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Contributions to Healthcare Systems Design and Implementation based on Wearable Wireless Sensor Networks

Contribuții la proiectarea și implementarea sistemelor de sănătate digitală bazate pe sisteme de senzori purtabili

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ABSTRACT

Nowadays, technological advances perform a significant role in the healthcare systems development especially with the speedy increased number of elderly populations in the last years. Patient Health Monitoring Systems importance is gained from the growing demands for medical care systems to observe several medical parameters. This research aims to identify the major techniques and communication protocols that are used in the wearable sensor networks and to highlight their advantages and disadvantages. A significant number of research papers will be reviewed as a current state-of-the-art for each technique. A large diversity of components of wearable health monitoring system (WHMS) will be illustrated and analyzed such as biosensors, control units, wireless communication modules, processing units, medical shields, links, power supplies, wearable materials, software, and also the advanced algorithms that are used for decision making and data extracting. An architecture emphasizing the wireless communication modules for WHMS is also proposed.

The overall goal of a complex wearable healthcare monitoring system (WHMS) is to support design and development of the high impact personalized ICT healthcare services based on measurements of health state acquired by sensors capturing everyday physical, cognitive and social activities. The acquired data will be fed into the risk prediction model to perform personal profiling and to identify deviations from the expected baseline of each specific user groups. In this research, a robust comparison of different solutions of architectures dedicated to Wearable Health Monitoring Systems (WHMS) based on microcontrollers and FPGAs are presented and analyzed. It is also proposed a new architecture that uses all the advantages of its components. An embedded microcontroller will facilitate the communication. An eHealth specialized platform like MySignals Hardware Development Platform V2.0 will be used for recording and analyzing the data coming from the medical biosensors. For a critical analyze of the current state of the art, a set of relevant research papers will be reviewed.

The Electrocardiogram (ECG or ECG) is a semi-cyclic, rhythmically, and synchronous signal with a cardiac function through the passive sensory apparatus in which bioelectric signals are generated mimicking the function of the heart. The ECG signals are inherently weak and noisy, built of many variable components due to several environmental factors like changes in body temperature, body movement or in the line frequency of 50/60 Hz. The ECG signal cannot be conditioned, amplified, nor reproduced directly and therefore, digital filtering techniques with adjustable window are used in this work. The work analyses several models of Finite Impulse Response (FIR) filters of low-pass and high-pass and their aspects in terms of response time, gain, and harmonic distortion, and rejection to determine the best band-pass filtering model to reproduce an ECG signal that closely resembles the actual Heart function of a patient. A hybrid filtering model is proposed and experimentally tested. Mean square error (MSE) is used to estimate a signal robustness. MATLAB environment has been used for the experimental part to simulate the signals.

The research presents a robust deep learning approach for ECG automatic diagnose. For this purpose, Deep Convolution Neural Network (D-CNN) algorithm and a multiclass model for SVM classifier will automate the detection process of ECG images specific to atrial fibrillation cases. In this research work, a pre-built and pre-trained D-CNN model is developed. It applies transfer learning which has been proved as a robust technique for computer vision. The early layers of convolutional network are frozen and only the last few layers are trained, identifying objects in images either through a database search or through real-time analysis and detection of the fetched image. Further, the study includes a comparison between the results of using data augmentation techniques and the results without using it. We achieved an average 99.21% of accuracy. The implementation environment of our work is based on MATLAB using Deep Network Designer toolbox.

Building an interactive healthcare environment became an essential need to improve and increase the effectiveness of professionals in the health field, along with the enhancement of security and confidentiality of medical data and the improvement of quality of healthcare services. This thesis presents the design and implementation of an enhanced healthcare monitoring system based on the web application framework and the cloud platform using four vital signs such as blood pressure, SPO2, body temperature, and electrocardiogram ECG. Advanced algorithms were utilized for the automated detection of abnormal vital signs. The designed HCare system adjust presentation on both desktop and mobile devices. The entire development process of HCare web-application has been presented in this work, emphasizing the main contributions brought to this domain. The design was based on different requirements that are determined based on a previous survey.

The system provides several functionalities for the patients and medical professionals (doctors and ambulance staff) such as monitoring the medical activities of the patients by the patients themselves and their doctors, and they will receive warning alerts as system notifications or SMS according to the severity of the medical condition of the patient. The application also includes modules for the previous developed filtering model and risk prediction and diagnose model in case of atrial fibrillation. The system offers various means of communication between the patients and the medical professionals via chats, emails, or phone numbers. Multiple functionalities are provided by the system to the patients such as a search for doctors based on the medical centers and the specialties of the doctors. Different security protocols were utilized in the designed HCare web-app system in order to maintain the integrity and confidentiality of sensitive medical data. HCare web application is developed by utilizing C#, ASP.net MVC, Jave Script (JQuery), Entity Framework, Bootstrap, and SQL Server technologies. The application has been implemented as a SaaS model.

The thesis ends by final personal conclusions, an objective overview on the main contributions related to the author's publications and a future development plan.

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List of Abbreviations

Abbreviation	**Stands For**
ECG	Electrocardiogram
EMG	Electromyography
PMU	Portable Monitoring Unit
FPGAs	Field programmable gate arrays
WMHS	Wearable Monitoring Healthcare System
PDAs	Personal Digital Assistant
OQPSK	Offset Quadrature Phase-Shift Keying
BPSK	Binary Phase Shift Keying
OFDM	Orthogonal Frequency Division Multiplexing
BAN	Body area network
FHSS	Frequency Hopping Spread Spectrum Technique
PTP	Point-to-point
BLE	Bluetooth Low Energy
OSI	Open System Interconnection
WSN	Wireless Sensor Network
IoT	Internet of Things
RFID	Radio frequency identification
LAB	Logic Array Block
IMD	Implanted Device
BWD	Body-Worn Device
NFC	Near Field Communication
MICS	Medical Implant Communications Service
IrDA	Infrared Data Association
UWB	Ultra-Wide Band
DSSS	Direct sequence spread spectrum
WWHMS	Wearable Wireless Healthcare Monitoring System
LUT	Small Lookup Table
EEPROM	Electrically Erasable Programmable Read-Only Memory
PWM	Pulse width modulation
HDL	Hardware Description Language
GUI	Graphical User Interface
DSP	Digital-Signal-Processing
SoC	System-on-Chip
VM	Virtual Machines
MXE	Modalism Xilinx Edition

API	Application Programming Interface
TFT	Thin Film Transistor
AWGN	Additive white Gaussian noise
MSE	Mean Square Error
CLB	Configurable logic block
THD	Total Harmonic Distortion
PSD	Power Spectral Density
SNR	Signal to Noise Ratio
EMG	Electromyogram
FIR	Finite Impulse Response
SG	Savitzky-Golay
CDC	Centers for Disease Control
D-CNN	Deep Convolution Neural Network
MI	Myocardial Infarction
PAF	Paroxysmal Atrial Fibrillation
CCR	Correct Classification Rate
SVM	Support Vector Machine
RNN	Recurrent Neural Network
PaaS	Platform as a Service
DDSM	Digital Database for Screening Mammography
CCA	Canonical Correlation Analysis
AFib or AF	Atrial Fibrillation
ReLU	Rectified Linear Unit
FC	Fully Connected
ML	Machine Learning
IIR	Infinite Impulse Response
SGDM	Stochastic Gradient Descent with Momentum
MBGD	Mini-Batch Gradient Descent
DA	Data Augmentation
IaaS	Infrastructure as a Service
fitecoc	Fit Error-Correcting Output Codes
RWD	Responsive Web Design
SPO2	Oxygen in the Blood
GUI	Graphical User Interface
ORM	Object Relational Mapper
UML	Unified Modeling Language
Hcare	Healthcare
2FA	Two-factor authentication
PHP	Hypertext Preprocessor
CSS	Cascading Style Sheets

SOAP	Simple Object Access Protocol
HTML	Hypertext Markup Language
SaaS	Software as a Service
LSTM	Long Short-Term Memory
PaaS	Platform as a Service
MVC	Model-View-Controller

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Mohammed Tali Qasim Almalchy

CHAPTER 1. INTRODUCTION

Recently, the area of healthcare intelligent systems utilizing wearable sensors got a lot of attention because of the quick upgrowth of the older populace in the most recent years and the increasing of healthcare costs. Different health applications have been developed for mobile devices and vastly utilized by patients and medical personnel [2]. These applications lead to improve communication between doctors and patients thus assist to enhance the quality of treatment in general, therefore the utilization of these applications is quite useful. Generally, people prefer to access their information including medical information, in an effortless and flexible way with the current speedy development of mobile devices, therefore it became necessary to prepare fitting interfaces according to these different devices with use of Responsive Web Design (RWD) to develop a modern web-application [3].

Building an interactive healthcare environment became an essential need to improve and increase the effectiveness of professionals in the health field, along with the enhancement of security and confidentiality of medical data, and as well as the improvement of quality of healthcare services.

Nowadays, various wearable mini-biosensors had become broadly available where it allows comfortable and non-intrusive monitoring of the activities of patients' lives. With the use of these biosensors that connect to mobile devices, we will be able to collect the medical data from the patients while they do daily life activities which allow us to identify and understand the patient's medical conditions.

Professionals in the health field attempt to benefit from analyzing and investigating these health data in order to comprehend the diseases and conditions that affect a specific country or community [4], taking into consideration the confidentiality and security of these health data as sensitive data. The medical cases and health data of patients have to be tracked by the doctors when the patients being outside hospitals with the potential to access their recorded data and the ability to record the diagnosis and treatment data to their health profiles.

This research presents a design and execution of an enhanced healthcare monitoring system dependent on the web application framework and the cloud platform using various vital signs for example blood pressure, SPO2, body heat level, and electrocardiogram ECG, with emphasis on the pre-processing of ECG signal, starting from filtering the signal then analyzing it using enhanced algorithms and techniques thus improve the quality of ECG diagnosis and treatment.

The Electrocardiogram (ECG or ECG) is a semi-cyclic, rhythmically, and synchronous signal with a cardiac function through the passive sensory apparatus in which bioelectric signals are generated mimicking the function of the heart. The ECG signals are inherently weak and noisy, built of many variable components due to several environmental factors like changes in body temperature, body movement or in the line frequency of 50/60 Hz. The ECG signal cannot be conditioned, amplified, nor reproduced directly and therefore, digital filtering techniques with adjustable window are used in this work. The work analyses several models of filters type of a Finite Impulse Response using both passes low and high and their aspects in terms of response time, gain, and harmonic distortion, and rejection to determine the best band-pass filtering model to reproduce an ECG signal that closely resembles the actual heart function of a patient. A hybrid filtering model is proposed and experimentally tested.

Further, a risk prediction and diagnose model for atrial fibrillation was developed. This contributes also to personal profiling and identification of deviations from the expected baseline of each patient. A web application system called Hcare where provides the physicians with the ability to monitor the health of their patients as well as provide health and medical consultation to them and allows the patients to observe their health activities. Hcare provides different functionalities for the patients and medical professionals.

In this thesis, we highlighted and illustrated the requirements of healthcare monitoring systems based on a previous survey that conducted in our published work [1]. The database approach of the proposed system was illustrated in this research as well. UML modeling diagrams for the proposed system were presented and discussed such as the Use-Case diagram of the entire system plus system administrator Use-Case diagram, as well as the sequence diagram of the appointment scheduling scenario and sequence diagram of the new registration and login scenario.

The information security issues has been investigated in this work represented by healthcare information threats in the system, information consent, and information sharing, to obtain better protection of patient information. Also, the techniques and approaches of security and privacy of our Hcare web-app were explained along with the confidentiality of the patient's information. The system provides appointments schedule management between patients and doctors and also provides Alert Mechanisms as system notifications or SMS according to the severity of the medical condition of the patient. The application includes the modules for the previous developed filtering model and risk prediction and diagnose model in case of atrial fibrillation.

This system is considered the best compared to its counterparts from the systems due to the use of enhanced and advanced techniques to filter and classify the vital signs of patients especially the ECG signal where these techniques were previously published in the articles [5] [6].

1.1 Main Objectives of Thesis

The essential object of this dissertation is building a robust e-health monitoring system. The below objectives are achieved to obtain this system:

- Design and implementation of an enhanced healthcare observing system based on the web application framework and the cloud platform using four vital signs like blood pressure, SPO2, the temperature of body, and electrocardiogram ECG.
- Identify the major techniques and communication protocols that are used in the wearable sensor networks and to highlight their advantages and disadvantages.
- Present solutions for wearable healthcare monitoring systems (WHMS) architectures based on microcontrollers and FPGAs.
- Present a critical analyze on healthcare monitoring systems requirements based on hardware features, operational system features, and healthcare system services.
- Develop a robust hybrid filtering model for noise cancellation from the signals of ECG depending on filtering techniques. Analyze several models of filters type of a Finite Impulse Response using both passes low and high and their aspects. A new proposed hybrid filtering model is developed based on a FIR Chebyshev filter algorithm and Savitzky-Golay filter.
- Explore the Transfer Learning approach in the Deep Learning field utilizing pre-trained Convolutional Neural Network to improve the accuracy of Atrial Fibrillation classification based on the short-term recorded ECG datasets thus providing robust results for an automatic prediction.
- Develop a risk prediction model and diagnose for atrial fibrillation based on the above analyzed D-CNN.
- Develop a robust application to furnish the physicians with the capability to observe the health of their patients, by means of continuous observation and analyze of their daily activities.
- Bring contributions to the functionalities regarding maintaining the integrity and confidentiality of sensitive medical data of patients using advance security protocols.
- Bring contributions to the functionalities regarding the improvements in the interactions between the medical professionals and patients by providing them various functionalities through the proposed system.
- Investigate the cloud computing models and their advantages and disadvantages and recognize the association between them and web-apps of healthcare monitoring systems.

1.2 Thesis Structure

The dissertation will be sorted out in six chapters, where chapter 1 discussed the introduction of the dissertation, the remainder of the chapters are structured as follows:

Chapter 2: This chapter will review the state of the art in the research and the improvement of wearable sensors based on healthcare monitoring systems. Challenges and standard requirements of wearable healthcare monitoring systems (WHMS) will be described according to the hardware features, operational system features, and healthcare system services. Many aspects of this field will be studied and analyzed to resolve most of these challenges. Also, this chapter will present the wireless communication modules for WHMS based on short and long-range communications and will highlight the requirements of these modules. Moreover, it will present FPGA architecture and Arduino architecture (as a type of Microcontroller) and then we will highlight the fundamental differences between the FPGA and Microcontroller. As well will attempt to review several research prototypes on wearable biosensor systems for health monitoring based on FPGA and Microcontroller. Furthermore, this chapter will describe the MySignals Hardware Development Platform V2.0 and as well will explain the difference between MySignals Platform and the old eHealth platform (eHealth Sensor Platform V2.0). Finally, a proposed solution for a healthcare monitoring system architecture will be presented.

Chapter 3: Different filtering techniques will be studied and analyses to remove the noises from ECG signals. This chapter will present a comparison between the digital filters FIR and IIR underling their advantages and disadvantages to shows the best option for our application. Digital filtering techniques with an adjustable window will be used in this chapter. Moreover, the chapter will analyses several models of filters type of a Finite Impulse Response using both passes low and high and their aspects in term of response time, gain, and harmonic distortion, and rejection to determine the best band-pass filtering model to reproduce an ECG signal that closely resembles the actual Heart function of a patient. Important features of Savitzky-Golay filter, relevant for ECG filtering are underlined also here. Also, the chapter will present the experimental environment and the data set. Furthermore, this chapter will offer the implementation details of the proposed hybrid filtering method. Finally, mean square error (MSE) will be used to estimate signal goodness.

Chapter 4: This chapter will present a comprehensive literature survey regarding the use of a deep convolutional neural network (D-CNN) in the medical fields. Here, a risk prediction model and diagnose for atrial fibrillation will be described and developed. D-CNN algorithm and multiclass model of SVM classifier will be used to automate the detection process of AFib ECG images. A pre-built and pre-trained D-CNN model will be developed. Further, this study will explore three experiments: feature extraction, transfer learning with data augmentation, transfer learning without data augmentation. The best results among it were presented.

Chapter 5: This chapter will present the design and implementation of an enhanced healthcare monitoring system based on the web application framework using four vital signs like blood pressure, SPO2, body temperature, and electrocardiogram ECG. This system includes cloud computing paradigms, mechanisms for security and confidentiality, and the use of the Responsive Web Design (RWD) pattern. The entire development process of HCare web-application will be presented in this chapter, emphasizing the main contributions brought to this domain. Also, the chapter will highlight the requirements of the proposed healthcare monitoring systems. The database approach will be illustrated in this chapter as well. Moreover, UML modeling diagrams for the proposed system will be presented and discussed such as the Use-Case diagram of the entire system plus system administrator Use-Case diagram, as well as the sequence diagram of the appointment scheduling scenario and sequence diagram of the new registration and login scenario. Further, we will investigate the information security issues represented by healthcare information threats in the system, information consent, and information sharing, to obtain better protection of patient information. Also, the techniques and approaches of security and privacy of our Hcare web-app will be explained along with the confidentiality of the patient's information. The alert Mechanism of the proposed system will be presented and illustrated where the alerts either to be a notification through HCare web application or via SMS in order to notify the patients themselves and the medical professionals about the abnormal and critical health conditions of the patients. Additionally, alerts will be sent according to the severity of the medical condition of the patient. Moreover, the chapter will illustrate the functionalities of the system for each user. The application also includes modules for the previous developed filtering model and risk prediction and diagnose model in case of atrial fibrillation. Thus, the system provides the doctor with the ability to analyze the ECG signal of a patient to determine the AFib disease or, if there is any other disease, he can add electronic diagnosis notes and treatment for the patient and save the results in the record of the clinical history of the patient. Additionally, the system provides patients with the ability to manage the appointments with the doctor and confirm\cancel the appointment by themselves. Also, the system offers various means of communication between the patients and the medical professionals.

Chapter 6: This is the last chapter and it will explain the conclusions of this thesis, will summarize our presented contributions and will show the possible future work.

CHAPTER 2. A CRITICAL ANALYZE ON THE DESIGN OF HEALTHCARE SYSTEMS BASED ON WEARABLE WIRELESS SENSOR NETWORKS

2.1 Introduction

Nowadays, the field of healthcare intelligent systems using wearable sensors got a lot of attention because of the speedy increase in the population of elderly people in the last years and the increasing of healthcare costs. The persistent monitoring has become an exigency for a precise analysis and treatment of a given patient. And also, it gives a flexibility for the doctors or nurses to keep observing multiple patients simultaneously while they are out of the hospital and also, they have the authorization to access their recording data from anywhere anytime. To achieve this demand, numerous researches has been done and a variety of healthcare systems prototypes and commercial products have been created lately. However, there are many challenges and difficulties that ought to be settled for wearable healthcare monitoring systems.

The wearable healthcare monitoring systems may consist of various types of biosensors. These sensors are measuring significant physiological parameters like blood pressure, electrocardiogram (ECG), muscle electromyography (EMG), oxygen level in the blood, body temperature, etc. The aggregated data from the biosensors are transferred into the portable monitoring unit (PMU) of the system with or without wires. The processed data will be transferred to its destinations.

Most of the devices that need a connection and interaction with any PC have an embedded microcontroller internally to expedite the connections. That is why this chapter offers a robust comparison of different architectures based on microcontrollers and FPGAs. An eHealth specialized platform like MySignals Hardware Development Platform V2.0 will be analyzed, emphasizing its main advantages with respect to old version eHealth Sensor Platform V2.0. A new architecture having all the required features of a flexible and scalable approach is also introduced.

2.2 Challenges and Standard Requirements of WHMS

There are yet many challenges in making the wearable healthcare monitoring systems more applicable to the real-life and to be more flexible to use by patients and other users taking into consideration the reliability, multifunctional and improve their quality of life. To design and develop a perfect wearable monitoring healthcare system (WMHS), various important features ought to be taken into consideration. The most important features of wearable health surveillance systems [7], [8] are:

- **Hardware Features:**
  1. The monitoring devices have to be comfortable to wear and take off, lightweight, robust, and reasonable for all patients and for different environments.
  2. Portable device that can be handled by any person and has the ability to be more flexible [9].
  3. Preferably the devices are small and can be hidden to maintain the privacy of the patient.
  4. Long battery life and low cost.
  5. The equipment must acquire high-quality signals.
- **Operational system features:**
  1. The ability to measure and observe multiple medical parameters with the better treatment.
  2. Real-life monitoring and high accuracy performance.
  3. All-day monitoring during the natural activities.
  4. Low power consumption.
  5. Easy to use by anyone like by patient and doctor.
  6. Data privacy and the ability to access the data from anywhere in the world by the authorized persons.
  7. Self-management for the chronic diseases.
  8. Data extracting and decision support.
- **Healthcare system services [10]:**
  1. Hospital services.
  2. Patient monitoring services.
  3. Parental monitoring services.
  4. Cloud storage services
  5. Real-time action suggestions.
  6. Emergency response services.

2.3 Wireless Communication Modules for WHMS

The measured data transmission in the wireless monitoring system is performed on three areas. The first area is the short-range communication where the aggregated data from the biosensors are transferred into the portable monitoring unit (PMU) of the system, by wires or wireless. The second area is also short-range communication where the processed data transfers from PMU into smartphones or PDAs (handled by doctor and patient). The third area (long-range transmission) transfers the data from the system of the patient's side into the remote medical stations as showed in Figure 2.1.

