CHAPTER 4

ROBUST AND EFFICIENT WIRELESS MEDICAL SENSOR NETWORKS-BASED DRIVER HEALTH MONITORING SYSTEM USING FUZZY LOGIC CONTROLLER

Health care applications are considered as promising fields for wireless sensor networks, where the system monitors patients using wireless medical sensor networks (WMSNs). The current WMSN health care research trends focus on reliable patient communication, patient mobility, and energy efficient routing, as a few examples. However, deploying new technologies in health care applications without considering security makes patient privacy vulnerable. Safety is a paramount requirement of health care applications, especially in the case of patient privacy if the patient has an embarrassing disease. This chapter presents a discussion on these critical issues since the success of health care application depends directly on patient security and privacy, for ethical as well as legal reasons.

Health is one of the global challenges for humanity. According to the constitution of World Health Organization (WHO), the highest attainable standard of health is a fundamental right for an individual.

A wireless sensor is the smallest unit of a network that has unique features, like, it supports large scale deployment, mobility, reliability, etc. Gjermundrod et al. (2007). WSNs are not limited to science and engineering, but they are included in other general applications such as the military, water monitoring, infrastructure monitoring, government security policy, habitat monitoring, environment monitoring and earthquake monitoring. The recent work in the fuzzy logic-based approach shows rapid growth such as the work towards the classification of driver’s drowsiness, an underwater vehicle, and aircraft engine monitoring, inpatient monitoring using fuzzy
logic, wireless mobile, and internet technologies.

Hence, the expert systems have the potential to improve clinician performance by accurately executing repetitive tasks to which humans are ill-suited such as physiological parameter analysis and surveillance. Additionally, expert systems can be used to standardize clinical guidelines and provide memory aids for the clinician. Expert systems have been developed to assist clinicians with their modernized health care system to provide better health services to people at any time and from anywhere in an economic and patient-friendly manner. Currently, the healthcare system is undergoing a cultural shift from a traditional approach to a modernized patient-centered approach. In the traditional approach, the health care professionals play the major role. They need to visit the patients for essential diagnosis and advising. There are two simple problems associated with this approach. Firstly, the health care professionals must be on the site of the patient all the time, and secondly, the patient remains admitted in a hospital, wired to bedside biomedical instruments for a period. To solve these two problems, the researcher has conceived patient-oriented approaches. In this method, the patients are equipped with knowledge and information to play a more active role in disease diagnosis and prevention. The key element of this second method is a reliable and readily available patient monitoring system (PMS).

The need for a real-time recording and notification of vital signs of a patient is of prime importance for an effective PMS. By encapsulating the advantages of modern bio-instrumentation, computers, and telecommunication technologies, a new PMS should acquire, record, display, and transmit the physiological data from the patient’s body to a remote location at any time. For more efficient, timely, and emergency medical care, the PMS must also be incorporated into an alarm system. To alert the patient as well as the health care service providers, the PMS should not only monitor and analyse the critical patient’s data, but it should also send alarming
messages in case the monitored data go outside their normal ranges. Hence an active database system must be in association with the PMS. Most of the proposed PMSs are centralized in a sense to store all patients’ data on a single server. By using necessary firmware and software, the server can be connected to an open communication network via Transmission Control Protocol/Internet Protocol (TCP/IP) protocol. Thus, a patient can be monitored from a remote location. Existing and extensive mobile phone networks can assist in this regard.

Recently, mobile networks are considered critical for solving future global health challenges. With the global market penetration of the mobile phones, the mobile health care system is a matured idea now. By using the mobile, the health system can be made available for people, who are living in remote areas without much access to other types of communications. Even a simple mobile phone can become a powerful health care tool now. Text messages and phone calls can quickly deliver real-time and critical information of a patient to a remote location. Thus, the patients, living in remote areas, can reduce unnecessary back-and-forth travel to the far located healthcare centers. However, mobile devices have become “smart” now to do more rather than solely transmit medical information and advice.

