) is the sigmoid function that transform any input values to a numerical value ranging from 0 to 1.

Output: Fatigue Detection Results (0 or 1)

Figure-3. Hardware implementation of ANN module.

System Integration Module
Input: Reset button
1. **while** (true) **do** 2.   **if** (! rst) **do** 3.   Collect data from the pulse sensor; 4.   Perform ADC and display HR. on LCD; 5.   Execute ANN computation; 6.   **if** (Result = 1) **do** 7.   Display fatigue word on LCD; 8.   Obtain location data from GPS; 9.   Activate GSM module to send warning SMS; 10.   **else do** 11.   Display normal word on LCD;
Output: Display on LCD; SMS sent if result = 1

Figure-4. Flow of system integration module.

EXPERIMENTAL SETUPS

In this section, the entire procedures of the experiments and works that had been carried out throughout the study are detailed as follows:

(1) 10 male subjects who aged between 20 and 25 are involved in the data collection experiments.

(2) For each subject, the reference heart rate and fatigue heart rate was collected.

(3) The reference heart rate was measured in daytime, while the fatigue data was collected when the subject feel sleepy.

(4) The combination of 2 measured reference heart rate form a non-fatigue dataset, while the combination of 1 reference heart rate with 1 fatigue heart rate from the same subject form one set of fatigue data.

(5) The collection of data was repeated at different date and time until 500 set of fatigue data and 500 set of non-fatigue data were collected.

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(6) 100 sets of data were randomly selected from each group (fatigue and non-fatigue) to conduct the t-test analysis using Minitab software.
(7) 70% data from each group were randomly selected for ANN training purpose. The remaining 30% or 300 sets of data served for the performance test.

EXPERIMENTAL RESULTS

Prior to the evaluation of the classification performance of the developed system, the changes of heart rate when a subject falls in fatigue was investigated using a statistical procedure called t-test. Total of 200 data which include fatigue heart rate and non-fatigue (or known as reference heart rate) were randomly selected from the collected data to conduct the t-test. The scatter plot, which shows the relationship between the two groups of data, is illustrated in Figure-5.

In order to determine the indication of significant difference between the fatigue and non-fatigue heart rate, the 95% confidence interval was used in the conducted t-test to investigate the magnitude of the difference. The following hypotheses were set up for the t-test:

- Null Hypothesis, H_o:μ_d = 0; where μ_d = the mean difference between the value of fatigue heart rate and non-fatigue heart rate.
- Alternate Hypothesis, H_a:$\mu_d \neq 0$.

The null hypothesis states that there is no statistically significant difference between the two groups of data stated above whereas the alternate hypothesis states that the difference between fatigue and non-fatigue data is statistically significant. The null hypothesis would be rejected if the resulted P-value is less than the chosen α value (0.05).

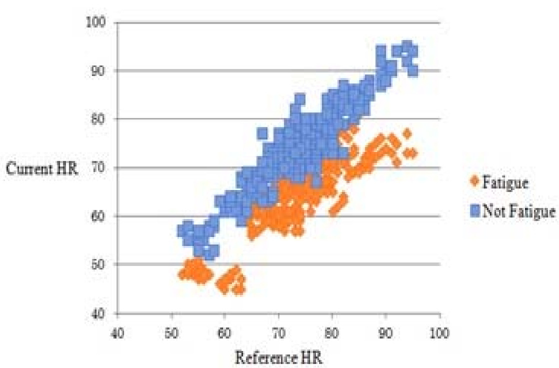


Figure-5. Scatter plot of the dataset.

Table-1. T-test results from Minitab.

	No. of sample	Mean	StDev
Non-fatigue HR	100	74.056	7.438
Fatigue HR	100	64.571	7.598
Difference	100	9.485	3.910