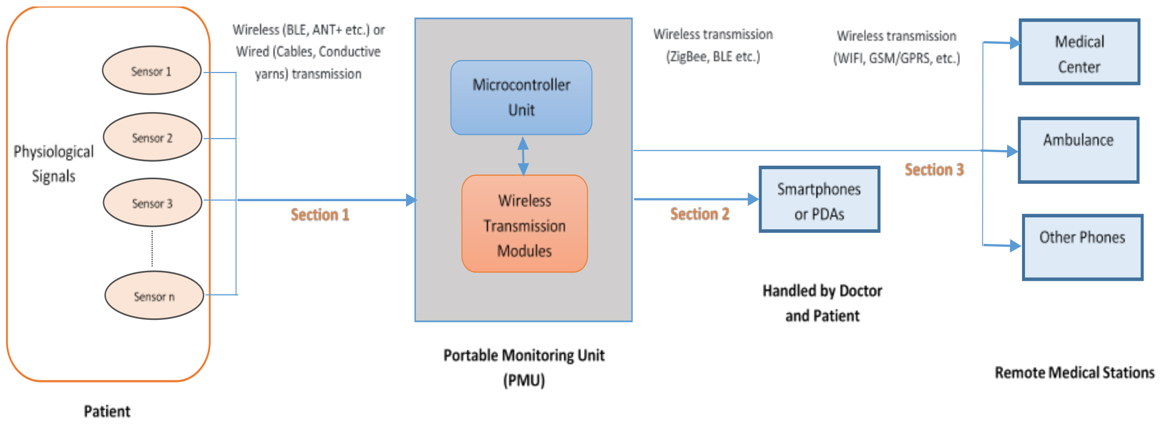


Figure 2.1 Data transmission in a healthcare monitoring system

The most widely used wireless communication modules in the WHMS are ZigBee 805.15.4, Bluetooth 805.15.1, ANT+ and NFC

2.3.1 ZigBee IEEE 802.15.4 standard

It was developed for wireless sensor and control networks by the ZigBee alliance. It is a global standard for interoperable products that enables reliable and secure remote patient monitoring and enhances collaboration between devices to manage multiple chronic diseases [11]. It provides real-time capability, self-management, easy to use, flexibility, long battery life and low cost. In the indoor case, the wireless range is up to 70m. For outdoors scenarios, the control can be done on 400m, ensuring high scalable solutions for thousands of devices. It runs in 27 channels, 16 channels in the frequency 2.4 GHz (ISM), 10 channels in the frequency 915 MHz and other channel with a frequency 868 MHz. It uses AES 128-bit encryption secures for personal information. Also, the ZigBee uses the access method CSMA-CA or synchronized channel access utilizing a direct sequence spread spectrum (DSSS) and beaconing approach. Finally, ZigBee supports multiple network topologies. Dagtas, Pekhteryev & Sahinoglu [12] used ZigBee technology to present a framework for WHMS in smart homes and one of the dominating advantages of that is the skill to detect wireless signal within the Body area network (BAN) through ZigBee network nodes with low-power and reliable data sensing. Hak Jong Lee et al. discussed in [14] some solutions that adopt the ZigBee standard, this being embedded in consumer electronics, medical sensor applications, industrial controls, home automation, games and even toys. Many other researchers and developers used the ZigBee technology implementing their WHMSs such as [13], [15].

2.3.2 Bluetooth over IEEE 802.15.1 standard

It is short-range wireless communications with minimal power consumption and low cost. The frequency hopping spread spectrum technique (FHSS) cover 79 channels and operates in 2.4-GHz ISM RF band. The transmission distance range is (10-100m) where the common mode is 10m. The network topology of Bluetooth is star and uses the piconet as a basic configuration. The connected radios can act either as master or slave where the master can be connected to 7 concurrent or 200+ slaves with active mode per piconet and each piconet most extreme limit (1 MSPS). It has options for encryption, provided by 64 or 128-bit SAFER+ algorithm [17]. There are two types of Bluetooth technologies. The Bluetooth Basic Rate/Enhanced Data Rate (BR/EDR) activates continuous wireless connections and the used network topology is point-to-point (PTP). The Bluetooth Low Energy (BLE) activates short-burst wireless connections. In this case, various network topologies are used, such as PTP, broadcast, and mesh. It uses to transmit amounts of data at low duty cycles like for (sensors, remotes, etc.) [16]. In the article [36], the author focuses on BLE in the WHMS, since BLE technology has wide communication range, lower power utilization with less data rate. Wearable healthcare systems should have implemented a lower power consumption feature. In order to respect this demand, one single small battery is desirable for this kind of wearable systems. That is why Bluetooth low energy offers a good solution when speaking about a reduced volume of the device and a longer life of its battery.

2.3.3 ANT+ proprietary protocol

It is the wireless technology for monitoring sensor data, designed and maintained by the ANT+ Alliance which is owned by Garmin [18]. It is low power consumption for long time monitoring, least processing power and least baud rate and this is the main reason is used for wireless sensor network (WSN) such as in the medical, sports or Smart Home fields [20]. It works in the frequency 2.4 GHz ISM and separates it into 125 channels of width equivalent to 1 MHz and a baud rate of up to 1 Mbps and to establish a connection between two nodes, both of them should be on the same channel. It has three types of communication to transfer the data are Broadcast, Acknowledged and Burst. ANT + handling management of physical layers, information connection, networks, and OSI transport layers [21, 22]. ANT+ is considered as robust protocol to transfer and store the data diversity using internet of Things (IoT) and supporting device interoperability by implementing device profiles [19]. Mehmood N. Q., Culmone R. & Mostarda [19] implemented a prototype to present a methodology for the web environment in real time, many issues should be addressed by this methodology including device connection, unique generic message interpreter, transferring data, and storage. Priyadharshni P., Priya A. V. and Swarnambiga A. [23] implemented a healthcare system based on ANT+ protocol and android application to measure the heart rate, temperature and patient's position. The system was very flexible and scalable in which we can integrate many sensors to it as well as we can integrate it with the webpages and applications.

2.3.4 NFC (Near field communication)

It is a set of communication standards that enables a short-range wireless communication between two devices, it establishes peer-to-peer radio communications to exchanges the data between the devices within a short period through radio waves in the frequency range 13.56 MHz on ISO/IEC 18000-3 air interface at a speed of 106 kbps to 424 kbps. With uses of NFC technology can decrease the system cost and also is suitable for some conditions that using RFID tag [28]. NFC is an extension of several RFID (Radio frequency identification). NFC can be very useful in many healthcare systems aspects which contributes to improve the people's life [29]. NFC protocol is used in the electronic medical record (EMR) systems, where the mobile devices that use NFC tags offer a novel way to access the data of healthcare system providing reliability and security [30]. The EMR applications can be implemented in two ways as per the patient's condition, the first is outside the human body and the second implants within the human body [28]. E-health cards have been implemented based on NFC tags in the article [31]. NFC technology is widely implemented in the new devices especially with mobile phones. The main disadvantage of this technology goes to its extremely short-range which it is ordinarily less than (10 cm) and some cases less than (4 cm).

There are other short-range wireless communications protocols that could be used for WHMS but there are not widely used like MICS or are not suitable like IrDA and UMW.

2.3.5 MICS (Medical Implant Communications Service)

It is extremely low power due to the use of Wake-up Circuit, unlicensed, short-range up to (2m) and high data rate. It operates in the radio frequency 401–406 MHz. It can be used in the case of implanted medical devices for the implementation of therapeutic functions or diagnose modules. The MICS network consists of either instilled devices internally in the patient’s body called an implanted device (IMD) or different devices that can be fixed externally on the patient’s body as wearable devices called BWD (body-worn device), including a programmer/controller (P/C) [24, 25]. In spite of the multiple advantages of MICS, it is not extensively utilized by the researchers and developers due to the lack of available commercial MICS solutions [7].

2.3.6 IrDA (Infrared Data Association)

It is a standard for transmitting information by means of infrared light waves. It is a short-range communication protocol within 1 meter only. It is a low power technology and supports data transmission speed up to 16 Mbps. The main disadvantage of IrDA is the inflexibility communication where the IrDA must be in direct communication with the line-of-sight so that it makes not suitable to be applied to wireless healthcare monitoring systems.

2.3.7 UWB (Ultra-Wide Band)

A type of transmission that possesses a wide data transfer capacity, being used to transmit large amounts of digital data spread over a large bandwidth (>500 MHz) with very low power and short-range. It spans both licensed and unlicensed frequencies, FCC approved the unlicensed utilization of UWB which is represented by frequency range 3.1-10.6 GHz [20]. There are two different approaches used by UWB: one is the Direct-Sequence Spread Spectrum (DSSS); the second Orthogonal Frequency Division Multiplexing (OFDM) uses multi-band. UWB standard is unlikely used with WBANs due to the high complexity in the hardware and protocol and also because the wide bandwidth modulation is unsuitable [27].

Table 2.1 provides a comparison among the most relevant characteristics of wireless communication modules.

Table 2.1 WIRELESS COMMUNICATION MODULES COMPARISON

	ZigBee	**Bluetooth 2.1 (EDR)**	**Bluetooth LE**	**ANT+**	**WIFI**		**UWB**	**NFC**	**IrDA**	**MICS**
Standard	802.15.4	802.15.1	802.15.1	Propr-ietary	802.11 a,b,g	802.11n	WiMedia	ISO 13157 etc.		Unlic-ensed
Data Rate	20-250 Kbps	1Mbps			2-11Mbps				16 Mbps	500 Kbps
Range	Indoor 70m – Outdoor 400m	Outdoor 100m (Class 2)	Outdoor 100m	30m	Indoor 38m-Outdoor 140m	Indoor 70m – Outdoor 250m	10m	< 10cm	1m	2m
Frequency	2.4 GHz\ 868-915 MHz	2.4-2.5 GHz	2.4-2.5 GHz	2.4 GHz	2.4-2.5 GHz	2.4-2.5 GHz	3.1–10.6 GHz	13.56 MHz	Infrared	402-405 MHz
Bit Rate	-	2-3 Mbps	1.0 Mbps	1.0 Mbps	(Max/Typ/Min) 54 Mbps / 36 Mbps / 1 Mbps	150 Mbps/90 Mbps Multi stream max 600 Mbps	-	106 - 212 & 424 Kbit/s	-	-
Air Interface	DSSS	FHSS	FHSS	-	OFDM	OFDM	OFDM-DSSS	ISO/IEC 18000-3	-	-
Power consumption	Ultra-Low	Low	Low		Medium	-	Ultra-Low	-	Low	Very Low
Battery life	6 Month	1-7 days	1 year	Up to 3 years	1-5	-				7-10 Years
Latency	30 ms - 1 sec.	10 sec.		Delay Time*	-	-	-	-	-	-
Network Topology	Star, tree, Cluster & Mesh	PTP	PTP, Broadcast & Mesh	-	Star	Star	-	PTP	-	-
Privacy	Mid	Mid	Mid	-	Low	Low	-	High	-	-
Device/ Network	65,535	7	-	-	-	-	-	-	-	-
Cost	Very Low	Medium			Higher	-	-	Low	-	-
Set-up Time	-	< 6 s	< 0.006 s	-	-	-	-	<0.1 s	-	-

** ANT protocol transmits 20568 Bits per second [21].*

2.4 Medical Biosensors

The biosensors play a significant role in clinical development field with the point of making clinical gadgets considerably increasingly successful and more secure. Several biosensors can be utilized in the wearable healthcare monitoring systems to be part of the BAN. It measures the physiological signals of the human's body and transfers them to the central node. The transmission of physiological signals can be handled either by wired such as (Cables, Conductive yards) or by wireless links such as (BLE, RF, ANT+ etc.) as depicted in the Figure 2.1. The list of various medical biosensors has been described in Table 2.2.

There are various basic requirements that must be met in wireless medical sensors [32, 33]:

- **Wearability**: The wireless medical sensors must be small and lightweight in order to make the wearable wireless healthcare monitoring system (WWHMS) non-invasive and unobtrusive. The weight and size of sensors mainly rely on the size and weight of batteries [34]. But the capacity of the battery is directly proportional to its size. Currently the Lithium batteries are the best option for the wireless sensor networks [35].
- **Reliable Communication**: The Reliable Communication is extremely important in the WHMS. The communication requirements of various medical biosensors rely on the required sampling rates which it is from less than 1 Hz to 1000 Hz. One of the reliability improvement approaches is to implement the processing on the biosensor signals. For instance, instead of sending a raw data of electrocardiogram (ECG) from sensors, we can perform features extraction on the sensor and transfer only information about an event. And that will reduce the high demands on the communication channel, saving on total energy expenditures and leading to the increase of the battery's life.
- **Security**: The other significant requirement is system security. The security issue occurs with all the three levels of a WWHMS. At the lowest level, wireless medical biosensors must meet all the privacy requirements imposed by the law for all medical devices and must ensure data integrity. In spite of the fact that key establishment, data integrity, and authentication are difficult tasks in resource restricted medical sensors, a relatively small number of nodes in a typical WWHMS and short communication ranges make these tasks achievable.
- **Interoperability**: The wireless biosensors ought to have the flexibility to use by the users in order to build a robust WWHMS relying on the health condition of the user. The standards that specify interoperability of wireless medical sensors will help vendor competition and finally result in more accessible and affordable systems.

Table 2.2 MEDICAL BIOSENSORS

Biosensors Types	**Description**
Electrocardiogram (ECG)	It utilized to evaluate the electrical functions of the heart muscle. It uses a “Continuous telemetry electrocardiogram" for long-term observing including three ECG electrodes utilization.
Electromyography (EMG)	Discovers the electrical possibility produced by muscle cells during the activation of these cells neurologically or electrically.
Electroencephalogram (EEG)	Measurement of automatic electrical activity in the brain and other brain capabilities.
Blood Pressure Sensor	It measures blood pressure; the recording of blood pressure consists of two values: systolic pressure (high pressure) and diastolic pressure (low pressure).
(SPO2) Sensor	It is pulse oximetry that indicating the arterial oxygen saturation of hemoglobin. Usually this sensor measures the heart beats too.
Glucometer Sensor	Determination of blood glucose concentration in an approximate form.
Body Temperature Sensor	This sensor allows us to measure and monitor the temperature of the human body with a maximum deviation of 0.1 ° C.
Airflow Breathing Sensor	A gadget used to gauge the breathing rate in a patient needing respiratory assistance. This sensor comprises of two parts one is an adaptable thread that fits behind the ears, and the other fixed in the nostrils.
Spirometer Air Capacity Sensor	A portable measuring device of pulmonary function that measures the highest flow of exhalation which is called forced expiratory volume in 1 second.
Galvanic Skin Response (GSR)	It quantifies the skin electrical conductance, which differs with its dampness level. The skin electrical resistance will be changed for any strong emotion because of the system of sympathetic nervous controlling the sweat gland.
Accelerometer Sensor	various patient positions are observing by this sensor such as supine, sit, stand, left, right, and prone. The sensor detects the position of patients through the use of a triple-axis accelerometer.
Snore Sensor	The sensor placed around the neck to record the snoring through vibrations by converting it into a small analog voltage that can be read clearly by the sensor.
Body Scale Sensor	This sensor measures numerous parameters such as weight, bone mass, muscle versus fat, bulk, the water of body, instinctive fat, Rate of Basal Metabolic, and Index of Body Mass.

2.5 FPGA and Microcontroller based devices for medical applications

In this section will talk about the FPGA- based architectures and Arduino architecture (as a type of Microcontroller) and then we will highlight the fundamental differences between the FPGA and Microcontroller. This section attempts to review a number of research prototypes on wearable biosensor systems for health monitoring based on FPGA and Microcontroller.

2.5.1 Architecture of FPGA

Field programmable gate array (FPGAs) is semiconductor device that is able to be programmed to behave like any digital circuit. FPGAs are manufactured by companies like Xilinx, Altera, and Actel etc. The most popular FPGA architecture composed of the following modules:

- Configurable logic block (CLB): it is also called logic array block (LAB) and it implements the user logic. It basically comprises a small lookup table (LUT) to actualizes the consensual logic functions, Register (D flip flip) to stores the LUT output, and the MUX part that utilized for selection logic purpose.

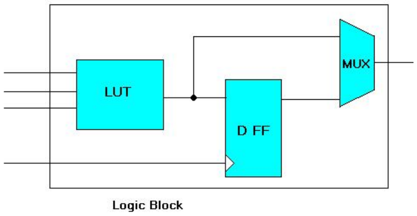


Figure 2.2 Logic Block [44]

- Interconnects: these interconnections provide a routing among the logic blocks to perform the user logic.
- Switch Matrix: it used for switching purpose between the interconnects rely on the logic.
- I/O Block or Pads: that are utilized for the outside world to connect with various applications.

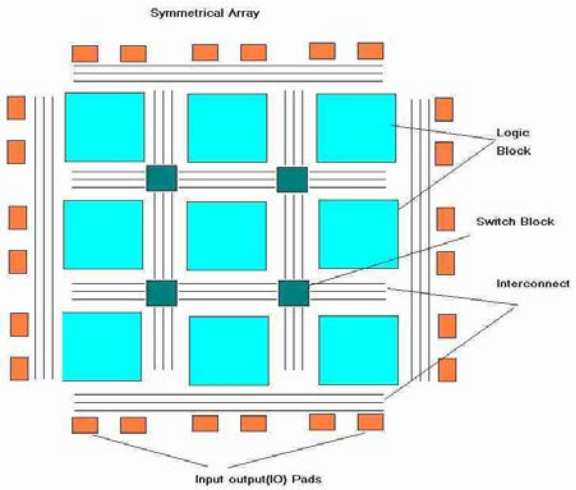


Figure 2.3 FPGA [44]

2.5.2 Microcontroller Architecture

A number of industrial microcontroller platforms available in the market which can be used to build healthcare systems. Therefore, we will make a comparison among several microcontroller platforms such as Intel Galileo, ARM7 LCP 2148, Arduino Uno Rev.3 and the Raspberry Pi board as well, and thus we will be able to select the proper option in order to build our proposed system (Wearable Wireless Healthcare Monitoring System (WWHMS)). Choosing a certain microcontroller platform is rely on the purpose of use and its requirements, so a comparison of platforms will be as per the proposed project requirements.

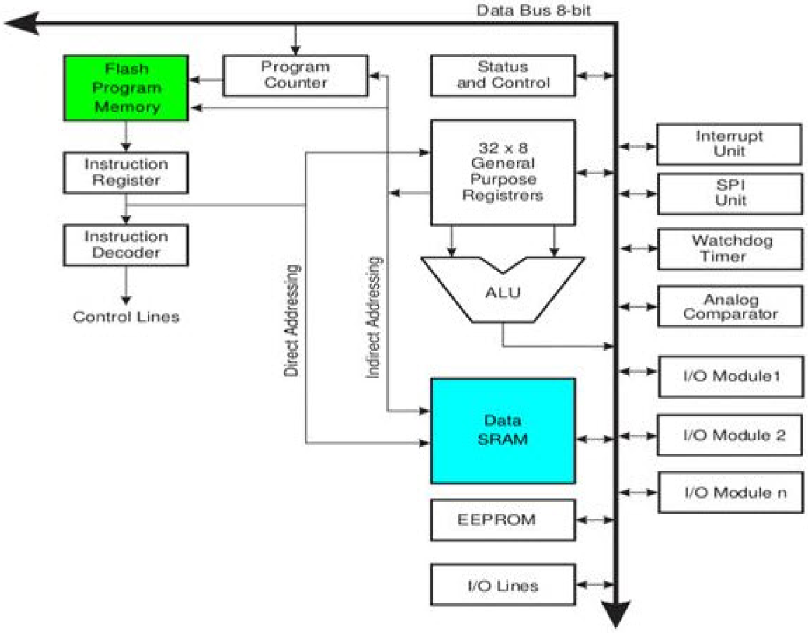


Figure 2.4 Arduino Architecture [45]

A comparison Among Arduino Uno Rev.3, Intel Galileo, ARM7 LCP2148 and Raspberry Pi Boards is discussed further:

- - Intel Galileo [46] is a microcontroller board and it has compatibility with Arduino (Uno R3). It has 400MHz 32-bit processor plus I/O ports such as full PCI Express mini-card slot, Ethernet port with 100Mb, Micro SD card storage up to 32 GByte, RS-232 serial port, USB Host, and USB Client ports. It has several storage options like DRAM with 256 MByte, NOR flash with 8MB, and 256 MByte DRAM and 11 Kbyte EEPROM. The main disadvantages of Intel Galileo microcontroller are the higher cost (€60) compared with the others and the fact that Intel is about to cease production [47], so you will not be able to get hardware or software support very soon.

- ARM7 LCP2148 [48] is a 32-bit ARM7TDMI microcontroller training board with LPC2148 processor. This board contains novel and advanced possibilities that will present the user the flexibility to execute the complex logic used in the embedded systems design. It has 2 serial ports, 12MHz crystal, USN ports, Dual Power supply, power on LED supply, on board Reset Circuit with a switch, on board UART, there are three regulators voltage onboard 1.8V, 3.3V, and 5V with up to 800mA current, moreover it provides Graphic LDC display interfacing port, CAN controller interfacing, MMC/SD card interfacing, 8 Bit LED interfacing and EEPROM Interfacing. Additionally, the LPC2148 chip has an on-chip static RAM with 32 KB and on-chip flash memory with 512 KB, 128-bit of wide interface/accelerator enables a high-speed 60 MHz operations. Single flash sector or full chip erase in 400 ms and programming 256 bytes per 1ms and many other features. Despite the many great features of this microcontroller but we still do not find it a good choice for portable wearable healthcare systems for the individual person due to the large size of the board. And as per the proposed project requirements, the system supposed to be portable and small size. Plus, it's not compatible with Arduino Shields and MySignals HW.

- Arduino Uno Rev.3 [49] is a type of microcontroller board types based on ATmega328P. This board contains 14 digital I/O pins divided as 6 PWM outputs and 6 analog inputs, also it has a 16 MHz quartz crystal, 32KB Flash Memory, 2KB SRAM, EEPROM 1 KB, and 16 MHz of Clock Speed. Additional it has a power jack, a USB connection, an ICSP header, 1.0 pinout added SDA and SCL pins that are near to the AREF pin and two other new pins located close to the RESET pin, Atmega 16U2 and a reset button. It provides almost all the required things that microcontroller needs it; developers can easily connect this board to the PC utilizing a USB cable or use an AC-to-DC adapter or battery to power it. It is less speed compared to other microcontrollers but it has several advantages that makes it pretty board such as the extremely low cost (€20) only compared with the others, it is flexible and appropriate for a wide assortment of applications, a wide range of application notes, easy programming, open-source developer kit is widely available [41]. Arduino Uno and ATmega328 comes together with a bootloader to allow the developers to exchange any new codes to it without the need of an external hardware programming engineer [40]. Arduino runs immediately after applying its power. Finally, Arduino Uno is directly compatible with MySignals HW shield. is directly compatible with MySignals HW shield.