4.1 Fuzzy Logic-based Driver Monitoring System

The proposed system is a fuzzy-based driver monitoring system. Here, the mobile network comprises a three-axis accelerometer to acquire the signals, to analyze and to derive the dangerous driving behaviors of vehicles. The three-axis accelerometers are installed on the vehicle body to capture the variation of acceleration of the moving vehicle. The fuzzy system identifies vehicle body posture through a proposed fuzzy inference system. The driving behavior analysis process is developed to determine vehicle status and detect whether the driving pattern of the vehicle is the cause for the dangerous
driving behavior. Once the system realizes the critical state driving behavior of the vehicles, it starts broadcasting the alert message to all vehicles in the range. As the system has already in connection with a mobile network with each other, it can be used to share different vehicle statistics with other cars in the range. In this research work, various features are extracted such as face detection, eye detection, ECG-based heart rate variability analysis, signal conditioning and ECG noise filtering. These feature extraction works are details described in Chapter 3, and in this work some additional features are also added to enhance the accuracy of the results, the additional features are described in section 4.1.1 to 4.1.5.

4.1.1. ECG Electrodes

An ECG electrode is a device attached to the skin on certain parts of a patient’s body such as arms, legs, and chest, during an electrocardiogram procedure. It detects electrical impulses produced each time the heart beats. The number and placement of electrodes on the body can vary, but the function remains the same. The electricity that an electrode detects is transmitted via this wire to a machine, which translates the energy into wavy lines recorded on a piece of paper. The ECG records, in detail, are used to diagnose a very broad range of heart conditions. An ECG electrode is usually composed of a small metal plate surrounded by an adhesive pad, which is coated with a conducting gel that transmits the electrical signal.

4.1.2. The LM35 Temperature Sensor

The LM35 series is precision integrated - circuit LM35 temperature sensors, whose output voltage is linearly proportional to the temperature in Celsius (Centigrade). The LM35 sensor thus has an advantage over linear temperature sensors, calibrated in °Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient
centigrade scaling.

4.1.3. Blood Pressure Sensor

Blood pressure sensor is a device that measures the pressure of the blood in the arteries as it is pumped around the body by the heart. When the heart beats, it contracts and pushes blood through the arteries to the rest of the body. This force creates pressure on the arteries. Blood pressure is recorded as two numbers the systolic pressure (as the heart beats) over the diastolic pressure (as the heart relaxes between beats). Some distinct features of blood pressure sensor include (i) automatic measurement of systolic, diastolic and pulse (ii) large LCD screen with LED backlight and (iii) touchpad key. Also, a typical blood pressure sensor can store 80 measurements data with time and date.

4.1.4. Blood Glucose Sensor

Blood glucose sensor is a medical device for determining the approximate concentration of glucose in blood. A small drop of blood, obtained by pricking the skin with a lancet, is placed on a disposable test strip that the meter reads and uses to calculate the blood glucose level. The meter then displays the level in mg/dl or mmol/l.

4.1.5. Microsoft Pro Tablet

A tablet computer is a mobile computer with display, circuitry, and battery in a single unit. Tablets are equipped with cameras, microphone, accelerometer, and touchscreen with a finger or stylus gestures replacing computer mouse and keyboard. Tablets include physical buttons to control basic features such as speaker volume, power and ports for network communications and to charge the battery. An on-screen pop-up virtual keyboard is usually used for typing. The EFM32 Tiny Gecko microcontroller
is connected with a smartphone using the audio jack interface of the phone. The EFM32 microcontroller communicates and harvests power from the phone. This solution based on an Apple iPhone and the "HiJack" concept was introduced by the researchers at the University of Michigan. This solution applies to any smartphone that can use this audio interface both for head phone output and micro phone input. These supports two-way communications between the EFM32 and the mobile phone.

4.2 Fuzzy-based Driving Behavior Detection System

The proposed system is a fuzzy-based driving behavior detection. Figure 4.1 shows the overall block diagram of the proposed driver monitoring system.

Figure 4.1 Overall block diagram of the proposed driver monitoring system
The system comprises several modules: EEG acquisition module, data analysis module, feature extraction module, basic framework module, Android module and an alert module. Figure 4.1 illustrates an overview of the system design for the proposed system. The phone receives EEG data, and an extraction process is performed to extract meaningful features from the received data, and these features then serve as input models to an inference network to analyze the driver’s vigilance level. An alert system is triggered if the statistical results indicate that the driver’s alertness is predicted to be lower. In the driving process, EEG acquisition device continually gathers driver’s brain waves, sends to the phone via Bluetooth, and the APP inside of the phone receives the EEG signals and preprocess, then extracts features. The Application (APP) judge whether the driver has drowsiness. If yes, the APP will take an alert display. Figure 4.2 shows the Fuzzy logic controller for the proposed driver monitoring system.