95% CI for mean difference: (8.709, 10.621)
T-Value = 24.26; P-Value = 0.000

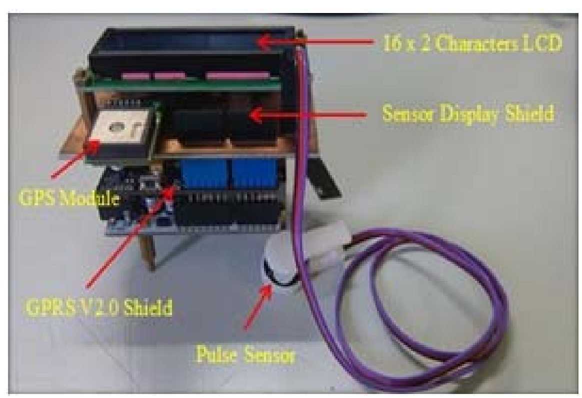
In general, the calculated P-value from the t-test indicates the strength of evidence provided by the sample data to reject the null hypothesis [6]. The smaller number of the P-value represents the greater strength of evidence. Table-1 show that the P-value from the conducted t-test is close to 0.000. Thus, the null hypothesis in this case was rejected and there is sufficient statistical evidence to conclude that the fatigue heart rate is not equal to the non-fatigue heart rate. In addition, the 95% confidence interval for non-fatigue heart rate was between 8.709 and 10.261 (as shown in Table-1). This means that the mean value of non-fatigue heart rate is between 8.709 and 10.621 higher than the mean value of fatigue heart rate. Therefore, the feature of heart rate can be used in the classification model to predict or identify the fatigue behavior.

The performance of ANN is typically measured by computing the percentage of accuracy in predicting the recognized pattern of all inputs presented to the model. For the ANN training, the simulated result in MATLAB show that the adopted model (2-3-1 architecture) achieves the training target with 94.7% of success rate.

For the evaluation of the real-time results of the implemented ANN system on the hardware (Table-2), total 300 sets of data, different with the training data were presented to the system. The obtained results are summarized in Table-2. Out of the 150 fatigue data, only 6 testing results failed to meet the target, giving a success rate of 96%. On the others hand, there are 11 failed cases for the non-fatigue prediction. In overall, the developed system achieves a success rate above 90%. Some captured images of the developed prototype system are illustrated in Figure-5.

Table-2. Results of ANN testing for fatigue detection.

Subject	Predicted as		Success Rate (%)
	Fatigue	Non-fatigue	
Fatigue	144	6	96.0
Non-fatigue	11	139	92.7



(a)

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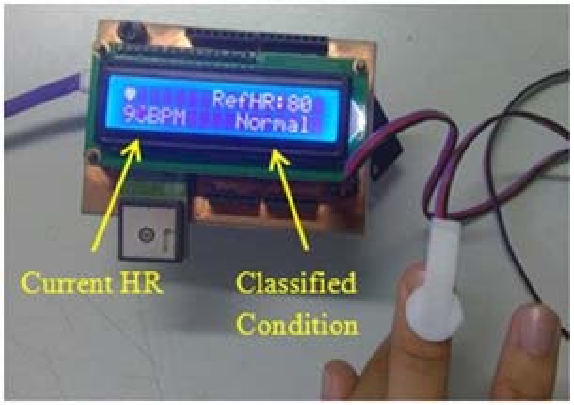

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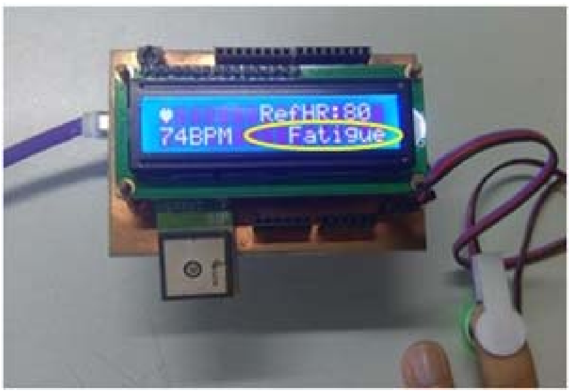
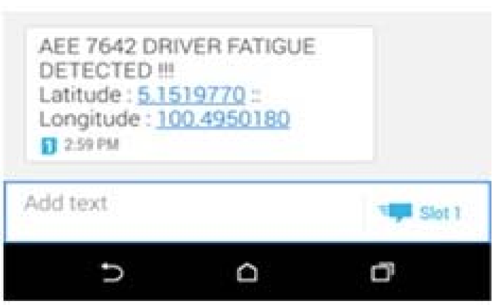


(c)



(d)

Figure-6. (a) System prototype. (b) Display of result when non-fatigue detected. (c) Display of result when fatigue detected. (d) Warning SMS.

CONCLUSIONS

The current paper presents a microcontroller-based system that is capable to detect the fatigue behavior and alerts the driver when he/she falls in fatigue or drowsy driving. The obtained results support the proposal that an electronic sensing system combined with ANN algorithm can be an alternative to the current vision system for the application of fatigue prediction. However, the presented study merely represents the preliminary investigations and first step toward creating and developing a practical device that is convenient to use while driving. The collected samples in this study are not enough to represent the entire community, more data from different age and gender should be investigated further to improve the system.

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