- Raspberry Pi [50] is a totally different machine. It is a suitable small scale PC contains an OS, where the file system contained on a flash drive. The user can connect keyboard, mouse, and screen, then run programs such as an internet browser on it. The most recent model of Raspberry Pi is (Model B+), the design is based on Broadcom BCM2835 SoC full HD multimedia applications processor which comprises an ARM1176JZF-S 700MHz processor, VideoCore IV GPU, and RAM with 512Mbytes, therefore, Raspberry Pi is faster than the others. It has MicroSD storage, 4x USB ports, Ethernet RJ45 Jack with 10/100mb, HDMI Combined RCA for video connections, Multi-Channel HD Audio through HDMI, Micro-USB power source and it's can works on the OSs: Raspbian, RaspBMC, Arch Linux, Risc OS, OpenELEC, and Pidora. The downsides are the Raspberry Pi (Model B+) costs more than Arduino but less than Galileo at around (€40), to use Raspberry Pi for any project that needs external Microcontroller as well as to connect the Raspberry Pi with any compatible Arduino shields we need to use Raspberry Pi to Arduino Shields Connection Bridge which it's cost (€72) [51], thus that will increase the cost of the system as well that will increase the size and the weight of the system. The other downside is the Raspberry Pi takes a longer time to start up than the Arduino (a few 10 of a second).

To summarize the main ideas of the above comparison and experimenting some of these discussed components, the following conclusions have risen:

- Arduino, Intel Galileo and ARM7 LCP2148 are microcontrollers, having no operating systems and this means that you have to upload the program from a computer via USB and that program runs each time you switch it on. On the other side, the Raspberry Pi is a small single-board computer that runs with an operating system.
- Both of Arduino and Intel Galileo can connect directly with any compatible Arduino shields whilst the Raspberry Pi needs to use a Connection Bridge to connect it with Arduino shields. ARM7 LCP2148 is not compatible with the Arduino shields.
- Due to the large size of the ARM7 LCP2148 board, it is unsuitable for the portable wearable healthcare systems for the individual user.
- The Raspberry Pi (Model B+) costs more than Arduino and less than Intel Galileo. Using Raspberry Pi to build a project that needs external hardware such as Microcontroller, Raspberry Pi to Arduino Shields Connection Bridge and etc. which will increase the cost of the system as well that will increase the size and the weight of the system.
- Raspberry Pi takes a longer time to start up than the Arduino (a few 10 of a second) where the Arduino runs immediately after applying its power.
- Arduino more flexible and appropriate for a wide assortment of applications, a wide range of application notes, easy programming, open-source developer kit is widely available.
- Eventually, although the Arduino has less speed than the others still it is more suitable for controlling sensors. Articles [40, 41, 42] show that utilizing Arduino in the healthcare systems with several biosensors could give accurate results. Finally, among all the mentioned boards, the Arduino could cover the most requirements of the proposed system.

2.5.3 Differences between FPGA and microcontroller

Most of the devices that need to establish a connection with any PC must have an implanted microcontroller internally to facilitate interaction. The most important difference between a microcontroller and an FPGA is that the microcontroller structure is almost analogous to a simple PC located on a single chip including all the fundamental parts such as the memory and timers placed internally. The microcontroller is fundamentally programmed to do some basic errands for other equipment. FPGA is an integrated circuit that could comprise a vast many rationale gates that can be arranged electrically to play out a specific undertaking.

Analyzing further, a Field Programmable Gate Array does not have a constant structure. On the contrary, it can be programmed according to the user applications. That means all the memory of transistors, external structures, including the connections all are fixed. Naturally, the FPGA allows it to be more flexible compared to most of the microcontrollers. We can realize from the name itself that the entire FPGA device has the possibility to be reprogrammed by the developers to do any logic task so that it can be adjusted to the gates number that it owns. The microcontroller has its own circuitry and instruction set that the programmers must follow in order to write codes which restricts it to particular tasks.

FPGA consumes more power than typical microcontrollers, and this the reason why it is sometimes inappropriate for applications where energy depletion is an issue. In order to implement an FPGA function for a particular task that would also take longer time compared to microcontroller's case because in one function needs to write all the code from scratch and then convert it to a machine language. Whereas with microcontrollers, we can buy packages that are prepared for a certain task and it just needs to be programmed to our exact specification relatively rapidly.

Concerning the price, a solution using FPGA could cost more than one based on microcontrollers. That is the reason FPGAs are ordinarily associated with products that have a significant level of complexity but only with low interest. At the point when the interest and demand rise and the large scale manufacturing got significant, the circuit is shifted to ASICs such as microcontroller where the cost of production is less.

From the programming language point of view, FPGAs needs Hardware Description Language (HDL) as VHDL or Verilog for implementation. The microcontroller utilizes the programming languages like C, C++, C#, etc.

2.5.4 Research Prototypes

2.5.4.1 Healthcare Researches Based on FPGA

Different heathcare systems have been developed in the last decade and many solutions proved to offer robust results. However, there are many improvements that can still be done in this area. Vaibhavi Bhelkar and D. K. Shedge [36] used three sensors: Heartbeat sensor, LM35 sensor and Accelerometer ADXL355 for monitoring the parameters heartbeat, temperature and motion in order to develop health monitoring device for patient based on FPGA. The graphical user interface (GUI) has been developed by using programming language visual basic and the collected data from the sensors is forwarded into GUI so that the patient will be able to see the parameter values. The SMS and email systems have been used in case of any emergency situation. The system was useful for patients, doctors and medical recording. The FPGA has been utilized in this project instead of Microcontroller because it is reconfigurable and additional necessary hardware can be added when required.

N. Sudheer Kumar et al. [37] design and model a Wireless Sensor Monitoring System based on FPGA. This system has the ability to integrate with other low cost systems. The remote short-range communications have been used in the wireless system. VHDL was used to perform the required FPGA functions such as bus data buffering, interfacing, compression and data framing. Compressing stored data with the use of RLE has proved to be very efficient. The real-time simulation for both Simulink and VHDL models was not the main goal of this work, but it proved a pragmatic design, suitable for future hardware implementations. Xilinx Spartan-3 device has been used for modules verification. The main motivation behind using the FPGA device to execute the model digital part was to have an ASIC-ready platform as well as the FPGA is configurable and so can be upgraded when needed.

Ravinder, K et al. [38] prepared "A Novel Wireless Biomedical Monitoring System with Dedicated FPGA-based ECG Processor". The system gives a portable and real-time ECG monitoring system. It uses HRV analysis and Bluetooth module to transfer the data wirelessly based on System-on-Chip (SoC) FPGA. The ECG monitoring system was presented as a proof-of-concept design.

L. Arul Leo Felix et al. [39] worked on "Zigbee based Wireless Patient Monitoring System using FPGA". This project was developed to observe two medical parameters - the body temperature and hearth beat rate - of the patient remotely and send the measured rate to the doctor through GSM Protocol. As well, the system gives the patient the ability to control the room devices such as fan, light and TV from the bed itself by using the Bluetooth technology. In this system, parallel communication is possible, and the efficiency is increased by using FPGA Spartan 3E.

P. Girish et al. [52] developed the "Wireless real time health monitoring system built with FPGA and RF networks". In this work, the ECG monitoring system in a real-time has been designed by displaying HRV (Heart Rate Variability) analysis and remote information transmission via radio frequency dependent on a System-on-Chip (SoC) improvement stage. The Xilinx ISE and Modalism Xilinx Edition (MXE) have been use for simulation and synthesis. The FPGA has been tested with a Xilinx Chipscope tool inside results while the logic running on FPGA. In this work, Xilinx Spartan 3E Family FPGA development board was used to provide real-time monitoring and controlling different multi-functions of the system. The ECG FIR filter design method was developed on FPGA. In this approach, the results emphasize the high-frequency and 50Hz power-frequency interference dual filters. The filters were used directly into the FPGA embedded ECG monitor system and their main purpose is to collect data, playback and store it. The wireless transmission was integrated into an FPGA chip. In this way, the analog circuits development is reduced, this implying further reducing costs of development, research and design cycle. Their research results underline the robustness of the application.

2.5.4.2 Healthcare Researches Based on Microcontroller (Arduino)

Sowmya, G. and Sandeep, B. L. [40] developed a "Remote HealthCare Monitoring System Using Arduino Board over Distributed Ubiquitous Environment". This system embeds a message passing framework to the device based on the sensor data variation. The framework consists of three segments such as Arduino Uno (ATmega328P), GSM modem, Pulse rate sensor (Ear clip Heart rate sensor) and temperature sensor. The processed data is sent from the microcontroller to the server where MATLAP programming is implemented to read data from the server. This system aims to improve the everyday life of patients experiencing unending heart diseases, by observing any cardiovascular occasions changing. It also enhances the nature of social insurance division.

Monicka, S. et al. [41] worked on "A Ubiquitous Based System for Healthcare Monitoring". This system composed of three main units are data acquisition, data processing, and data communication which in turn interact with each other to present real-time observation, processing, and reporting. The Arduino analyses the data in real-time from the sensors that attached on the patient's body which are Pulse sensor, Glucometer sensor, Body Temperature sensor and heartbeat sensor and then determines whether the patient needs external help by offering suggestions based on the processed data. After the data is processed, a SMS alert is sent to the patient, doctor or ambulance according to a Threshold value in an emergency situation. The local database is created with the use of MYSQL. Fundamentally, the aims of this work are to improve the patient's health, reduce in hospitalization and assistant cost.

Shivwanshi, R.R et al. presented the "Design and Development of Wireless Sensor Network for Biomedical Application" [42]. A motion sensor was developed in this research where this sensor can be utilized for different applications by utilizing it at various timeframes, for example, monitor rehabilitation exercise, steps counting, tracking of sleep, and consumed calories calculation. This model consists of a 3-axis accelerometer, Arduino microprocessor

(ATmega-328p) and Bluetooth HC-05. The device needs 5 V power. It can transfer the signals properly within the range (5-10) m. This work shows that the small and lightweight sensor module can serve to multiple applications with high accuracy.

2.6 MySignals HW Shield V2.0 and e-Health Sensor Shield V2.0

In this section, some eHealth-dedicated development boards are discussed. In the context of so many FPGA and microcontroller - based approaches, new hardware solutions for data acquisition and healthcare application implementation have arisen. MySignals Hardware Development Platform V2.0 is an example that will be discussed further, the difference between different versions of them being explained (MySignals Platform vs. eHealth Sensor Platform V2.0).

2.6.1 MySignals HW Shield V2.0

MySignals [43] is an eHealth development platform launched by Libelium for medical devices and its applications, as shown in Figure 2.5. It can be used to develop your own eHealth web. Different sensors can be added, and Android or iOS applications can be also implemented in order to build a new medical device. This platform allows to measure more than 20 biometric parameters including pulse, breath rate, muscle electromyography signals, oxygen in blood, blood pressure, electrocardiogram signals, , glucose levels, lung capacity, galvanic skin response, snore waves, patient position, , airflow and body scale parameters (weight, body fat, bone mass, muscle mass, visceral fat, body water, Basal Metabolic Rate and Body Mass Index).

MySignals platform receives the data from its sensors, encrypts it then sends it to a private account of user at Libelium Cloud over a communication technique Wi-Fi or Bluetooth. Libelium offered two different types of APIs for the developers to facilitate information access. First, the API of iOS / Android that allows receiving the data from MySignals directly utilizing Bluetooth Low Energy (BLE). The second API is for the cloud to provide access to the private account of user; thus, the stored data will be reachable and visualized in a third-party platform.

Figure 2.5 MySignals HW Development Platform V2.0

2.6.2 Differences between MySignals HW Shield and e-Health Sensor Shield V2.0

MySignals HW Shield is a new generation of eHealth and medical development products specially designed for developers, researchers and makers. There are novel features in the MySignals which are significantly improved from the earlier version (e-Health Sensor Platform V2.0) as Figure 2.6 presents and as illustrated below [43]:

- The sensor's number increased with 6 sensors to be totally of 16 sensors.
- The newly available sensors are Spirometer, Snore, Blood Pressure (Embedded BLE), Glucometer (BLE), SPO2 (BLE), and Body Scale.
- The sensor's accuracy improved in this platform.
- The probes of sensor became more powerful now.
- MySignals HW Shield integrates a faster MCU due to the high memory 4 times more than the old version eHealth V2.0.
- The radios Wi-Fi and BLE are integrated now on the PCB.
- The basic graphics available with a TFT (Thin Film Transistor) touch screen.
- There is a new type of audio, jack connectors that allow the non-technical personnel to utilize it.
- Cloud Storage is available now for the new generation to save historical information.

The table 2.3 indicating the comparison of the general features of the MySignals HW Shield and the eHealth sensor Shield V2.0.

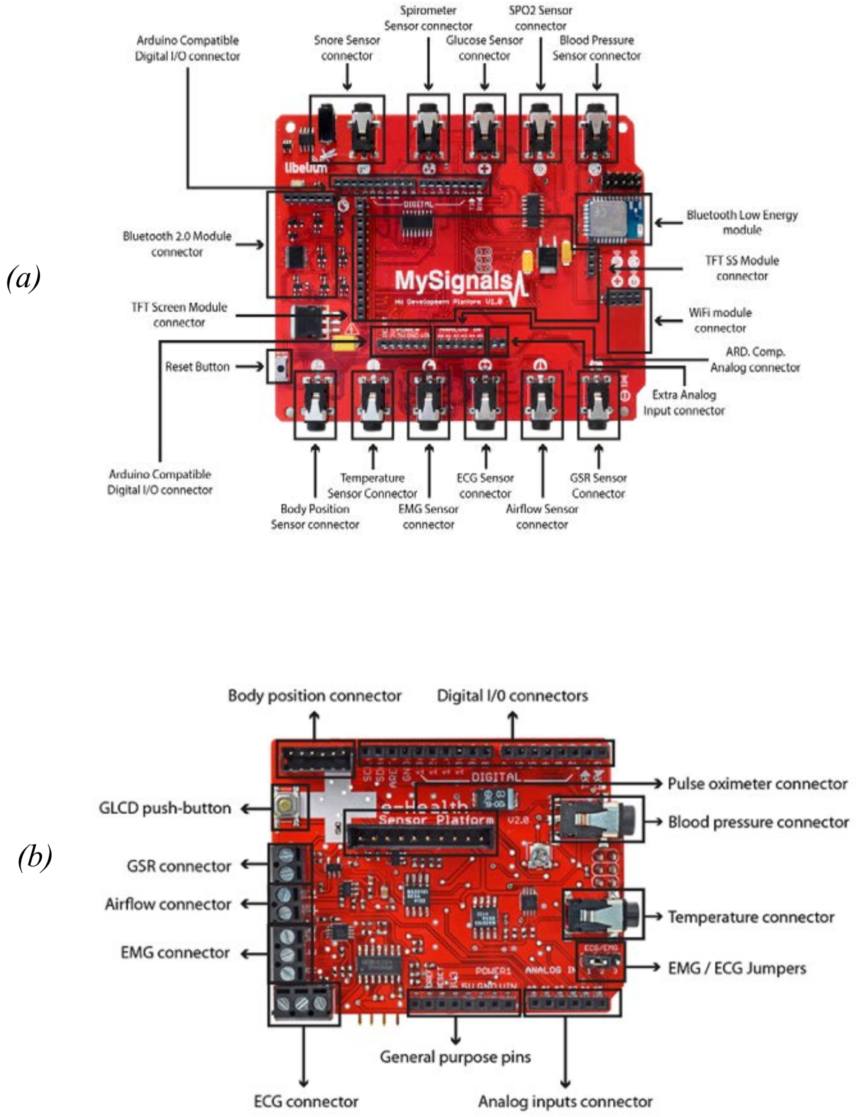


Figure 2.6 (a) MySignals HW Platform & (b) eHealth Sensor Platform V2.0 [43]

TABLE 2.3 COMPARISON BETWEEN MYSIGNALS HW & E-HEALTH V2.0 [142]

Item	e-Health V2.0	MySignals HW
Architecture	compatible with Arduino	compatible with Arduino
Memory	2K RAM- 32K Flash	2K RAM- 32K Flash
Microprocessor	Arduino UNO (Atmega 328)	Arduino UNO (Atmega 328)
UART sockets	1	1 (multiplexed)
Screen	GLCD - optional (basic graphics)	TFT (basic graphics)

Touch screen	No	Yes
Cloud Storage	No	Yes
Android / iOS App	Yes	Yes
Sensors	10 sensors	16 sensors
Wired Sensors	10	11
Wireless Sensors	10	16
API Cloud	No	Yes
API Android/iOS	No	Yes
Radios on board	-	BLE, WiFi
Extra Radios	BT, ZigBee, 4G / 3G / GPRS	BT, ZigBee, 4G / 3G / GPRS

2.7 The Proposed Architecture

Based on the critical analyze of the components of a wearable healthcare monitoring systems presented and discussed till now, a new architecture is proposed selecting the elements that are the most appropriate for achieving our goals. In this proposed approach, the information from 6 sensors is recorded and analyzed by MySignals shield. Due to the decision module implemented on Arduino, all the values of the parameters that exceed a certain range are sent real time to the application running on the doctors' smartphone. The doctor will be able to monitor the parameters in two different communication modules, short-range communication (ZigBee) and long-range communication (GPRS/GSM). First, the doctor can have a real-time and direct monitoring when he is available within the coverage area of the ZigBee signal (inside the hospital). Second, in case a patient is outside the hospital, in another word, if the ZigBee signal cannot be reachable by a doctor then all the values of the parameters that reached the threshold will be sent real-time to the doctor's smartphone through SMS.

The GPRS/GSM (SIM900) shield will be used in the system to transfer the data from MySignals HW and store it in the cloud database. Advanced algorithms will be implemented in Arduino microcontroller for decision making where the threshold values will be sent real-time to the patient, doctor, and ambulance according to the threshold values emergency situation. For instance, in case the blood pressure rate for systolic (upper) is (120-139) mm Hg or for diastolic (lower) is (80-89) mm Hg then SMS will be sent to the patient's smartphone as an alarm; warning him for taking precaution. And if the systolic (upper) blood pressure is (140-159) mm Hg or for diastolic (lower) is (90-99) mm Hg then an SMS will be sent to the doctor's smartphone so that he takes an immediate treatment to prevent the situation from worsening. And in case the blood pressure rate of the patient is critical like if the systolic (upper) blood pressure is (160) mm Hg or higher \ for diastolic (lower) is (100) mm Hg or higher, then the SMS will be send to the ambulance where the ambulance can detect the patient's location from the GPRS of portable wearable system of the patient, so that they can send him immediately to the hospital to save his life. All the values in this example were taken from the medical book [53].

The architecture has a cloud component that can be useful to run the software. Such an approach provides robust support for testing and collaboration, expanding also the needed storage. The modules can be implemented in a Software as a Service manner, in this way enhancing scalability and agility to the application. The doctor will write diagnosis and prescriptions from the application that runs on his smartphone according to information that he received from the patient's system and then save it in patient's profile in the cloud database. The medical information of the patient that is stored in cloud database will be accessible by specific people who have the authorization to access such as patient himself, doctor, patient's family member, etc.

The transferred data among system components will be encrypted by security protocols to protect it from any malicious acts of the hackers. Figure 2.7 shows the proposed solution for a healthcare monitoring system architecture.

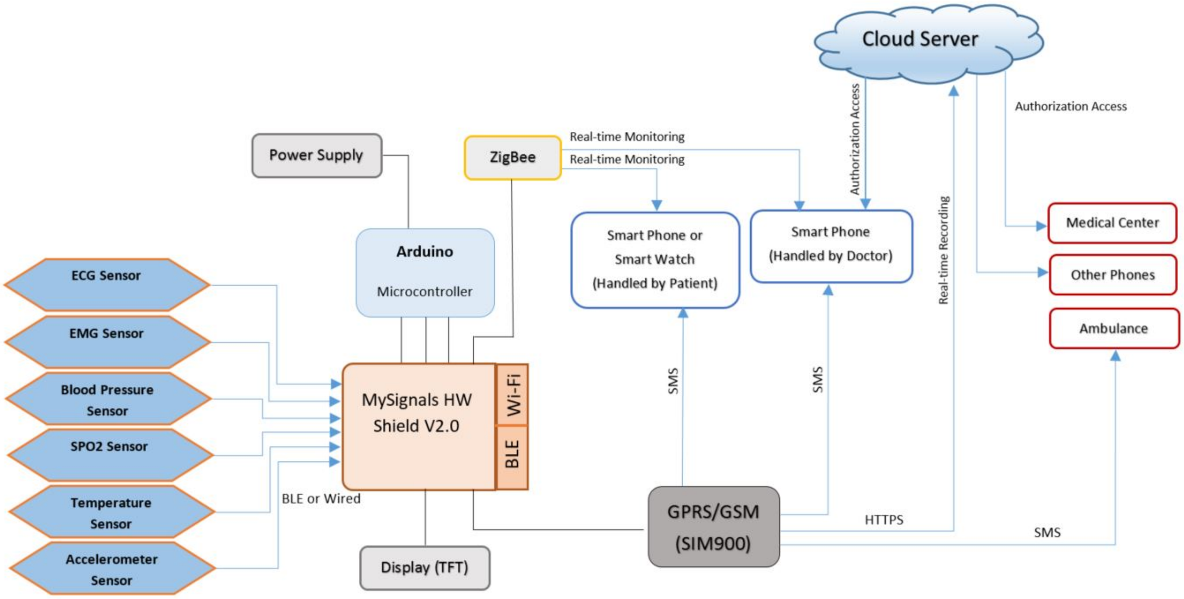


Figure 2.7 Proposed Solution for a Healthcare Monitoring System Architecture

2.8 Conclusion

The critical analysis presented in this chapter reviewed the state-of-the-art in the research and the development of wearable sensors based on healthcare monitoring systems. This kind of WHMS has the potential to revolutionize in healthcare field by providing a variety of features commensurate with the patient's demands such as: easy to wear and remove, lightweight, robust, suitable for all patients and for different environments, portable device that can be handled by any person and has the ability to be more flexible, small size and can be hidden to maintain the privacy of the patient, the ability to measure and observe multiple medical parameters with the better treatment, real-time monitoring, high accuracy performance, all-day monitoring during the natural activities, low power consumption, long battery life, low cost, easy to use, data privacy and the ability to access the data from anywhere in the world by the authorized persons, self-management for the chronic diseases, data extracting and decision support. To achieve all these requirements, many aspects in this field have been studied and analyzed to resolve most of the challenges so that they can be accepted by the patients and other users.