Figure 4.2 Fuzzy logic controllers for the proposed driver monitoring system
In general, a Fuzzy Logic System (FLS) is a nonlinear mapping of an input data vector into a scalar output. Figure 4.3 depicts an FLS that is used widely in fuzzy logic controllers. An FLS maps crisp data into crisp outputs, and this mapping can be expressed quantitatively as \( y = f(x) \). It contains four components: fuzzifier, fuzzy rules, inference engine, and defuzzifier.

![Figure 4.3 The structure of FLC system](image)

A Fuzzy Logic Control (FLC) system is designed for health monitoring services, which is one of the components in the pervasive computing prototype health status. The FLC system receives context information from sensor (sensor data stored in the database) equipment as the inputs of the FLC, and the fuzzification module converts the input into fuzzy linguistic variable inputs. On analyzing the data requirements of health services, four linguistic variables were defined, representing the physical sign of the patient. Figure 4.4 illustrates the membership functions of these input parameters of the fuzzy logic, and Figure 4.5 shows output functions.
Figure 4.4 Membership functions for input pulse
Pulse= \{ low, normal, high \}

Figure 4.5 Membership functions for output status
Status= \{ Below Normal, Normal, Above Normal \}
4.3. Results and Discussion

In the process of fatigue prediction, a safety monitoring system must be able to notify a driver within a very short period when a dangerous situation arises. Driving fatigue is one of the main reasons for accidents at present, preventing the occurrence of driving fatigue can successfully reduce automobile accidents. However, due to technical and financial aspects, devices which prevent fatigue driving are not universal. Due to the rapid development and popularization of the intelligent mobile terminal, a fatigue driving alert system of automobile based on brain wave is possible, and with limited equipment installing in the intelligent mobile terminal. The fatigue alarm function can be realized, which can provide a further guarantee for safe driving. In the brain wave monitoring service, through the analysis of the EEG features, the software is not limited by the car model. At the same time, the system can be combined with acceleration data, the engine running state and the vehicle traveling time, complete data processing and analyzing whether the driver is in a tiredness driving state. The proposed systems experimental results are evaluated using the evaluation metrics such as sensitivity, specificity and accuracy, it is given in Equation (4.1).

\[
\text{Sensitivity} = \frac{TP}{TP + FN} \\
\text{Specificity} = \frac{TN}{TN + FP} \\
\text{Accuracy} = \frac{TN + TP}{TN + TP + FN + FP} \tag{4.1}
\]

Here, \(FN\) stands for False Negative, \(FP\) stands for False Positive, \(TP\) stands for True Positive and \(TN\) stands for True Negative. Sensitivity is the proportion of true positives that are correctly identified by a diagnostic test as proposed by the equation above. It demonstrates how efficient the test is at detecting a drowsy stage. The proportion of the true negatives adequately identified by a diagnostic test is known as specificity. It recommends how good the test is at identifying awake (negative) conditions. The proportion of
true results, either true negative or true positive, in a population is called accuracy.

In the proposed DMS system, the classification process contains two stages, training stage and testing stage. In training stage, 30 samples (20 drowsy samples and 10 awake samples) are used for training purpose and the remaining 50 samples are used for testing purpose. The obtained experimental results of the existing and the proposed methods are given in Table 4.1 and the corresponding comparison results are visualized in Figure 4.6. The outcomes of the experimentation prove with 94% of accuracy in the proposed fuzzy logic-based driver health monitoring system.