This analyze guided us to propose a suitable solution for a system architecture that supports the discussed requirements. Thus, MySignals shield will be utilized to aggregate the physiological signal from several biosensors such as ECG sensor, EMG sensor, SPO2 sensor, etc. Two communication modules will be used to transfer the data like in the scenario described in section 2.7: the first is the short-range communication (ZigBee standard) and the second one is the long-range communication (GPRS/GSM) so that the doctor will have more flexibility to observe the patient inside and outside the hospital. The data will be stored in the cloud database to enhance agility and scalability where that will provide global access to the patient's medical data. Security protocols will be implemented to protect the data from any malicious acts. Advanced algorithms will be implemented in Arduino microcontroller for decision-making. Data extracting algorithms can be implemented on the stored data.

CHAPTER 3. NOISE REMOVAL FROM ECG SIGNALS BASED ON FILTERING TECHNIQUES

3.1 Introduction to ECG Concept

The Electrocardiogram (ECG) signal is an electrical representation of the heart function by a transducer component/device, which senses and converts the mechanical energy (vibration) into electrical signal for filtration, processing, and further analysis by specialists to assess the health condition of a patient. The conversion is achieved by the movement to a diaphragm that is placed on the skin of the patient as part of a balanced bridge configuration in which the instrument shall record voltage disturbances as a result of the diaphragm senses the vibration of the heart.

Fundamentally, there are two kinds of noises associated with an ECG signal. Some of them are high-frequency components as electromyogram noise, power-line interference noise (50-60) Hz, and additive white Gaussian noise (AWGN). AWGN is a noise that is associated with any random signal or process that occurs in nature. The others are noises with low-frequency such as baseline wandering and motion artifact. These noises in the ECG signal may lead to misinterpretation [56]. Figure 3.1 shows the ECG waveform that explains the clinical characteristics of the ECG, comprising wave interval timings and wave amplitudes. The ECG signal is distinguished via five valleys and peaks marked up as P, Q, R, S, T respectively, and there is a U wave which is almost absent, having a very low amplitude. The ECG waveform embodies the atrial depolarization which is the period needed for an electrical impulse formed from the sinoatrial node to multiply over the atrial musculature. It has the duration around (0.06-0.11) seconds [57].

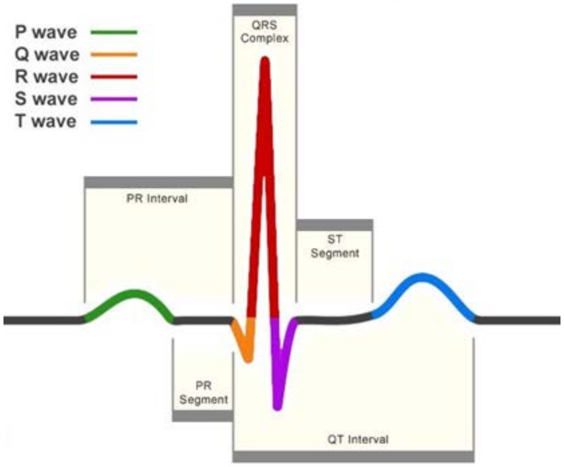


Figure 3.1 ECG Waveform [56]

The interval (P-R) extends from the starting point of P-wave and ends at the starting point of the QRS-complex. This interval indicates the time that the impulse elapses to move the whole distance from the node of sinoatrial into the fibers of the ventricular muscle. The typical time period for it is around (0.12-0.20) seconds. The QRS-complex represents the ventricular depolarization and consists of three waves onset from Q wave, R wave, and then S wave. The first negative deflection is presented by the Q wave. The R-wave indicates the first positive deviation, regardless of the reality if it is exceeded by the wave Q or not. The S wave is the next negative deviation that is subrogated by the wave R. The duration of QRS complex is about (0.05 - 0.10 s) [60]. The interval Q-T indicates the required period for the ventricular depolarization and repolarization that starts from the beginning of the complex of QRS and to terminus of T wave. In the S-T segment, the T-wave represents the fundamental time for a ventricular repolarization. Occasionally, U-wave, which follows the T wave, can also be observed and it represents a repolarization of the His-Purkinje fibers [57].

Essentially, signal processing techniques should be applied in a pre-processing phase of any application for a more efficient signal analysis, for enhancing non-invasive diagnosis, observing the critically unwell patients remotely or in addition to rehabilitating and supporting the disabled in a sensory way.

The main ECG signal processing objective is numerous and involves the enhancement of measurement precision and reproducibility. An ECG analysis is concerned with the interpretation of ECG, stress measuring, intensive care observing, or ambulatory observing, utilizing a set of algorithms that specify the signal for various kinds of noise or artifacts, cardiac detection, extract basic ECG measurements from the amplitudes and durations of the waves, and obtain an efficient storage and transmission by compressed data.

TABLE 3.1 CHARACTERISTIC FEATURES OF ECG WAVEFORM

ECG Waveform Components	Represents	Durations (Sec.)
P-Wave	Atrial depolarization	0.08-0.10
P-R Interval	Atrial depolarization with AV nodal delay	0.12-0.20
QRS Complex	Ventricular depolarization	0.05-0.10
Q-T Interval	Length of depolarization with repolarization	0.20-0.40
T-Wave	Ventricular repolarization	Not detected yet
S-T Segment	The photoelectric period of depolarized ventricles	Not detected yet
U-Wave	His-Purkinje fibers repolarization	Not detected yet

Generally, the level of signal voltage is as low as from 0.5 to 5 mV. In the case it is larger than this range, it can be considered as artifacts. The ECG signal frequency range is from (0.05Hz to 100Hz) [56][58][59]. The artifacts elimination plays the indispensable role in the ECG signal processing. The specialist will face difficulties in diagnosis of illnesses, if the noise still exists in the ECG signal. ECG signal processing implies noise detection, filtering and smoothing as it will be described in this chapter.

3.2 Related works

Several denoising techniques were proposed and applied in the former researches to reduce the interferences from the actual ECG signals. Singh et al. [65] designed FIR filter using many windows techniques such as Blackman, Hanning, Rectangular, Hamming, and Kaiser windows, to remove a Baseline wander from an ECG signal. The SNR of these techniques was calculated as per the spectral densities and average power. The FIR filters consider the best in terms of the trade-off between the average power and spectral densities compared to the other filters. 0.5Hz cut-off frequency has been utilized for high-pass filtering purpose, moreover the spectral density for those under 0.5Hz has been estimated before and after signals filtration. The techniques based on the Rectangular and Kaiser windows give better results but due to the high number of the filters order, the computational load is very complex. As for Blackman and Hanning windows, order of filter was extremely high. In this research, the Kaiser window was proved to be as a better choice among the others. Priyanka and Kaur, G. [66] used different windowing techniques: Kaiser, Rectangle, Hamming, Hanning and welch windows to denoise the power line interference, muscle and EMG noises from ECG signals. Some parameters like SNR, MSE, THD and Positive Peak were used to evaluate the output. For PLI noise the Kaiser window was the best option to remove it among the others. Kaiser window and Rectangle window gave best results to remove the EMG and muscle noises.

AlMahamdy M. and Riley H. B. [67] presented and applied many methods to denoise several noise levels from 5-45 dB SNR. The analysis and comparison show that performing NeighBlock wavelet method offered the best solution among the others. P.C.Bhaskara and M.D.Uplaneb [68] present a low pass FIR filter using several windowing techniques to cancel high-frequency Electrocardiogram interference utilizing Distributed Arithmetic (DA) based on FPGA and Xilinx system generator software. Kaiser Window gave an excellent performs to remove the noise. Choudhary M. and Narwaria R. P. [69] deals with noise ratio and average power to make comparison among three digital filters (IIR) which are Butterworth, Chebyshev Type-I, and Type-II. The results have shown that using low-pass Butterworth filter could remove more noise than the others. Mahawar et al. [70] have used windowing methods, Kaiser and DC, to develop FIR lowpass filter with use of high attenuation. The results can be inferred quantitatively, and visual inspection can be realized based on signal error measures such as PRD, PRD1, SNR, and MSE. Sharma M. and Dalal H. [71] deal with the design FIR and IIR digital filters using windowing techniques to cancel the low-frequency baseline wander from the abnormal ECG signal. They compared different window techniques such as Hamming, Kaiser, Rectangular, Chebyshev, and Elliptic before and after filtration according to the average power, spectral density and filter order, as well as the wavelet transform at 4 and 6 dB output. In this paper the Kaiser window gave a better result.

Rastogi, N. and Mehra, R. [72] developed an integrated technique, which consolidates Daubechies wavelet decomposition with many thresholding methods with the IIR digital Chebyshev or Butterworth filter to denoise the Baseline Wander interferences. DWT shows a good capability to decompose the signal. The wavelet thresholding was robust in removing the noise from a decomposed signal. The quantitative evaluation results of both filters were based on MSE, PSNR and SIR. The final results show that the denoising performance of both Butterworth and Chebyshev methods gave almost the same efficiency.

Patial P. and Singh K. [59] deal with FIR Low Pass Filter using various window techniques i.e. Kaiser, Hamming, and Hanning to filter an ECG signal and remove any interferences from it. Three estimation parameters such as average power, power spectral density and the signal to noise ratio has been used to calculate the performance of these window methods and then to be compared. The peak detection algorithm was also implemented and the efficiency of waveform smoothing and suppressing line noise has been proved to be very good for this algorithm. Sreedevi G. and Anuradha B. [73] analyze and compare IIR and FIR filters and their performances according to the Power Spectral Density (PSD) to denoise the baseline wander from noisy ECG signal. Mbachu C.B. and Offor K.J. [74] used a FIR digital notch filter with Hamming window for powerline noise (50Hz) removal in the ECG signal. The performance efficiency of the Hamming algorithm was compared with an adaptive filter. The result has shown that the adaptive filter was the best to process the ECG signal.

3.3 Noise Types in ECG Signal

ECG signal noise is an undesirable signal that intervenes with the wanted signal. These artifact signals can arise from several external and internal sources. The electrocardiogram (ECG) will be corrupted by these noises, changing its characteristics. The main challenge of biomedical signals noise refers to a level of signal amplitude required with noise, in other words, the power ratio of an input signal to the noise signal power which is called the Signal-to-Noise Ratio (SNR) [60]. Using noise reduction is a significant stage to solve most of the issues in the analysis of biomedical signal due to the difficulty of extracting useful information from the ECG signal. The main noise sources are [58]: baseline wandering, EMG noise (Muscle noise), motion artifacts, power line interference, the noise of electrode contact, channel noise, and high-frequency noises in ECG. They will be further discussed.

Power line interference

This kind of interference can be easily detected where the interfering voltage in the ECG is likely to be at 50 Hz frequency. The current alternate fields can occur an adverse impact because of a loop in the cables that connected to the patient which can lead to this kind of intervention. There are also other causes can lead to this interference such as loose contacts in the cable of patient and dirty electrodes too. The improper grounding of the ECG equipment and the patient may cause an interference of power line which can entirely disorganize the ECG waveform [61]. When an electrode gets disconnected, a high disturbing signal will result, and this is the most common reason for getting 50 Hz interference. Also, the interference of electromagnetic from the power lines leads to bad quality tracking, as well as the electrical machines such as X-ray units, conditioner and elevators that make a high-power line current which includes signals with 50/60 Hz frequency for the ECG equipment circuits [56]. The existence of this interference in the ECG signal is considered as to have a more negative impact on the ECG signal compared with other noise sources [58].

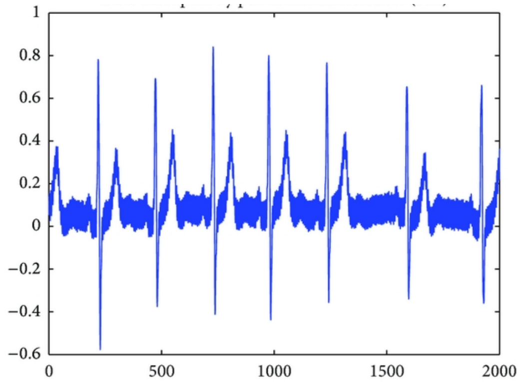


Figure 3.2 ECG corrupted by power Line Interference (PLI) [84]

Baseline wandering

Baseline wander noise is a low frequency greater than 1Hz that appears in the ECG signal. The respiration and body movement are the main sources of baseline wandering. The wandering baseline noise causes troubles when detecting and analyzing the peaks [56].

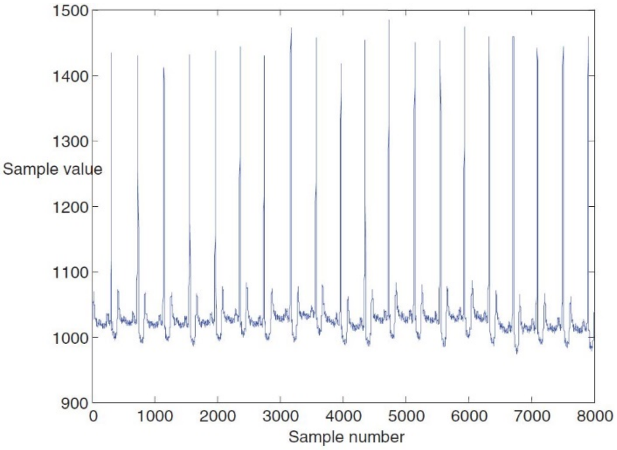


Figure 3.3 ECG signal having Baseline noise [65]

Electromyogram (EMG) Noise (Muscle Artifacts)

The electrical activity of the muscle considers the main source of Electromyogram (EMG) noise. Some of ECG segments could be damaged and interfered due to the EMG noises that released from the muscles. This noise appears as rapid fluctuations and it is faster than ECG waves [63].

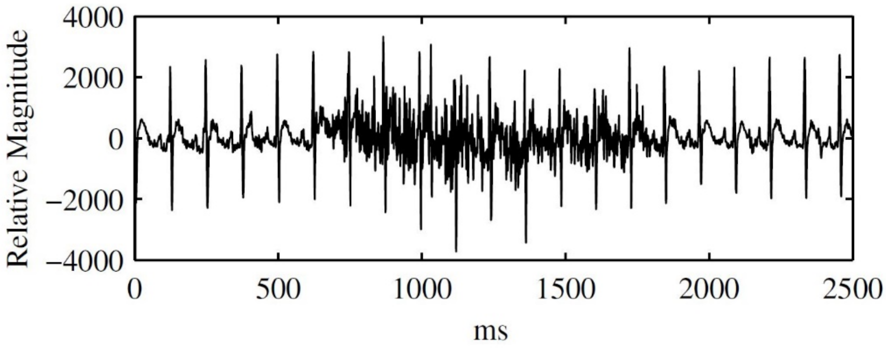


Figure 3.4 Electromyogram (EMG) noise [63]

Electrode Contact Noise

The frequency of electrode contact is less than 0.5 Hz. This noise occurs because of contact loss between the skin and the electrode, which would be caused by the detach of the measurement system from the subject.

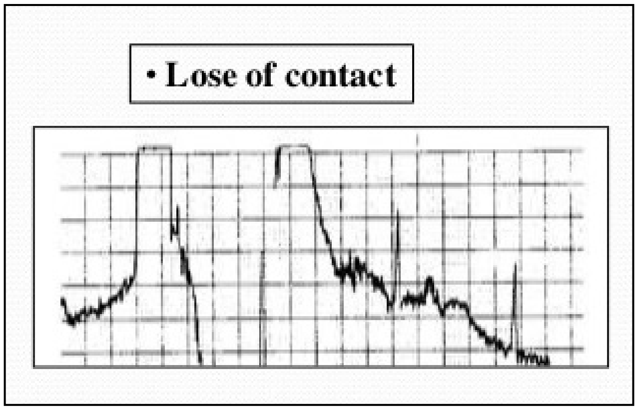


Figure 3.5 Electrode Contact Noise [85]

Motion Artifacts

Motion artifact appears usually because of the movement or vibration when the changes of the electrode-skin impedance in motion causes changes in the transient baseline. Since this impedance changes, a different source impedance will be recognized by the ECG amplifier. The amplifier input voltage relies on the source impedance which changes when an electrode position changes. The movement or vibration can be respiration (0.4–2 Hz), patient movement (1–3 Hz) or transport (3–15 Hz) [87].

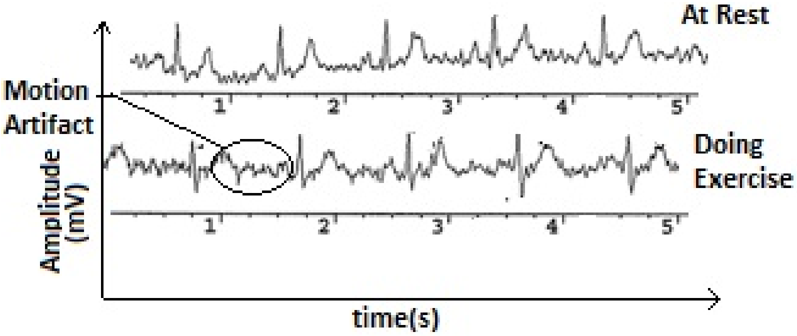


Figure 3.6 The motion artifact [87]

Channel Noise

Channel clamor shows up when the ECG signal is transmitted through channels. This kind of noise is originated because of the bad states of the channel. Primarily it resembles the noise of white Gaussian which incorporates all frequency parts [56].

High-frequency noises in the ECG

High-frequency noises can cause interference in ECG signal like in the mobile phones. In case the mathematical or physical variable is changed quickly then it can cause high frequency [64]. There are other different noise sources that can distort the ECG signal such as the noise that is produced by the electronic equipment used in the circuits for signal processing, by the external electrical interference to the subject and the recording system, and by the sounds of lung, bowel, and breath that pollute the heartbeats signals.

3.4 ECG Filtering Techniques

The techniques of filtering are essential for signal preprocessing and ordinarily is implementing in the ECG analysis systems widely. ECG signal filtering is a procedure that should be implemented. Most of the interference types that influence the ECG signals are sometimes eliminated by using bandpass filters, but even implementing such a bandpass filter, the results are not satisfying. Finding a proper filtering method relates to the noise type contained in the ECG signal [58]. Normally, the ECG signal is extremely sensitive to any external interferences, which means in case any single small noise is merged with the original signal will affect it badly, and that will change in the characteristics of signal. Therefore, the corrupted data by noise must either be filtered or disposed of. Different types of noises were presented in the section 3.3, but in this chapter the filtering techniques are presented for the most common three noises: motion artifacts, electromyogram (EMG) and baseline wander.

Table 3.2 presents three types of noise which are contained in our ECG signal, with the reference to the corresponding frequency range of it and its sources.

TABLE 3.2 NOISE TYPES WITH ITS CHARACTERISTICS

Type of Noise	Noise Sources	Frequency Range
Baseline wander	Respiration and body movement	Below 1 Hz (0.15-0.5) Hz
EMG	Produced by the muscle electrical activity	>100 Hz
Motion Artifacts	Occurs due to the stretched of skin, which leads to a change in skin voltage at the second layer of the skin (stratum lucidum).	0.4-15 Hz

3.4.1 Digital Filters

In the pre-processing phase of the signals, the digital processor of the digital filter to implement numerical operations on the values of sampled signals for filtration reduces or enhances the particular parts of that signal. The processor can be a computer for generic purposes or can be a specialized one such as a digital signal processing chip. In this case, the digital filters can be changed easily without any effect on the circuits of the devices. Due to the flexibility of digital filters design, they became more popular and have been used instead of analog filters. Digital filters process signals in a discrete time and are distinguished by their impulse responses. Two types of digital filters are available. The first type includes the non-recursive filters called the Finite Impulse Response (FIR) filters. The second type is represented by the recursive filters, called Infinite Impulse Response (IIR) filters, due to the feed-back operations of the output signal to the input [75]. Both of FIR and IIR filters are various classes of digital filters and can be implemented for different applications. Selection of any of these two filters depends on the practical implementation of the required application [64].

3.4.1.1 Finite-Impulse-Response Digital Filters

The Finite-Impulse-Response filters are linear phase digital filters, composed of impulse responses with finite duration (finite in length). It means that the time-domain response of the filter to an impulse will be zero after a finite amount of time [76] as explained in figure 3.7.

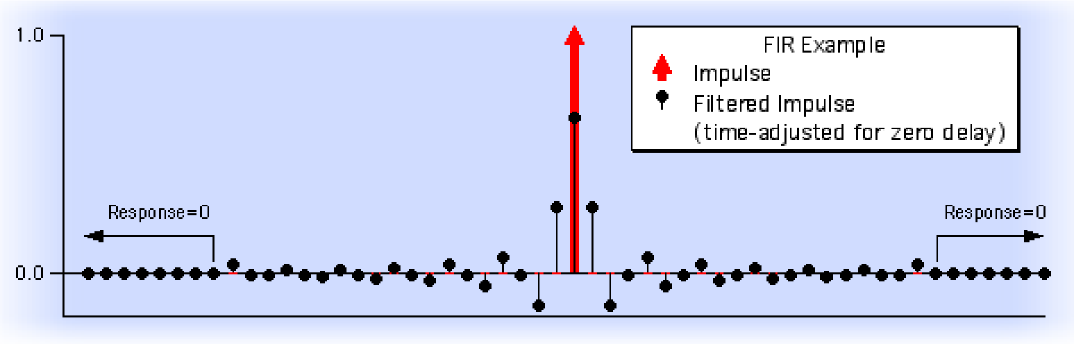


Figure 3.7 FIR Impulse Response [79]

FIR filters are non-recursive digital filters. They have good characteristics and can be included into a design to execute in any kind of frequency response, in a digital way. This filter is realized with the series of multipliers, adders, and delays to obtain an output [77]. Figure 3.8 presents the diagram of a finite-impulse-response filter of order D. Equation (1) describes the relation between input and output sequences, where each output sequence value is the weighted sum of the most recent input values. The top part of the figure 3.8 is the D-stage delay line with (D + 1) taps, where every unit delay is a (z−1) operator in Z-transform notation [78]:

$$\begin{aligned} y[d] &= r_0\, x[d] + r_1 x[d-1] + \cdots + r_D x[d-D] \\ &= \sum_{i=0}^{D} r_i\, x[d-i] \end{aligned} \tag{1}$$

Where:

$x[d]$: input signal,
$y[d]$: output signal,
D: filter order, which has (D+1) terms (taps) on the right side.
R_i: impulse response value, i'th instant of $0 \leq i \leq D$ of the D-order with FIR filter.

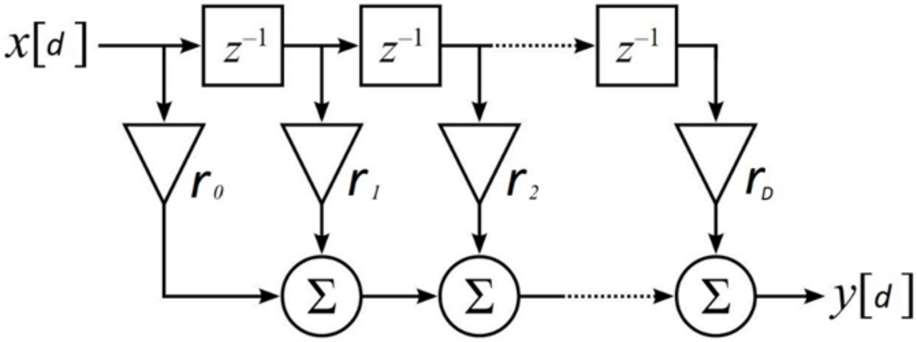


Figure 3.8 FIR Filter Diagram [78]

3.4.1.2 Infinite-Impulse-Response Digital Filters

The Infinite-impulse-response (IIR) filters (shown in figure 3.10) are not linear phase filters and can be either analog or digital. This filter must be implemented recursively. The impulse response of these filters is non-zero over unlimited length of time, which means it persists eternally because the terms recursively return the energy into the input of the filter and then keep it [80], as described in Figure 3.9. From the following equation, we can see that IIR filter consists of a recursive and a non-recursive component.

$$y[d] = \sum_{k=1}^{D} a_k \; y[d-D] + \sum_{k=1}^{F} r_k \; x[d-F] \qquad (2)$$

Where:

$x[d]$: input signal,
$y[d]$: output signal,
D: feedforward filter order,
F: is feedback filter order,
a_k feedforward coefficient,
b_k is feedback coefficient.

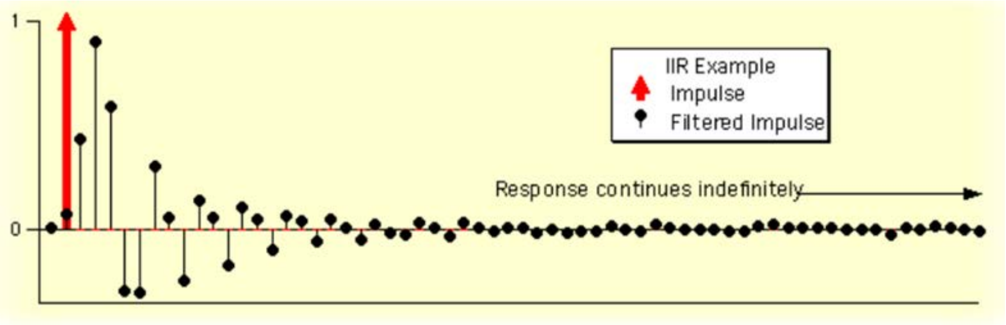


Figure 3.9 IIR Impulse Response [79]

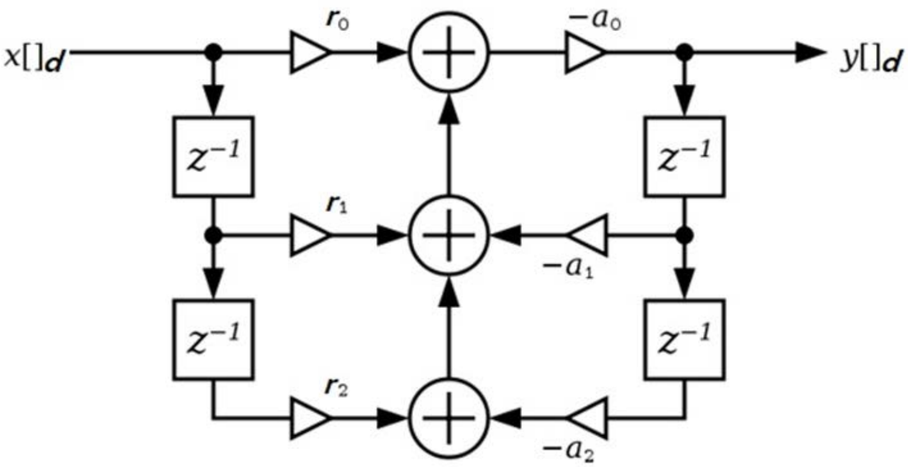


Figure 3.10 IIR Filter Diagram [81]

3.4.1.3 Comparison between IIR and FIR filters

The IIR and FIR filters are two different kinds of digital filters, that can be implemented for different applications. The selection of any one of them is based on the practical performance of the required application [64]. There are many variations between FIR and IIR filtering that will be explained further [82] [83]:

- FIR filters are plain to be designed and can make a delay to the input signal without deforming its phase. This feature makes it to be considered as a stable filter. IIR filters are unstable because it is difficult to implement it and have no certain phases, which means that the delay and distort adjustments can change the poles and zeroes.
- FIR filter can only be digital, whereas the IIR filter can be either analog or digital.
- Usually, the FIR filters require only one MAC (Multiply and Accumulate) per tap, whereas IIR filters require more MAC because FIR filters have a higher-order

compared with IIR, which has lower-order and uses the structures of polyphase. In FIR, most Digital-Signal-Processing (DSP) microprocessors perform the MAC operation in a single instruction cycle.

- FIR filter is contingent on the linear-phase characteristics, whilst the non-linear applications utilize an IIR filter for their operations.
- FIR filters have desirable numeric features. Practically, all DSP filters must be realized utilizing finite-precision arithmetic, which means the number of bits are limited. The utility of finite-precision arithmetic in IIR filters can lead to significant issues generated by the feedback. FIR filters are typically implemented using fewer bits due to the un-use of feedback. Thus, the designer will not have a lot of problems related to implementation of non-ideal calculations.
- FIR filters can be executed utilizing fractional arithmetic, while IIR filters cannot. FIR filter always has a possibility to execute using coefficients of a magnitude smaller than 1.0.
- The FIR filter is adapted to multi-rate applications. "Multi-rate" means either a rate reduction of the sampling or a rate increasing of the sampling or both. In both cases using FIR filters allows deleting some calculations, hence presenting a meaningful computational efficiency. But unlike IIR filters, the calculation must be performed separately for each output; even if this output is eliminated, consequently the feedback will be integrated into the filter.
- FIR filters need more further memory than IIR filters to achieve a specific filter response due to the high calculations during the implementation. Further, some responses are not practical for implementation with FIR filters.

3.4.2 Windowing Methods

The acquisition time of a signal is called *window*. Using windowing methods to design FIR digital filters is quick, opportune, and robust [70]. Windowing is a technique used to minimize the interruptions amplitude at the edges of each finite sequence when performing FFT over a non-integer number of cycles. This technique is composed of multiplying the recorded time (the acquisition time) of the signal by the finite-length of the window with the amplitude that changes rapidly to zero.

Discontinuities happen when the measured signal is not an integer from the periods in which the finite set of data of the measured signal is a shortened waveform, different from the original signal. In this case, the finite set of data produces sharp transition changes and is imposed on the measured signal. These sharp transitions are called discontinuities and are high-frequency components without being part of the original signal. These signals are much higher than the Nyquist frequency, which is twice the rate as the fundamental frequency thus producing a spread version of the fundamental frequency in which it gives the impression that the energy from one signal has leaked into the other frequencies and makes this signal look much wider. This phenomenon is called spectral leakage.

3.4.3 Window Selection

A snap-shot to a frequency spectrum reveals the main lobe of spectral leakage and the side lobes of both sides. For any frequency part in the time-domain, there is a main centered lobe and some side lobes oncoming zero. The peak of lateral lobes refers to the effect of windowing technique on frequencies around the main lobe. The response of lateral lobes to a strong sinusoidal signal can overcome the response of the main lobe of a nearby proximal sinusoidal signal. To reduce the effect of spectral leakage, the lateral lobe roll-off rate must be increased but this process leads to an increase in the main lobe bandwidth.

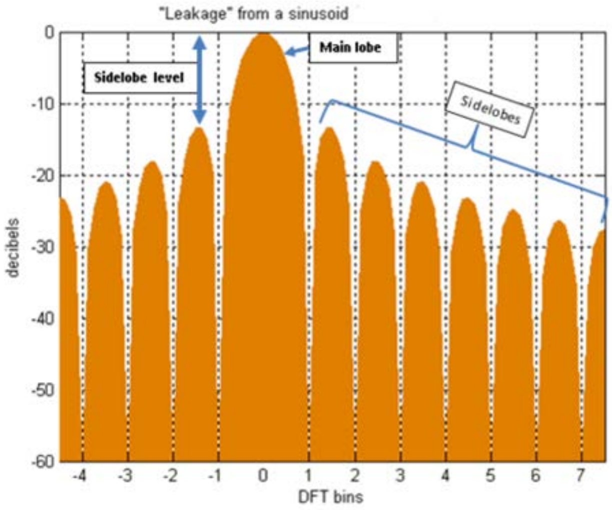


Figure 3.11 Zoomed view of spectral leakage [90]

In addition, the characteristics of each window function are different where each window function has its appropriateness for particular applications, and the selection of a Window function becomes challenging in estimating the frequency spectrum and the content of the signal. The below table 3.3 shall offer a guide-line to examine the response and the behavior of each model window to select the most appropriate one for an application.

TABLE 3.3 SIGNAL FREQUENCY CONTENT OF WINDOW FUNCTIONS

Filter type	Window characteristics	Spectral Frequency Content
Chebyshev Window	Smooth Window w/ high lateral lobe Roll-off rate	Strong interference distant from the fundamental frequency.
-	Low maximum lateral lobe level	Strong interference near to the fundamental frequency.
-	Smoothing Window w/ very narrow main lobe	The fundamental includes two or more signals quite close to each other, where the resolution of spectral is significant.
Kaiser Window	Window w/ wide main lobe	The amplitude accuracy is significant for each single frequency component.
Tukey Window	Uniform Window or No Window	Flat signal spectrum, or broadband frequency content

There is no window optimum in all its aspects and the selection of it should be according to the requirements of a certain application. Different window functions are available. The most important windows functions that are used in this Ph.D research are Chebyshev, Tukey, Taylor, and Kaiser.

i. Chebyshev Window

This filter is used to process the signal for its good characteristics. The main-lobe of it has a minimum width for the given side-lobe attenuation. Chebyshev window is equi-ripple and the height of side-lobe is similar at all frequencies. Chebyshev window can be described according to the Mth-order Chebyshev polynomial defined by the equation (3):

$$C_M(x) = \begin{cases} \cos[M\, cos^{-1}(x)], & for\ |x|\ \leq 1 \\ cosh[M\, cosh^{-1}(x)], & for\ |x|\ > 1 \end{cases} \qquad (3)$$

The Chebyshev window is defined as

$$w_{D\,C}(n) = \begin{cases} \frac{1}{M=1}\left\{\frac{1}{r} + 2\sum_{i=1}^{\frac{M}{2}} C_M \left[x_0\, cos\left(\frac{i\pi}{M+1}\right)\right]\, cos\left(\frac{2ni\pi}{M+1}\right)\right\}, & for\ |n| \le \frac{M}{2} \\ 0, & for\ |n| > \frac{M}{2} \end{cases} \tag{4}$$

where, r is the ripple ratio that defined as $r = \frac{\delta r}{\delta p}$ and

$$x_0 = cosh\left[\frac{1}{M}\, cosh^{-1}\left(\frac{1}{r}\right)\right] \tag{5}$$

With determination of M and r, we can compute x_O from equation (5), and then compute the window coefficients from equation (4).

The sequence is given by $h'(n) = W_{DC}(n)\, h(n)$, where $h(n)$ is the ideal filter impulse response. The below equation determines the resulting FIR filter:

$$H(z) = z^{-\frac{M}{2}} Z\{h'(n)\} \tag{6}$$

Generally, this windowing method is described by the width of main-lobe, thus the altering M can be used to control the resulting filter transmission band. An independent factor r is used to control the ripple ratio of the window. All side-lobes have an equal amplitude. Consequently, the resulting filter stopband is equi-ripple [93].

ii. Taylor Window

This window is almost analogous to the Chebyshev window, but the main-lobe is not the narrowest for a specified side-lobe level. Using Taylor window allows you to make trade-offs between a width of main-lobe and side-lobe level. The distribution of Taylor eschews boundary cutoff; therefore, Taylor window side-lobes are monotonically reduced. The coefficients of this windowing method are not normalized. Ordinarily, Taylor window are most used in radar applications [88].

iii. Tukey Window

It is a significant window due to its effective characteristics, being called *tapered cosine window*. The following equation defines the N–point of the Tukey window [88]:

$$= \begin{cases} \frac{1}{2}\left\{1 + \left(\frac{2\pi}{a}\left[x - \frac{a}{2}\right]\right)\right\} & 0 \le x < \frac{a}{2} \\ 1 & \frac{a}{2} \le \ x < 1 - \frac{a}{2} \\ \frac{1}{2}\left\{1 + \cos\left(\frac{2\pi}{a}\left[x - \frac{a}{2}\right]\right)\right\} & 1 - \frac{a}{2} \le x \le 1 \end{cases} \tag{7}$$

where x represents an N–point linearly spaced vector. The parameter α indicates the ratio of the tapered section to constant section with $0 \le \alpha \le 1$. If you assign a negative value, $\alpha \le 0$, an N-point rectangular window is returned. If you assign $\alpha \ge 1$, a Hann window is returned [89].

iv. Kaiser Window

Altering a parameter α allows the side-lobe level of this window to be controlled in relation to the peak of main lobe. The parameter β of Kaiser Window affects the side-lobe attenuation α db [65]. The adjustment of the filter length allows modifying the main-lobe width.

$$B = \begin{cases} -0.1102(a - 8.7),\ a > 50 \\ 0.582(a - 21)^{0.4} + .07886(a - 21), 21 \le a \le 50 \\ 0,\ a < 21 \end{cases} \tag{8}$$

Here, $\alpha = -20 \log 10\delta$ is the attenuation of the stop band in db. By increasing parameter β, the side lobe amplitude gets reduced. The filter order D for FIR filter is presented by:

$$D = \frac{a - 8}{2.285\Delta\omega} + 1 \tag{9}$$

where, Δω is the width of the smaller transmission area.

3.4.4 Filters Response Analysis

The examination of the four filters have suggested that the Chebyshev filter algorithm offers the best result for Low-pass filter from frequencies between 0.05 Hz to 100 Hz respectively. Four filters were examined under the same parameters' values:

- Chebyshev
- Taylor
- Tukey
- Kaiser

The examination determined the best noise rejection against the Electromyogram (EMG) Noise. The design criteria for the above-mentioned filter are given in Table 3.4.

TABLE 3.4 VALUES OF FILTERS PARAMETERS

Parameters	**Values**
Cut-off Frequency (Fc)	100
Filter Order	400 Hz
Sampling Frequency (Fs)	360 Hz
FIR Filter Method	Window

The tests' results revealed that the magnitude response was as follow:

a. Chebyshev window Magnitude Response

Low-pass window has shown sharp roll-off at 97 Hz (-3 dB) with a clean signal starting at 103 Hz. Ringing in the sampling signal has accord at frequencies greater than 105 Hz with low power of less than -100 dB in which the data set becomes very insignificant to cause any issue with the calculation.

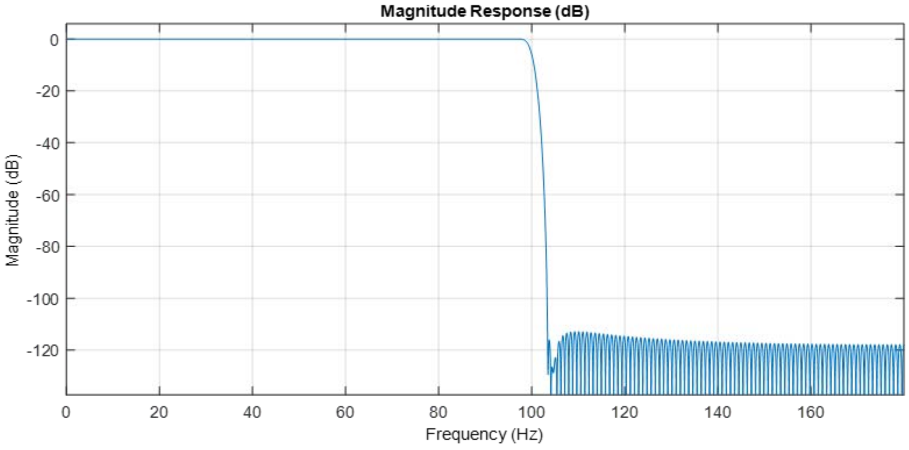


Figure 3.12 Chebyshev window Magnitude Response -Lowpass

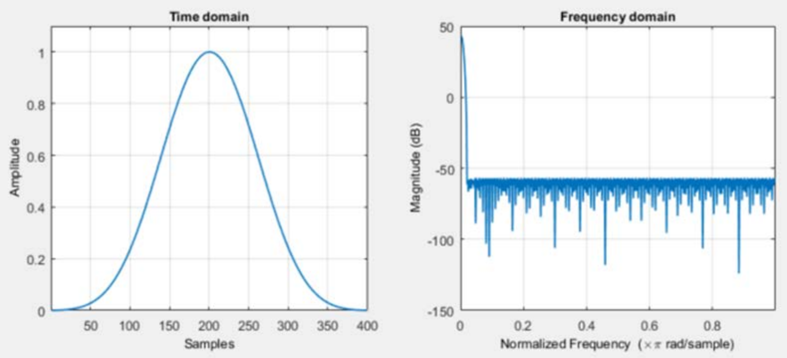


Figure 3.13 Time and Frequency Domain-Chebyshev window

b. Kaiser window Magnitude Response

Low-pass window has shown minor ripple effects with sharp roll-off at 98 Hz (-3 dB), and sharp ringing starting at 100 Hz (-22 dB). Hence, the data set could impose significant interference to the ECG signal.

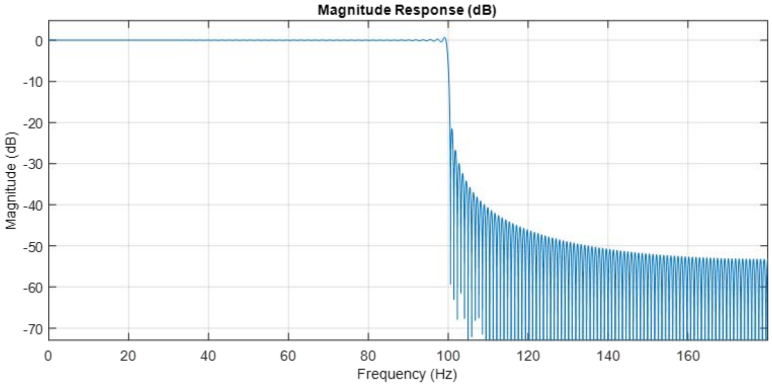


Figure 3.14 Kaiser window Magnitude Response -Lowpass

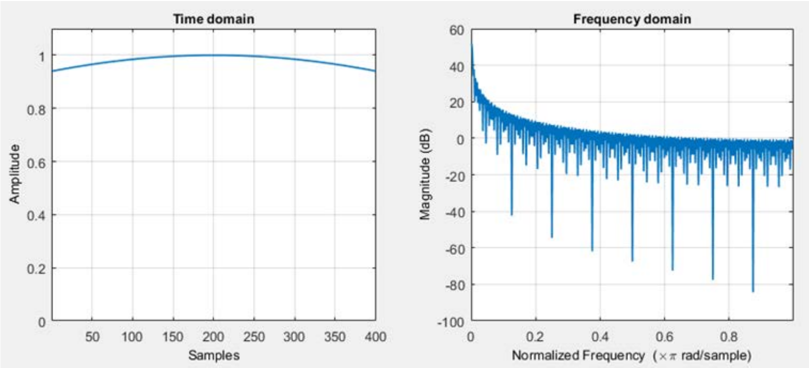


Figure 3.15 Time and Frequency Domain-Kaiser window

c. Taylor window Magnitude Response

Low-pass window has shown ripple effects with sharp roll-off at 99 Hz (1 dB), and sharp ringing starting at 101 Hz (-23 dB). Hence, the data set could impose significant interference to the ECG signal. Note: The Side-lobe level was set to 13.

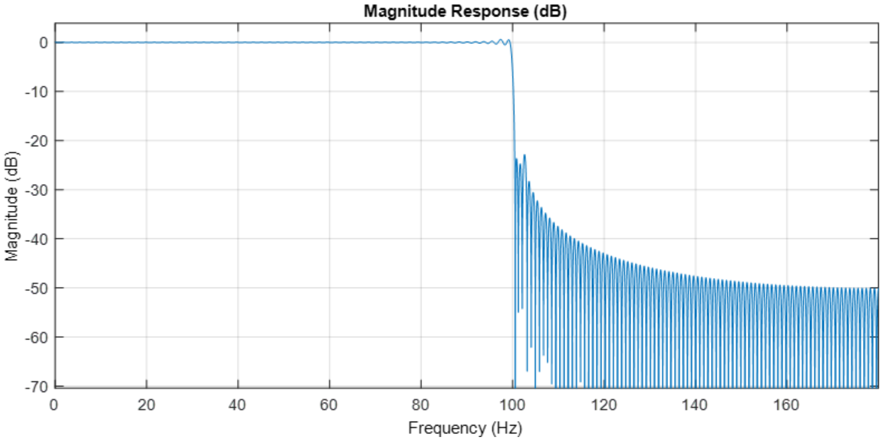


Figure 3.16 Taylor window Magnitude Response -Lowpass

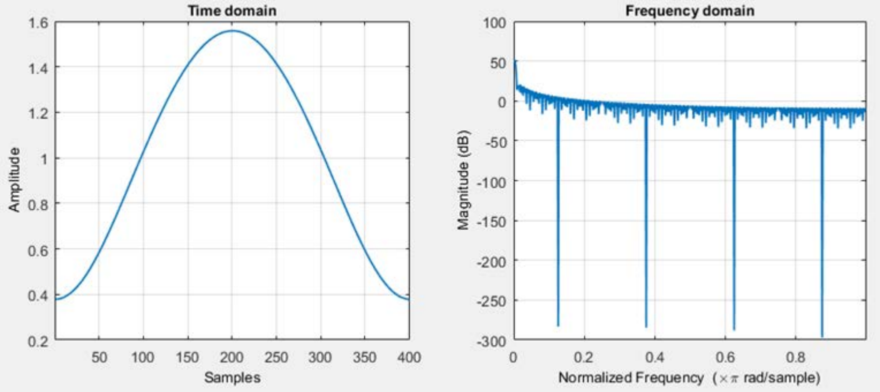


Figure 3.17 Time and Frequency Domain-Taylor window

d. Tukey window Magnitude Response

Low-pass window has shown low ripple effects with sharp roll-off at 98 Hz (1 dB), and sharp ringing starting at 101 Hz (-22 dB). Hence, the data set could impose significant interference to the ECG signal.