Table 4.1 Classification accuracy of the proposed driver health care system and with various classifier approaches in Samples data set

<table>
<thead>
<tr>
<th>Evaluation metrics</th>
<th>Textures Features with SVM</th>
<th>Textures Features with RBF</th>
<th>Textures Features with FLC (Proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>37</td>
<td>35</td>
<td>38</td>
</tr>
<tr>
<td>FN</td>
<td>8</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>TN</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>FP</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>92.5</td>
<td>87.5</td>
<td>95</td>
</tr>
<tr>
<td>Specificity</td>
<td>80</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>Accuracy</td>
<td>90</td>
<td>86</td>
<td>94</td>
</tr>
<tr>
<td>Error rate (%)</td>
<td>10</td>
<td>14</td>
<td>6</td>
</tr>
</tbody>
</table>

SVM – Support Vector Machines, RBF- Radial Basis Function, FLC- Fuzzy Logic Controller
Radial Basis Function (RBF) network is an artificial neural network that uses radial basis functions as activation functions. These function networks have many uses, including function approximation, time series prediction, classification, and system control. Classification of images can also be performed using Support Vector Machines (SVMs). Experimental results show that SVMs achieve significantly higher search accuracy than traditional query refinement schemes. By analyzing the plotted graph, the performance of the proposed technique has significantly improved the drowsy detection compared with SVM and RBF neural network classifier. The evaluation graphs of the sensitivity, specificity and the accuracy graph are shown in Figure 4.6.

![Graph showing comparison of sensitivity, specificity, and accuracy for different classifiers](image)

**Figure 4.6 Experimental results of texture features with various classifiers of drowsy detection system**

In Table 4.1, the sensitivity of the proposed method Textures + FLC approach is better compared to other methods Textures + RBF and Textures + SVM. The classification accuracy of the proposed system is extremely higher.
than all other approaches. Based on the experimental results, the proposed system error rate is less compared to other classifier.

Table 4.2 shows the overall experimental results of the proposed and various driver monitoring system.

**Table 4.2 Overall investigational results of the several drivers observing System**

<table>
<thead>
<tr>
<th>Sensors / Parameters</th>
<th>Algorithm</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEG, ECG</td>
<td>Mean power frequency</td>
<td>---</td>
</tr>
<tr>
<td>Respiration Rate, Heart Rate, Heart Rate Variability</td>
<td>Power Spectrum</td>
<td>---</td>
</tr>
<tr>
<td>Cameras/ Eyelid movement, head movement and facial expression</td>
<td>Kalman filtering tracking</td>
<td>Yawn–82% PERCLOS–86% AECS–95%</td>
</tr>
<tr>
<td>IR Camera</td>
<td>Thresholding, Mean</td>
<td>---</td>
</tr>
<tr>
<td>Camera / facial features of eyes, mouth and head</td>
<td>Fuzzy reasoning</td>
<td>Only focused on detection rate for facial tracking and face tracking rate</td>
</tr>
<tr>
<td>EEG</td>
<td>Principal Component Analysis (PCA)</td>
<td>Training–92.6% Testing–74.6%</td>
</tr>
<tr>
<td>ECG, EEG</td>
<td>Dynamic Bayesian network, first- order Hidden Markov Model</td>
<td>Drowsy(best) –91% Active (best) –91%</td>
</tr>
<tr>
<td>Eye movement, driving performance data</td>
<td>Support Vector Machine(SVMs)</td>
<td>Distraction detection (average) –90%</td>
</tr>
<tr>
<td>Smartphone (display and front camera), ECG, PPG</td>
<td>Fuzzy Bayesian network</td>
<td>Awake –95% Drowsy– 96%</td>
</tr>
<tr>
<td>DHMS using Fuzzy logic controller (Proposed)</td>
<td>Texture features and FLC</td>
<td>Awake –96% Drowsy– 97%</td>
</tr>
</tbody>
</table>
4.4. Summary

A new application is introduced on a smart phone device with a real-time non-invasive driver fatigue detection system. The smart phone has a very significant impact regarding performance, thus designing and developing an integrated software/hardware framework, particularly for a vehicle, that exploits low-cost dedicated hardware to interact with sensors on board and in the vehicle surroundings. The achieved system records the behavior of vehicles and uploads to the cloud server for further solicitations. For example, if the system detects the vehicle unsafe, the vehicle location will be updated in clouds, and an alert message will be issued to the particular user. They can track the movement of this vehicle. Also, in a traffic accident, the system is helpful to elucidate the accountability timely.