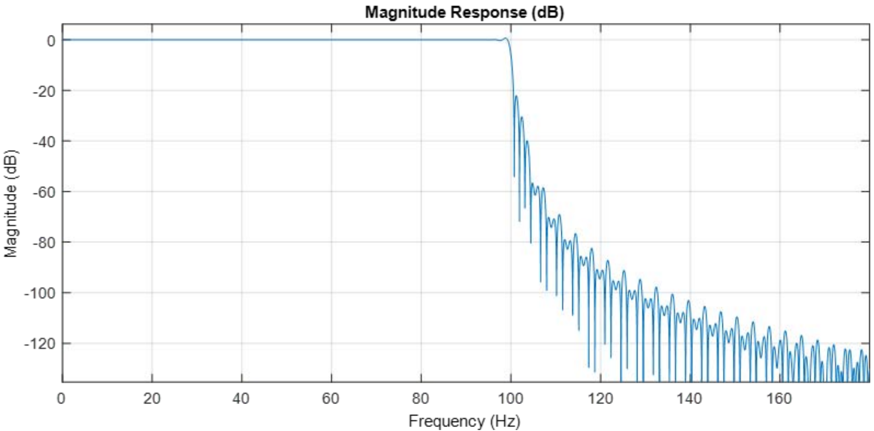


Figure 3.18 Tukey window Magnitude Response -Lowpass

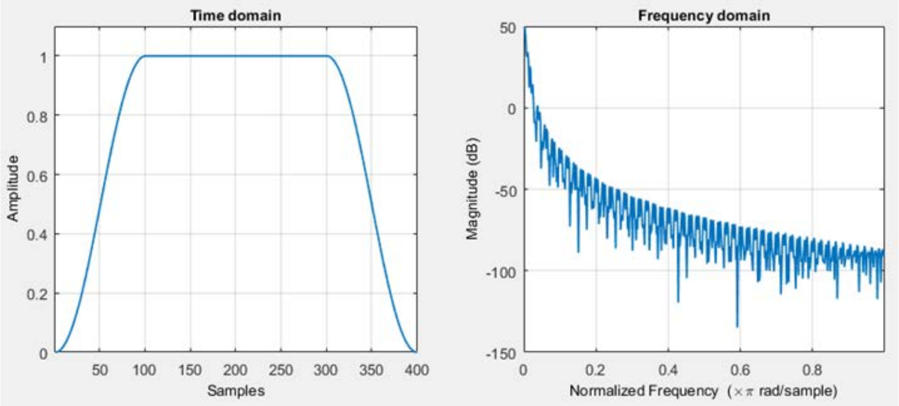


Figure 3.19 Time and Frequency Domain-Tukey window

3.5 Savitzky-Golay (SG) filter

The SG filter was discovered by researchers Savitzky and Golay in 1964 as a method of data smoothing based on the approach of local least-squares polynomial approximation. To comprehend this method implies to involve applying a polynomial on a number of input samples and thereafter estimating the resulting polynomial at one point and that is during the approximation which equates discrete convolution with the fixed impulse response. These researchers were attempting to smooth the noisy signals of the chemical spectrum analyzers and they have discovered that the least squares smoothing could reduce the noise and maintains the height and shape of the waveform peaks. The SG filters can be applied in smoothing noisy ECG signals. Peak and shape conserving property of the SG filters has proved to be quite efficient for precise ECG processing [94]. Birle el al. (2015) used Savitzky-Golay filter to remove a noise and smooth the noisy ECG signal without loss of much information, characteristics, and originality of the signal. Nahiyan, K. M. T., and Abdullah-Al Amin [95] proposed a method based on Savitzky-Golay filter to cancel the baseline wander from an ECG signal, which is moving average filter, considering the order of polynomial with the moving average when the signal is approximated. This method allows to approximate the baseline wander with high efficiency. Although in some cases the ECG signal is almost distorted when contrasted with the habitual methods of polynomial fitting, and it still outstands the conventional methods in terms of accuracy, generalization, and simplicity. SG filter can be employed upon a time-domain of signal and has not any parameter subject to a frequency domain. This makes it appropriate for ECG signal processing. Thus, utilizing SG filter will not impact the portions of ECG signal that contains overlapping frequency spectrum with Baseline wander. Therefore, in this work, we are interested to use the Savitzky-Golay filter to remove the baseline wander and motion artifact and smoothing the ECG signal.

The below theoretical base of SG filter has been taken from Orfanidis book [98] because it is presented in a simple way.

Let us consider that X is the data vector with *N* data points, where *N* is odd, in the form *N=2M+1*. This means that M points are on both x_0 sides:

$$X = [x_M, \dots, x_{-1}, x_0, x_1, \dots, x_M]^T \tag{10}$$

Now, we consider N data samples in X and are fitted by the polynomial of degree d:

$$\hat{\mathrm{x}}\mathrm{m} = c_0 + c_1\mathrm{m} + \cdots + c_d\, m^d, \qquad -\mathrm{M} \le \mathrm{m} \le \mathrm{M} \tag{11}$$

There are d+1 polynomial basis vectors s_i, i=0,1,…, d and the components are defined as:

$$s_i(m) = m^i, \qquad -M \le m \le M \tag{12}$$

Here, the corresponding N*(d+1) matrix S has s_i columns:

$$\mathrm{S} = [s_0, s_1, \dots, s_d] \tag{13}$$

The smoothed values in the equation (66) can be formulated in the vector form:

$$\hat{\mathrm{X}} = \sum_{i=0}^{d} c_i s_i = [s_0, s_1, \dots, s_d]\begin{bmatrix} c_0 \\ c_1 \\ \cdot \\ \cdot \\ \cdot \\ c_d \end{bmatrix} = \mathrm{Sc} \tag{14}$$

After that, the SG filter design steps can be summarized as follows:

$$F = S^T S \qquad G = SF^{-1} \tag{15}$$

$$\mathrm{B} = \mathrm{GS}^{\mathrm{T}} = \mathrm{SG}^{\mathrm{T}} = \mathrm{SF}^{-1}\mathrm{S}^{\mathrm{T}} \equiv [\mathrm{b}_{-\mathrm{M}}, \dots, \mathrm{b}_0, \dots, \mathrm{b}_{\mathrm{M}}] \tag{16}$$

The components of B are SG filters of length N and order d. The corresponding smoothed data vector will be:

$$\widehat{\mathrm{X}} = \mathrm{BX} \leftrightarrow \hat{\mathrm{x}}_m = b_m^T\mathrm{X}, \quad -\mathrm{M} \leq \mathrm{m} \leq \mathrm{M} \tag{17}$$

The resulting of length N, order d, and SG filter for the smoothing a noisy sequence $x(n)$ will be formulated in the steady form:

$$\mathrm{y(n)} = \sum_{m=-M}^{M} b_0(m)\mathrm{x(n+m)} = \sum_{m=-M}^{M} b_0(-m)\mathrm{x(n-m)} \tag{18}$$

3.6 Mean Square Error (MSE)

It is the standard parameter for estimation of the signal quality fidelity and is considered as the best choice for the design engineers who attempt to optimize signal processing algorithms [96]. To measure the value of mean square error, we have to calculate the squared norm of the difference between a signal s and its approximation $s\hat{}$ then divide the result by the number of elements in the signal [97], as given below:

$$MSE = \frac{\|s - s\hat{}\|^2}{k} \tag{19}$$

3.7 Envionment and Dataset

3.7.1 MATLAB

MATLAB environment is a programming platform created especially for engineers and scientists. It is a thorough, robust, and plain to use platform for technical and scientific computations. It utilized for different purposes such as data analyzation, algorithms development, models and applications creation. MATLAB has an ability to build its own reusable tools. Filter design and analysis tools have been utilized in this research to design FIR low-pass and high-pass filters using window design methods. WFDB toolbox was utilized in

MATLAB to convert the ECG signal dataset files into (.mat) files so that they can be performed in MATLAB.

3.7.2 ECG Dataset

The ECG database used in this work was obtained from the online PhysioNet database [91] that provides free permission to access enormous groups of recorded physiological signals. The dataset entitled as MIT-BIH Arrhythmia Database has recorded signals that are converted into digital at 360 samples per second per channel with 11-bit resolution over a 10mV range [92]. A text header file (.hea), a binary file (.dat) and a binary annotated file (.atr) describe the ECG signals, while the recordings of noise were generated utilizing physically active volunteers and standard ECG recorders, electrodes, and leads.

3.8 The New Proposed Hybrid Filtering Model Implementation and Results

The ECG signal dataset used in this research is corrupted by three types of noise during the recording process. Also, the baseline of signal has different trends which do not represent the true amplitude. In this section, I presented a new technique by integrating windowing methods, thresholding algorithma and Savitzky-Golay filtering in order to denoise the signal as shown in figure 3.20. The results have proved to be a robust solution for filtering the ECG signals.

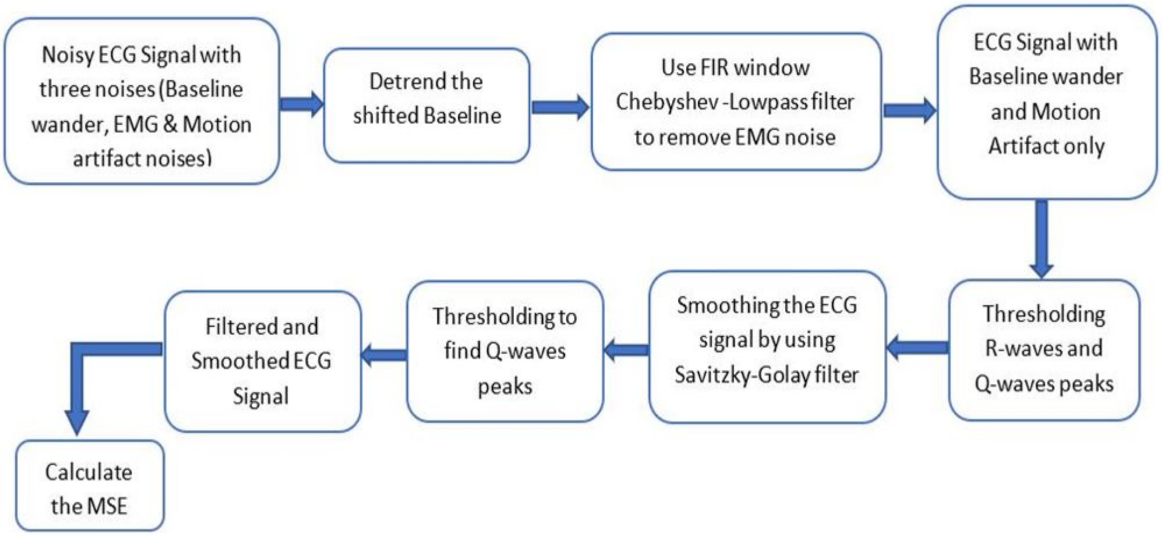


Figure 3.20 Block diagram of the filtering model

The process of implementation of the proposed technique was accomplished through several steps, as illustrated below:

Phase 1: Firstly, we converted the used ECG dataset by using WFDB tool to the formula (.mat) and then load it and display it in MATLAP, as shown in figure 3.21.

Phase 2: The signal shows a baseline shift which does not represent the real amplitude of the signal. In order to detrend the signal, we fitted a low order polynomial to the signal and utilized the polynomial to detrend it; the entire signal detrended perfectly as shown in figure 3.22.

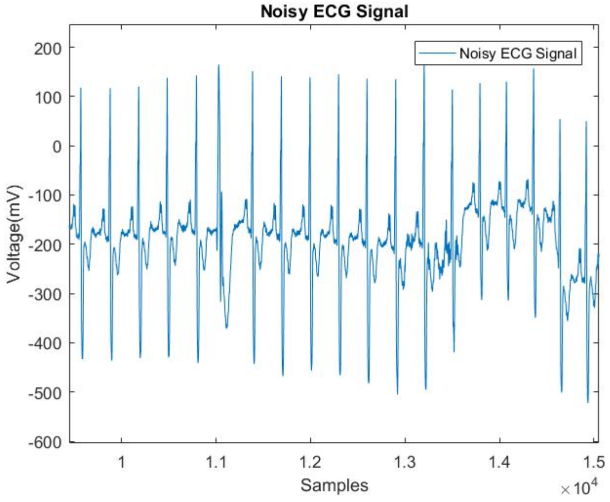


Figure 3.21 Segment of noisy ECG signal

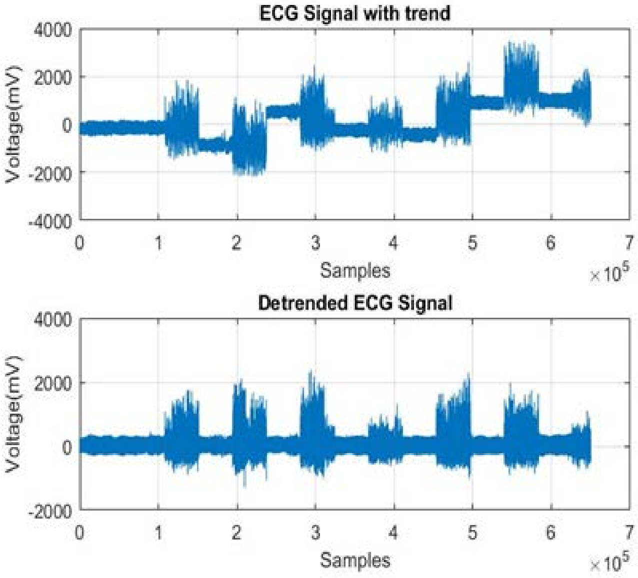


Figure 3.22 48-hour recording ECG signal with trend and after detrend

Phase 3: After that, we applied the FIR windowing method using the Chebyshev lowpass filter to denoise the EMG noise which has more than 100Hz. A sampling frequency of 360 Hz has been used for the filter because the recording dataset was digitized at 360 samples per second. The cut-off frequency was 100Hz. The used filter order was 400 and we utilized a high order to get more accurate result. Experimentally, we found that if the filter order increased more than 400 then a ripple will raise, and thus new noise appeared. If we can decrease the filter, this will be at the expense of accuracy. Memory size and processor speed of the device should be taken into consideration to determine the number of filter order. The high frequency noise has been removed with less than 5mV as shown in figure 3.23.

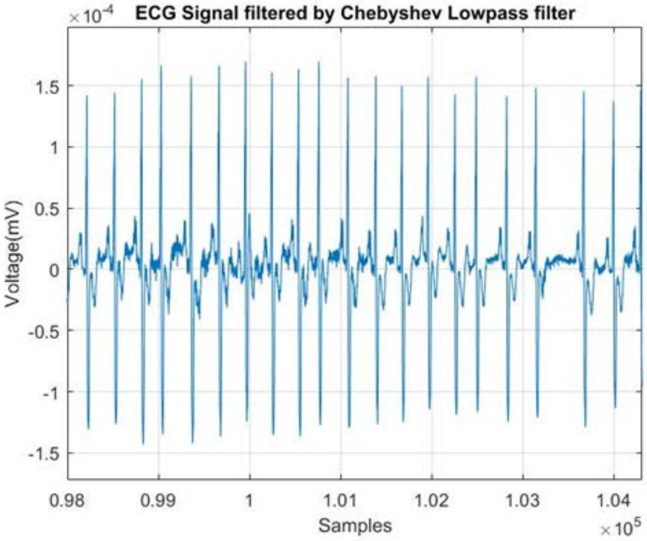


Figure 3.23 ECG Signal filtered by Chebyshev Lowpass filter

Phase 4: Thresholding the peaks of QRS-complex by using thresholding algorithm. In this phase, we threshold the only R-wave and S-wave. The R-waves detected by the thresholding peaks is above 0.5mV, using ‘MinPeakHeigh’. The R-waves are separated by more than 200 samples. Therefore, we utilized a function called 'MinPeakDistance' to specify the peaks distances and then we will be able to cancel the unwanted peaks. For the S-wave thresholding we inverted the filtered signal and we applied the same function and values of R-wave. The figure 3.24 shows the thresholding peaks in the signal.

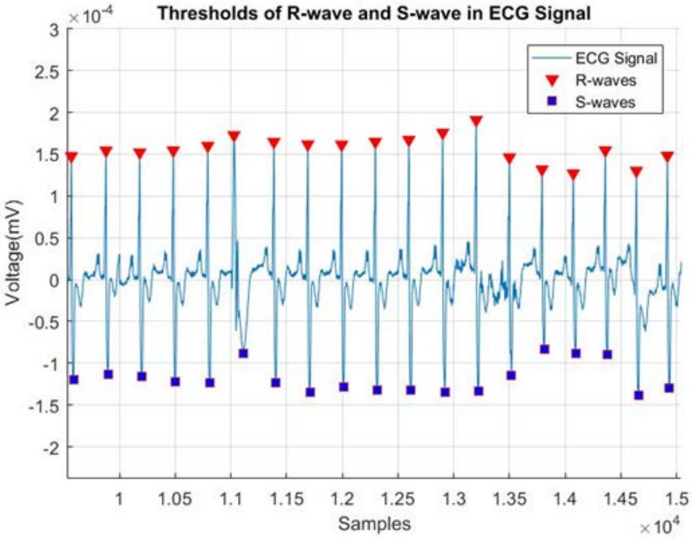


Figure 3.24 Thresholds of R & S-waves in ECG Signal

Phase 5: Next, we attempted and determined the Q-waves locations. Thresholding the peaks to locate the Q-waves results in detection of undesirable peaks where the Q-waves are buried in the noise. Consequently, we have filtered the signal and then we have found its peaks. Savitzky-Golay filter is applied to eliminate the baseline wander and motion artifacts noise in the signal. Changing the values of order filter and frame of the filter effects the accuracy of filtering results. Through experiments, we found that the value 1 for filter order and value 9 of the frame parameter give better results. Figures 3.25 and 3.26 shows the ECG signal after smoothing the signal.

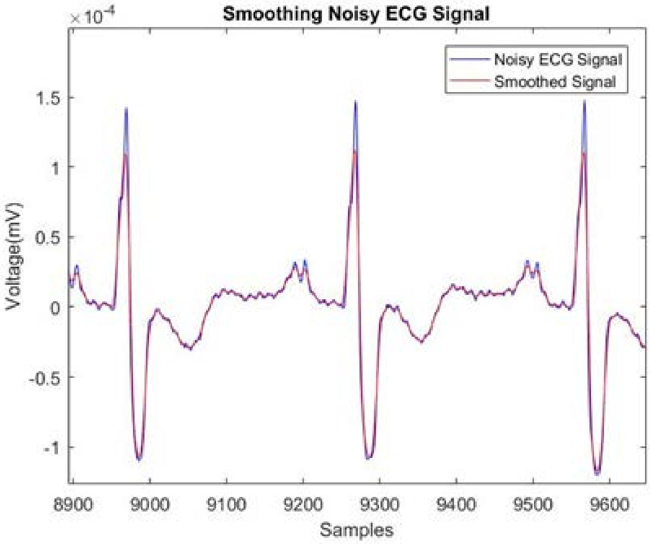


Figure 3.25 Smoothing in ECG Signal

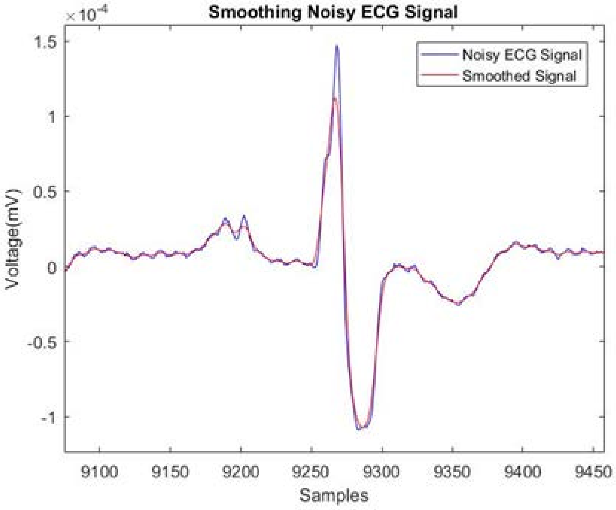


Figure 3.26 Enlarged the Smoothed ECG Signal

Phase 6: We executed a peak detection on the smoothed signal and utilized logical indexing to detect the Q-waves locations between -0.2mV and 0.2mV. The Q-waves are separated by more than 30 samples. Figure 3.27 shows that the QRS-complex has been identified in the filtered ECG signal.

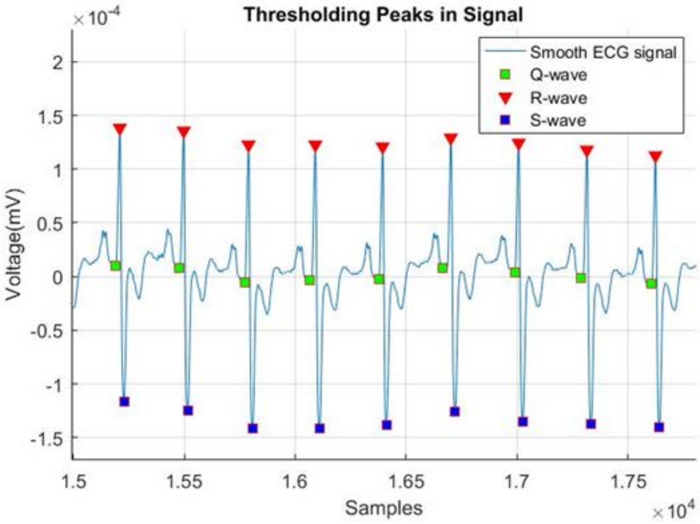


Figure 3.27 Threshold QRS-complex in filtered ECG Signal

Phase 7: Apply the Mean Square Error (MSE) algorithm to calculate the average difference among the QRS-complex in the raw, detrended, filtered, and smoothed signal. The results are presented in table 3.5.

TABLE 3.5 MSE OF QRS-COMPLEX

Signal	**Mean Square Error (MSE)**		
QRS-complex	**R-wave**	**S-wave**	**Q-wave**
Original vs Detrended	53.8323	52.9964	54.7763
Original vs Filtered	567.1675	-272.1602	10.9185
Original vs Smoothed	567.1676	-272.1602	10.9185
Detrended vs Filtered	513.3352	-325.1566	-43.8577
Detrended vs Smoothed	513.3352	-325.1566	-43.8577
Filtered vs Smoothed	1.6899e-05	-2.9398e-06	-3.1697e-06

3.9 Conclusion

In this chapter we have compared the digital filters FIR and IIR underling their advantages and disadvantages and the result shows that the FIR filtering can be the best option for our application. Different windowing techniques has been studied and analyses according to their magnitude responses, the examination of filters responses have suggested that the FIR Chebyshev filter algorithm offers the best result for Low-pass filter from frequencies between 0.05 Hz through 100 Hz respectively, and it could perfectly remove the electromyogram (EMG) noise. The dataset of ECG signal used in this research contains a baseline shift which does not represent the real amplitude of the signal.

Therefore, we must detrend the signal before to apply any filtration on the signal. We fitted a low order polynomial to the signal, and we used the polynomial to detrend it. Thresholding the peaks of QRS-complex is very important since it corresponds to the depolarization of the right and left ventricles. This phase is necessary in the feature extraction stage; therefore, it can be utilized to define the patient's cardiac rate or can also predict malfunctions of the heart. The undesirable peaks are detected by thresholding them. When we locate noisy Q-waves, we smooth the signal and we find the peaks. Savitzky-Golay filter is applied to eliminate the baseline wander and motion artifacts noise in the signal. Filtering the ECG signal using SG filter was efficient and, in some cases, it reduced the R-waves voltage to a certain extent. In conclusion, the experimental results have proved that the proposed hybrid filtering model offer robust results in the case of ECG signal filtering.

CHAPTER 4. ATRIAL FIBRILLATION AUTOMATIC DIAGNOSIS BASED ON ECG SIGNAL USING PRETRAINED DEEP CONVOLUTION NEURAL NETWORK AND MULTICLASS MODEL FOR SVM

4.1 Introduction

Computer Aided Diagnosis of various cardiovascular diseases has taken a precedent over other techniques as another viable tool to diagnose patients with cardiovascular diseases. These tools could offer an added value to medical professionals in terms of accuracy and speed, which otherwise could prove to be challenging especially in critical conditions.

Deep Convolution Neural Network D-CNN method has been a leading technique used by many researchers, using neural layers for each layer to search for a feature. As the process moves from one layer to the next, the function starts to approach the connecting layer where the routine connects the image/signal to the prospective classification.

Atrial fibrillation (AFib) is the medical term for a heart disease condition associated with the irregular pulse in the two atria which is the upper chambers of the heart causing uneven flow of blood from atria to the two ventricles (the lower chambers of the heart) [99, 100]. Commonly, the AFib readouts in the electrocardiogram ECG are associated with the lack of consistent P waves; alternatively, rapid oscillations or fibrillatory waves are present that differ in shape, size and timing which shall be associated with an irregular response of ventricular when the atrioventricular conduction is in a normal case. [99]. Figure 4.1 illustrates the normal heart activity on the left side and AFib condition on the right side.

Moreover, the risk of AFib increases with growing old. According to the Centers for Disease Control and Prevention (CDC), more than 6 million people suffer from atrial fibrillation condition, and this prevalence is growing up with the aging [100]. Some patients who have AFib cannot recognize that they have it and do not have any physical symptoms even if it is a possible serious cause of stroke [104]. Additionally, medical costs of the patients of AFib disease in the U.S. are around 6 billion dollars per year [100].

Therefore, the early diagnosis of AFib is extremely important, since it helps the affected people to obtain treatment in a timely manner, thereby reducing mortality. Early diagnosis of atrial fibrillation can be done based on the electrocardiogram (ECG).

Clinical Diagnosing Systems are used to monitor critical conditions in patients and provide medical professionals with the recorded data that may include classification and/or critical and life-threatening information. Hence, the accuracy of the classified data has become an important criterion of the system design. D-CNN technique with added feature specific layers could provide needed accuracy as the number of feature-defined layers increase, which may require an intense computational power to meet the required accuracy and reduce training time.

Deep learning is a class of machine learning based on preset criteria of the data defining the class. Typically, deep learning is implemented by utilizing a neural network architecture [101]. It consists of three layers: an input layer, hidden layers in which these layers are connected successively, and then the output layer [102]. All interconnected layers are linked through nodes (neurons).

The relationship of multiple layers of deep learning neural network is nonlinear and it uses the backpropagation algorithm for training [103]. Commonly, CNN or ConvNet is considered as one of the most popular neural network techniques [103]. Therefore, we proposed the D-CNN for implementing the risk prediction model and automatic diagnose of atrial fibrillation.

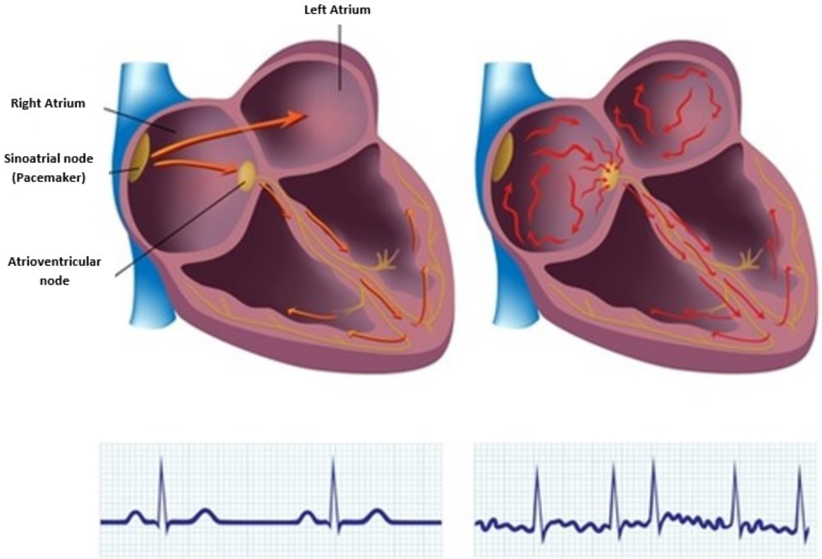


Figure 4.1 (left) Normal Heart Activity. (right) Atrial Fibrillation (AFib) Disease [100]

4.2 Literature review

Nowadays, advanced tools and techniques have significantly improved the algorithms of deep learning. D-CNN has been utilized in the medical research fields as a state-of-the-art technique. Acharya et al. [103] designed an application for automated detection of myocardial infarction utilizing 11-layer Deep CNN based on ECG signals. This study implemented using normal and abnormal (MI) ECG signal with noise and without noise. For ECG beats with noise, the average accuracy, the sensitivity and the specificity were 93.53% and 93.71%, 92.83% respectively. For ECG beats without noise, the average accuracy, the sensitivity and the specificity were 95.22% and 95.49%, 94.19% respectively. These researchers have employed two various datasets one with noise and the other without noise. The proposed system has achieved high-performance results even with noises present in the signal. In the context of medical image analysis, Tajbakhsh et al. [105] tried to find out whether using the pre-trained deep Convolutional Neural Networks with adequate fine-tuning can eliminate the necessity of training deep CNN from the first stage. Four different medical imaging applications are considered in 3 specialties like cardiology, radiology and gastroenterology comprising classification, detection, and segmentation from three different imaging modalities. The AlexNet architecture has been employed in these experiments. Parameters of learning are used in AlexNet for training and fine-tuning. In each AlexNet the training and fine-tuning took around 2-3 hours and relied on the training set size. A free-response operating characteristic (FROC) analysis is used for polyp and PE detection. For the training phase, the Caffe library was utilized and fine-tuning CNNs. The experiments confirmed the importance and potential of CNNs for processing medical imaging because both of fully trained CNNs and deeply fine-tuned CNNs performed better than the handcrafted alternatives.

Erdenebayar et al. [106] implement a method to predict the AF automatically utilizing the CNN model to extract features from the data. The data was preprocessed utilizing a discrete wavelet transform and band-pass filter to remove the two types of noises which are high-frequency noise and baseline wandering from the ECG signals. 3 to 13 layers of convolutional, pooling, and MLP were designed and the output layer has two classes for Normal and AF. The beginning points of AF segments cannot be detected. Python v.3.5 with the Keras library were used to implement their model. They achieved 98.7% of prediction accuracy. Bahareh et al. [107] proposed a Paroxysmal Atrial Fibrillation (PAF) patient screening system from the ECG time-series signals directly that is by utilizing a deep CNN. Two different approaches have been applied in this paper to investigate the PAF classification issue, the first is an end-to-end Convolutional Neural Networks to extract the features from the ECG signals to output with two classes and the CNN took 88 epochs to complete the training; the correct classification rate (CCR) is 85.33%. The second one uses the first few layers from the CNN network to acquire features and then other conventional classifiers such as MLP (CCR is 86.33%), KNN (CCR is 91%), and SVM (CCR is 90%) have been applied. They did not use a validation set in their experiments because of the small size of their available data and they used only training and testing sets.

Runnan et al. [108] developed a method based on 2D convolutional neural network and continuous wavelet transform in order to detect the AF by analyzing the time-frequency features of the ECG signals. This method is compared with other existing ones. It can be able to detect AF episodes with the use of five beats only. This algorithm obtained a sensitivity of 99.41%, specificity 98.91%, positive predictive value 99.39%, and overall accuracy 99%. Oliver et al. [109] presented a straight forward approach for AF detection in heart rate (HR) signals based on deep Recurrent Neural Network (RNN) using Long Short-Term Memory (LSTM). Their proposed method obtained an accuracy of 98.51% with 10-fold cross-validation in ten subjects.

In addition, there are a few published papers that applied the transfer learning approach using deep CNNs. Ribeiro et al [112], employed to explore the approaches of Deep Learning and Transfer Learning with the used of CNNs to enhance the classification accuracy of colonic polyp disease. They surveyed different architectures to estimate the impact of the number and size of filters in the applied classification of this work besides the number of output units in the last layer (fully connected layer). Several pre-trained CNNs architectures such as CNN-M, CNN-S, AlexNet, VGG DV16 & 19, and Google LeNet have been explored and estimated by the authors to extract features from the images of colonoscopy by knowledge transfer between the medical and natural images presenting what is called off-the-shelf CNNs features. In this work, the pretraining CNNs achieved the best result. Lévy D. and Jain A. [113], presented a deep learning Convolutional Neural Network that uses transfer learning, followed by a pre-processing stage and data augmentation in order to classify pre-segmented breast masses from mammograms. In their experiments, they used the Digital Database for Screening Mammography (DDSM). Three network architectures have been evaluated in this work: a shallow CNN (the baseline model), AlexNet and GoogLeNet in which they achieved accuracy of 60%, 89%, and 92 respectively. The approach obtains good results in which the interpretability provides more comfortable adoption in real-world environments.

Jiang et al [114], presented a transfer learning method utilizing pre-trained CNN for Paroxysmal Atrial fibrillation (PAF) automatic detection from ECG data from the dataset and BCG data from acquisition equipment in which the data is preprocessed and segmented as a 24-s frame followed by 17-layer 1-dimensional CNNs. The designed CNN was pre-trained by ECG data that has a large amount of knowledge, which is transferred to BCG data that has a smaller amount. 10000 frames of the ECG data from the database have been employed to pre-train the convolution neural network as well as 1200 frames of BCG data from the acquisition equipment were utilized to fine-tune the network thus obtaining the results of classification. The accuracy, sensitivity, specificity, and precision of classification performance were 95.8%, 98.3%, 93.3%, and 93.7% respectively. Raghu M. et al [121], studied the transfer learning efficiency based on the applications of medical imaging. Their experiments were on two datasets: medical imaging dataset that has medical images and CIFAR-10 dataset that consists of natural images. Transfer learning has been successful in moving features in spite of the differences between medical images and the domains of natural images. In this paper, two methods have been used to execute this analysis. The first one is Filter and Activation Visualization; the second one is Canonical Correlation Analysis (CCA). Also, the representations that were obtained over ImageNet pretraining, random initialization, and Mean Var initialization are compared. The authors explored that transfer learning increases the speed of convergence significantly.

In the case of my new proposed automatic diagnose system for atrial fibrillation, as it will be presented and discussed in the next sections of this chapter, the transfer learning technique based on the pre-trained CNN model and the Multiclass SVM classifier have been examined, analyzed, used and tested to solve a classification problem. The chief objective of classification is the automatic diagnosis of AFib using a small dataset. This study was based on three experiments: feature extraction, transfer learning with data augmentation and transfer learning without data augmentation. The last experiments based on transfer learning without data augmentation obtained the top result with 99.21% of accuracy as it will be explained in section 4.5. This experiment gave the best result compared with the other works in this approach to the best of our knowledge.

4.3 Materials and Methods

4.3.1 Data used

The use of recorded ECG signals became an important object of research in medical decision support systems. The used dataset of our proposed work was obtained from PhysioNet online website [110]. Short-term recorded ECG signals are utilized as a major input of the presented method to predict arrhythmia automatically. Several signals are classified: a normal signal, an atrial fibrillation case, a different rhythm, very noisy signals. The length of the recorded signals ranges between 30 to 60 seconds as shown in Table 4.1. The training set is consisting of 400 signals and these signals are converted to images to train the pre-trained CNN model.

TABLE 4.1 DATA DESCRIPTION OF THE TRAINING SET

Classes	Labels	Time Length (s) of Signal	
		Min	Max
Atrial Fibrillation	AFib	10.0	60
Normal Signal	Normal	9.0	61.0
Other Rhythm	Other	9.1	60.0
Too Noisy Signal	Noisy	10.2	60

4.3.2 Deep Convolutional Neural Networks D-CNNs

D-CNN method has been a leading technique used by several researchers in which the method utilizes additional neural layers for each layer to search for a feature. As the process moves from one layer to the next, the function starts to approach the connecting layer where the routine connects the image/signal to the prospective classification. Generally, the architecture of Deep-CNN algorithm consists of four stages to achieve fully connected ECG signals to their classifications. Figure 4.4 illustrates a simple CNN architecture. These stages are the following:

i. Convolution Layer

This layer places a set of the ECG signal through a set of convolutional filters in which each filter defines a specific feature in the ECG signal. Each feature represents a parameter in the class under-examination.

ii. Pooling

Pooling is a process whereby the algorithm preforms a nonlinear down-sampling algorithm, which reduces the learning parameters the network requires. There are two types of pooling layers. One is the average pooling layer which collects the average of whole input values for a little neighborhood in the image into the neighboring layer. The other is the max-pooling layer which takes the maximum value inside a receptive field of the image to the neighboring layer. Max-pooling is utilized in the most recent CNN models [115]. Figure 4.2 illustrates both types.

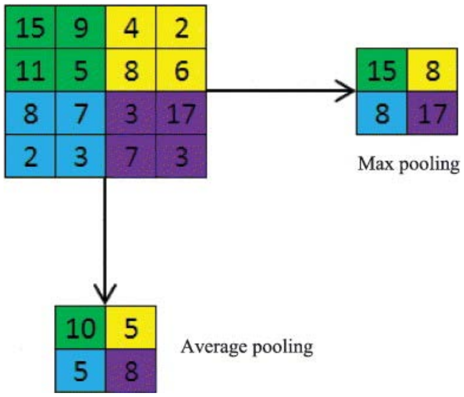


Figure 4.2 illustration of Average and Max pooling processes [115]

iii. Rectified Linear Unit (ReLU)

This algorithm shifts the negative value of a data set to zero and maintains the positive value to its original value. ReLU routine gives a faster and effective training process to identify features. Figure 4.3 shows the ReLU activation function.

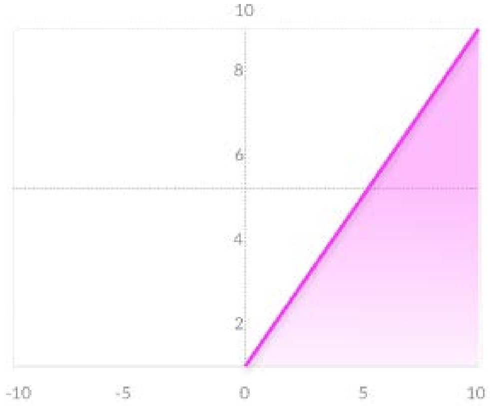


Figure 4.3 ReLU Activation Function [116]

iv. Fully Connected Layer

Fully connected (FC) layer is that layer where the neurons are in a fully connection status to entire activations of the previous three layers. The classifier is composed of FC layers to assort the images based on the determined features. In this work, we used the Multiclass SVM classifier to extract features by knowledge transfer from a pre-trained CNN model in which the features are used to connect the ECG signals to their classifications (i.e. AFib ECG).

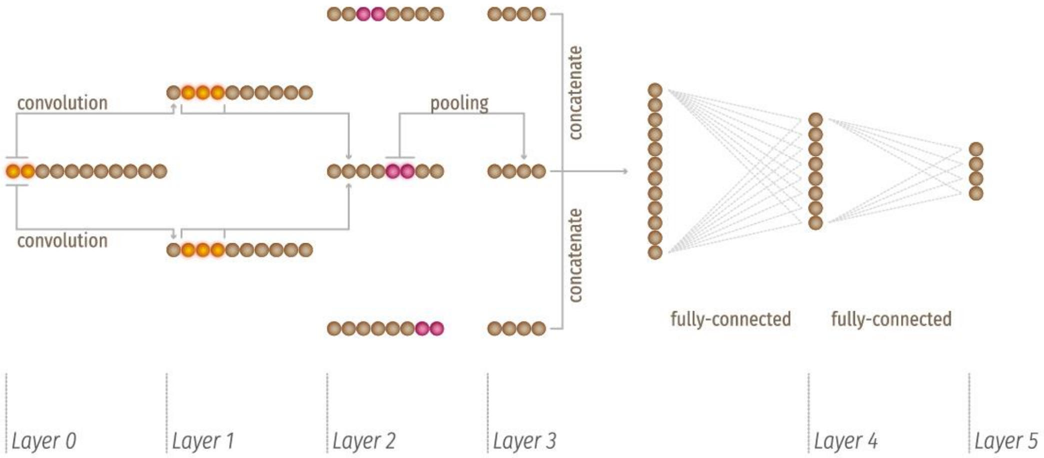


Figure 4.4 Simple architecture of CNN [111]

4.3.3 Transfer Learning

It is a technique utilized to enhance model performance by reusing the knowledge partly or wholly obtained by another task [112]. In lieu of learning the models from scratch, using transfer learning allows us to build accurate models in a timesaving way and that is by initiating the learning process from patterns that already learned from a different problem [115]. Pan and Yang [115], defined the transfer learning by the following model. A domain D is defined by two elements, first one is a feature space, symbolized by X, and the second one is a probabilistic distribution symbolized by $P(X)$, where X={x1,…, xn} ∈X and $D = \{X, P(X)\}$. In addition, in the given domain D, a task with two elements are the ground-truth (Y) and the objective function (T), where $Y = \{y1, y2, \ldots, yn\}$, $T = \{Y, f(\cdot)\}$, assuming the function can be learned by training dataset. The predictive function $f(\cdot)$ is utilized for the correspondent class $f(x)$ of a novel instance x. Technically, transfer learning is expressed through the employ of pre-trained models which will be discussed in the next section. Figure 4.5 illustrates the difference between the traditional machine learning (ML) and transfer learning.

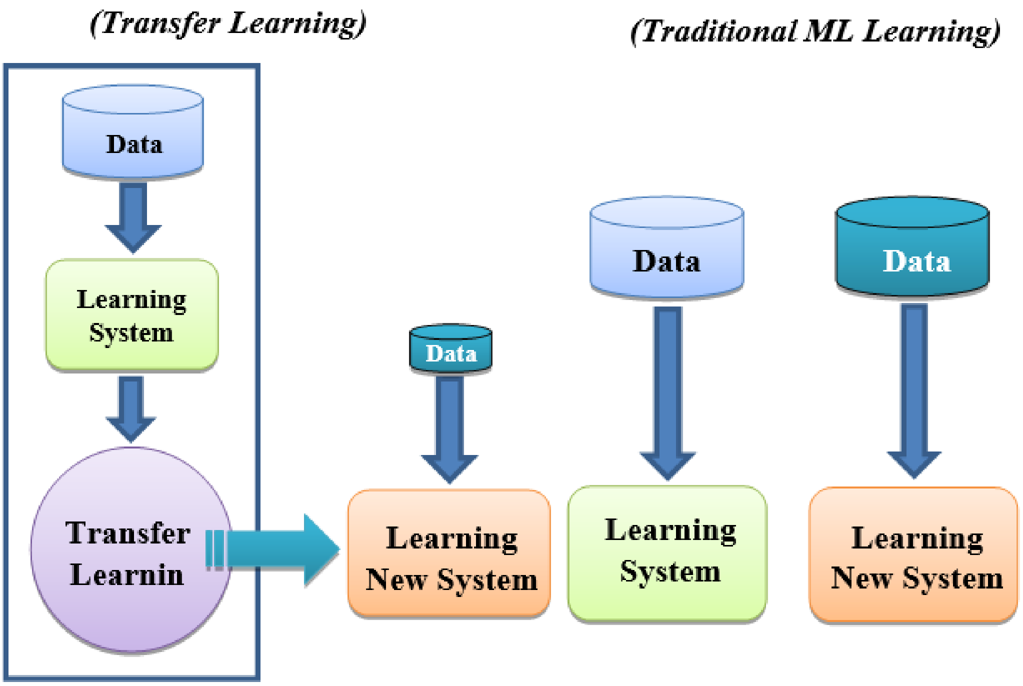


Figure 4.5 Comparison between Traditional ML Learning and Transfer Learning

4.3.4 Pre-trained Model Selection

The pre-trained model is an open-source neural network model which is trained by using huge benchmark datasets such as ImageNet. Utilizing pre-trained models in the deep learning field is considered the main cause of speedy development in Computer Vision researches where the researchers can use the pre-trained models instead of building everything from scratch. Carneiro et al emphasized in their book [119] the fact that the pre-trained CNN models are advantageous in the applications of medical images. Erhan et al [120], indicated in their experiment results that pre-training models that have lower layers are more effective than if they have higher layers.

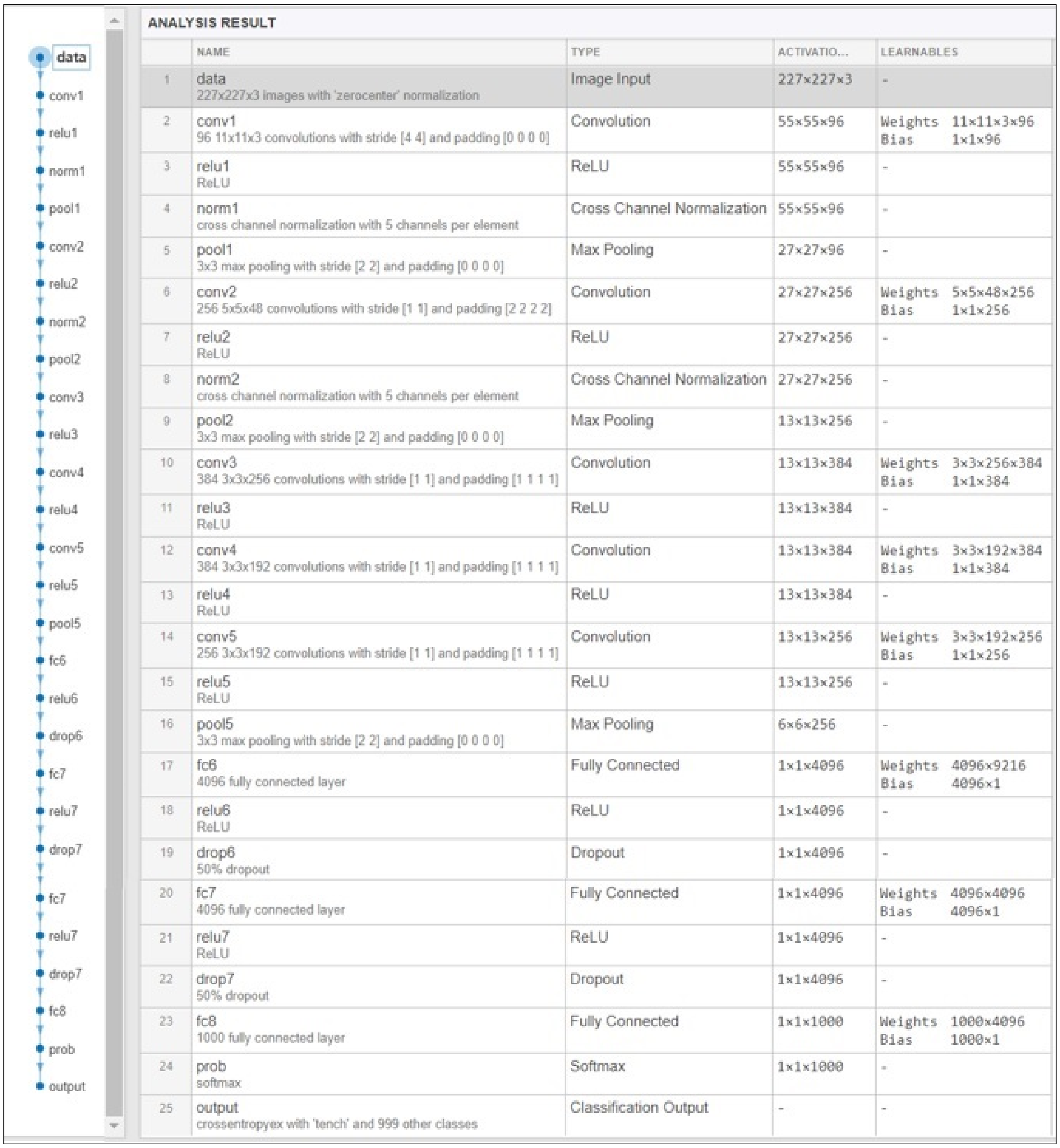
There are several pre-trained available models that can be selected according to a suitable problem. Different pre-trained models have been investigated and tested during our experiments in order to select a suitable one for our problem. Our experiments were based on the pre-trained AlexNet model because it gives the best results among the other models taking into consideration the validation accuracy and the duration of pretraining. Additionally, since the data augmentation cannot be used in our work to fix the overfitting issue as illustrated in section 4.5, the selection of pre-trained AlexNet model could help to solve the overfitting problem in our network because the computational resources are lower due to the less number of its layers along with the existence of Dropout technique in this network. The analysis of pre-trained AlexNet model architecture is shown in figure 4.6.

TABLE 4.2 PRE-TRAINED ALEXNET NEURAL NETWORK FEATURES

Features	Value
First Layer Input Size	227 x 227 x 3
Type of Network	Series
Number of Layers	25
Size	227 MB
Number of Classes	1000
Parameters (Millions)	61.0

The architecture of pre-trained AlexNet network has been analyzed and plotted by utilizing the below MATLAB code:

```
>> net = alexnet;
>> analyzeNetwork(net)
```



ANALYSIS RESULT

	NAME	TYPE	ACTIVATIO...	LEARNABLES
1	data 227x227x3 images with 'zerocenter' normalization	Image Input	227×227×3	-
2	conv1 96 11x11x3 convolutions with stride [4 4] and padding [0 0 0 0]	Convolution	55×55×96	Weights 11×11×3×96 Bias 1×1×96
3	relu1 ReLU	ReLU	55×55×96	-
4	norm1 cross channel normalization with 5 channels per element	Cross Channel Normalization	55×55×96	-
5	pool1 3x3 max pooling with stride [2 2] and padding [0 0 0 0]	Max Pooling	27×27×96	-
6	conv2 256 5x5x48 convolutions with stride [1 1] and padding [2 2 2 2]	Convolution	27×27×256	Weights 5×5×48×256 Bias 1×1×256
7	relu2 ReLU	ReLU	27×27×256	-
8	norm2 cross channel normalization with 5 channels per element	Cross Channel Normalization	27×27×256	-
9	pool2 3x3 max pooling with stride [2 2] and padding [0 0 0 0]	Max Pooling	13×13×256	-
10	conv3 384 3x3x256 convolutions with stride [1 1] and padding [1 1 1 1]	Convolution	13×13×384	Weights 3×3×256×384 Bias 1×1×384
11	relu3 ReLU	ReLU	13×13×384	-
12	conv4 384 3x3x192 convolutions with stride [1 1] and padding [1 1 1 1]	Convolution	13×13×384	Weights 3×3×192×384 Bias 1×1×384
13	relu4 ReLU	ReLU	13×13×384	-
14	conv5 256 3x3x192 convolutions with stride [1 1] and padding [1 1 1 1]	Convolution	13×13×256	Weights 3×3×192×256 Bias 1×1×256
15	relu5 ReLU	ReLU	13×13×256	-
16	pool5 3x3 max pooling with stride [2 2] and padding [0 0 0 0]	Max Pooling	6×6×256	-
17	fc6 4096 fully connected layer	Fully Connected	1×1×4096	Weights 4096×9216 Bias 4096×1
18	relu6 ReLU	ReLU	1×1×4096	-
19	drop6 50% dropout	Dropout	1×1×4096	-
20	fc7 4096 fully connected layer	Fully Connected	1×1×4096	Weights 4096×4096 Bias 4096×1
21	relu7 ReLU	ReLU	1×1×4096	-
22	drop7 50% dropout	Dropout	1×1×4096	-
23	fc8 1000 fully connected layer	Fully Connected	1×1×1000	Weights 1000×4096 Bias 1000×1
24	prob softmax	Softmax	1×1×1000	-
25	output crossentropyex with 'tench' and 999 other classes	Classification Output	-	-

Figure 4.6 Screenshot after running a Pre-trained AlexNet Model Architecture

4.4 Implementation and optimization

To implement our proposed D-CNN model, the MATLAB R2018b software and Deep Network Designer toolbox were utilized. The model was trained and analyzed using graphics processing unit GPU (GeForce 940MX; NVIDIA) computing in Windows 10 64-bit operation system. The main objective of classification is the automatic diagnosis of AFib using small datasets. The training of the pre-trained AlexNet neural network for AFib prediction was full supervised and the parameters of the model were optimized utilizing the function of cross-entropy loss in the classification layer that used stochastic gradient descent with momentum (SGDM). Mini-Batch Gradient Descent (MBGD) is also used in our model with 10 observations at each iteration in order to train the network faster. Commonly, the MBGD is called "Batch Size", it is the most recommended Gradient Descent algorithm in the deep learning field and especially the state-of-the-art deep learning libraries [117].

4.5 Experimental Result

In the experiments, the pre-trained AlexNet model was used. Here, the last three layers of the model are replaced and fine-tuned for the new classification problem according to the new data. The Multiclass SVM classifier is applied to extract features by the knowledge transfer from a pre-trained CNN model in which the features are used to connect the ECG signals to their classifications (AFib, Normal, Noisy, and Other). Figure 4.7 illustrates the diagram of the proposed method. Short-term recorded ECG signals are utilized in our experiments. The database is divided into three sets: training set, validation set, and test set. The data has been processed by plotting and segmenting the signals to train the network.

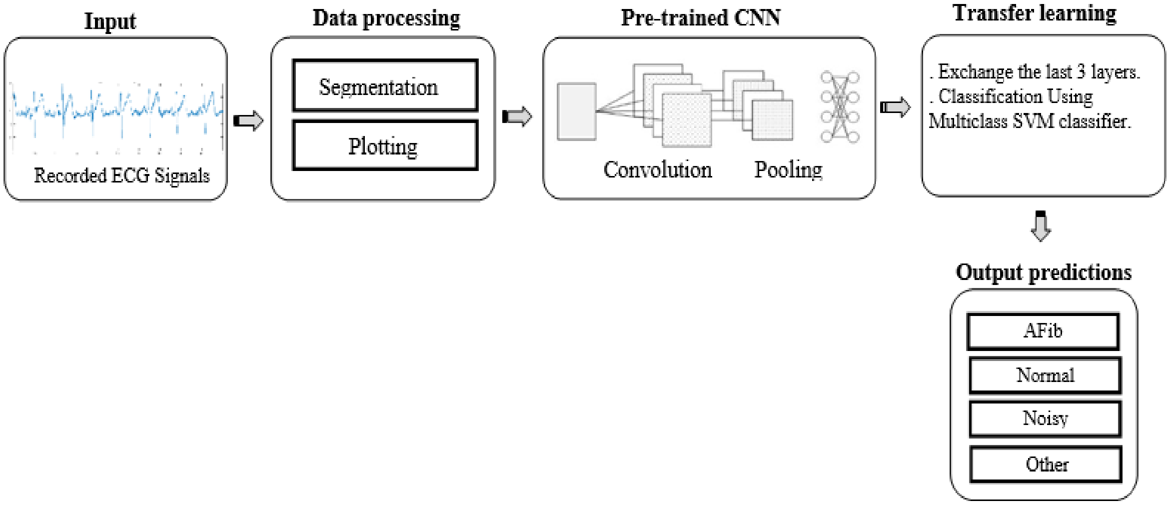


Figure 4.7 Diagram of the proposed method for automatic prediction

Tables 4.3 and 4.4 show the details of imported data used in our experiments and the number of labels of each category.

TABLE 4.3 INSIGHT OF IMPORTED DATA

Data features	**Value**
Image Size	525 x 300 x 3
Images Number	421
Number of Train Images	295
Number of Validation Images	126
Number of Classes	4
Counts of Each Labels	Refer to the table [4.4]

TABLE 4.4 COUNTS OF EACH LABEL

No.	**Categories**	**Number of Images**
1	AFib	100
2	Normal	118
3	Noisy	102
4	Others	101

The deep learning CNN can be performed in three ways: training the model from scratch, feature extraction, and transfer learning. The method of training the model from scratch requires a very large labeled database. It could be hundreds of thousands of labeled images. Therefore, we did not consider this method for our experiments. This work investigates the AFib classification problem under three experiments:

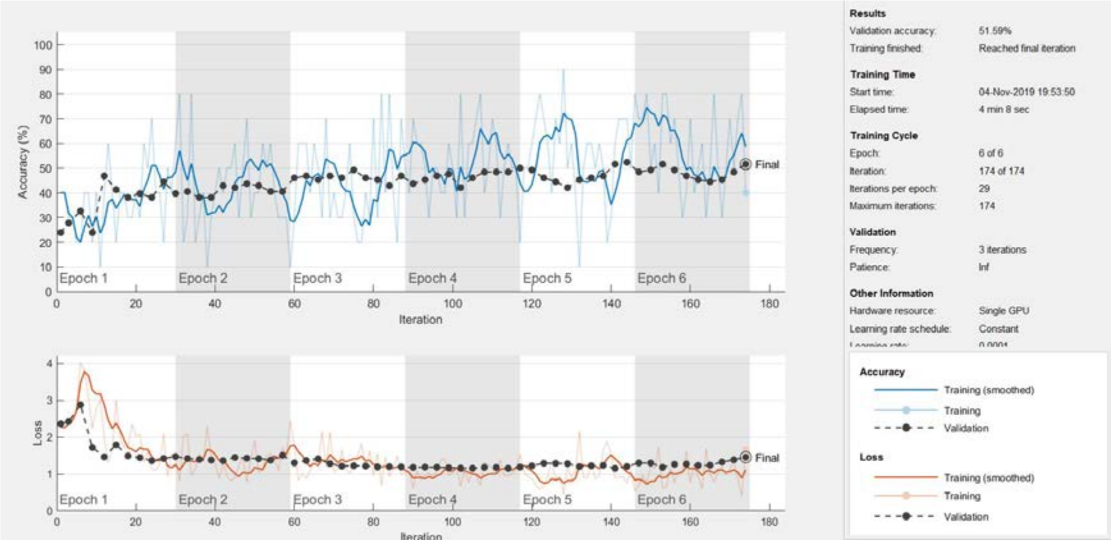
i. Feature extraction.
ii. Transfer learning with data augmentation (DA).
iii. Transfer learning without data augmentation (DA).

In the first experiment, we have used the pre-trained CNN as feature extractor to extract the features from the learned images. The activations are used on the fully connected layer to obtain the feature representations of the training images in which the features are extracted through activations. Fit error-correcting output codes (fitecoc) function is utilized to train a support vector machine (SVM) to predict the output. This experiment obtained 28.25% of prediction accuracy. This means that the expected features of the signals of images pulled from the network were very poor.

In the second experiment, we have used the transfer learning method to fine-tune the pre-trained CNN to execute classification on the new data based on the DA technique. DA is a set of techniques performed on the images in case the training data is very small. Therefore, utilizing DA techniques such as rotating, cropping, flipping, resizing will increase the number of input images [20]. DA is one of the techniques used by many researchers to reduce the overfitting problem on models. In this experiment, we have used the data augmentation to resize the new input images because the input layer of pre-trained network required input images with size 227-227-3 but the size of the used input images in the image datastore is 524-300-3, where number 3 is the number of color channels. We have created a new datastore (training and validation datastores) for the augmented images, stored the resized images to it and then used the new datastore as input argument to the activations. Figure 4.8 illustrates the training progress and the result of this experiment. It was obtained 51.59% of validation accuracy.

In the third experiment, the transfer learning method has been also used to fine-tune the pre-trained CNN but, instead of using the data augmentation technique to resize the input images to fit with the required input images size of the input layer of the network, we have replaced the input layer to fit our input image size 525x300x3. The experiment has been realized with different epochs starting from 1 to 6 epochs. The test with 6 epochs gave the best accuracy. This experiment decreased the training time and achieved a very high accuracy of 99.21% with 6 epochs, as shown in figure 4.9. Table 4.5 illustrates the network analysis results after the transfer learning.

From the second and third experiments, we can remark that fine-tune of the pre-trained CNN after augmented the input ECG images by resizing it, could affect the real feature of the ECG signal image giving inaccurate results.



Results
Validation accuracy: 51.59%
Training finished: Reached final iteration

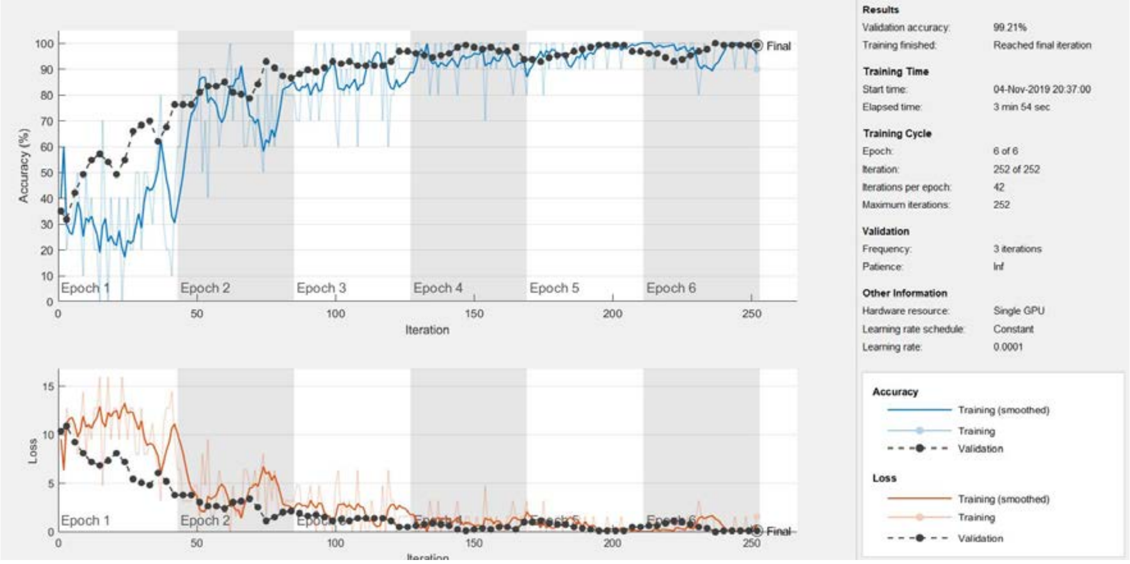
Training Time
Start time: 04-Nov-2019 19:53:50
Elapsed time: 4 min 8 sec

Training Cycle
Epoch: 6 of 6
Iteration: 174 of 174
Iterations per epoch: 29
Maximum iterations: 174

Validation
Frequency: 3 iterations
Patience: Inf

Other Information
Hardware resource: Single GPU
Learning rate schedule: Constant
Learning rate: 0.0001

Figure 4.8 Training Progress and Result Using DA



Results
Validation accuracy: 99.21%
Training finished: Reached final iteration

Training Time
Start time: 04-Nov-2019 20:37:00
Elapsed time: 3 min 54 sec

Training Cycle
Epoch: 6 of 6
Iteration: 252 of 252
Iterations per epoch: 42
Maximum iterations: 252

Validation
Frequency: 3 iterations
Patience: Inf

Other Information
Hardware resource: Single GPU
Learning rate schedule: Constant
Learning rate: 0.0001

Figure 4.9 Training Progress and Result Without Using DA

TABLE 4.5 NETWORK ANALYSIS RESULTS AFTER TRANSFER LEARNING

No.	Layer Name	Type of Layer	Activations
1	Data	Image Input	525x700x3 images
2	Conv1	Convolution	96 11x11x3 convolutions with stride [4 4] and padding [0 0 0 0]
3	Relu1	ReLU	ReLU
4	Norm1	Cross Channel Normalization	cross channel normalization with 5 channels per element
5	pool1	Max Pooling	3x3 max pooling with stride [2 2] and padding [0 0 0 0]
6	Conv2	Convolution	256 5x5x48 convolutions with stride [1 1] and padding [2 2 2 2]
7	Relu2	ReLU	ReLU
8	Norm2	Cross Channel Normalization	cross channel normalization with 5 channels per element
9	Pool2	Max Pooling	3x3 max pooling with stride [2 2] and padding [0 0 0 0]
10	Conv3	Convolution	384 3x3x256 convolutions with stride [1 1] and padding [1 1 1 1]
11	Relu3	ReLU	ReLU
12	Conv4	Convolution	384 3x3x192 convolutions with stride [1 1] and padding [1 1 1 1]
13	Relu4	ReLU	ReLU
14	Conv5	Convolution	256 3x3x192 convolutions with stride [1 1] and padding [1 1 1 1]
15	Relu5	ReLU	ReLU
16	Pool5	Max Pooling	3x3 max pooling with stride [2 2] and padding [0 0 0 0]
17	Fc6	Fully Connected	4096 fully connected layer
18	Relu6	ReLU	ReLU
19	Drop6	Dropout	50% dropout
20	Fc7	Fully Connected	4096 fully connected layer
21	Relu7	ReLU	ReLU
22	Drop7	Dropout	50% dropout
23	-	Fully Connected	4 fully connected layer
24	-	Softmax	Softmax
25	-	Classification Output	crossentropyex

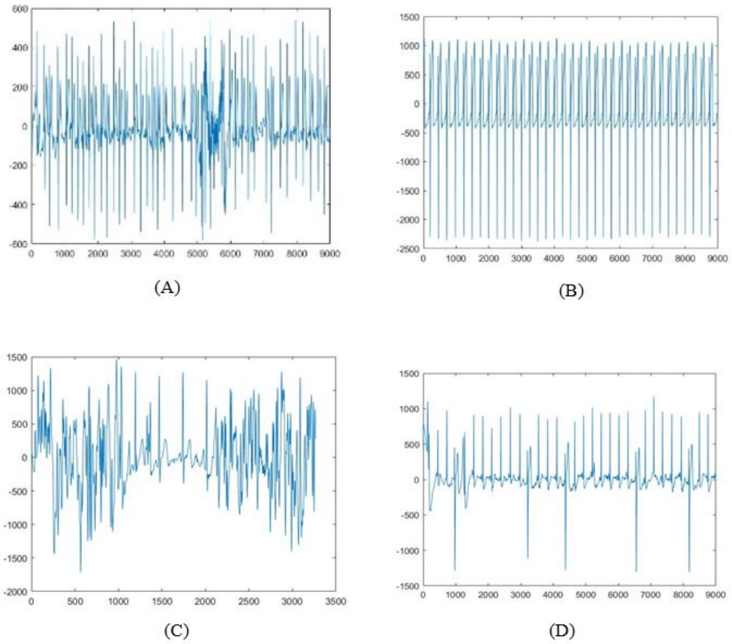
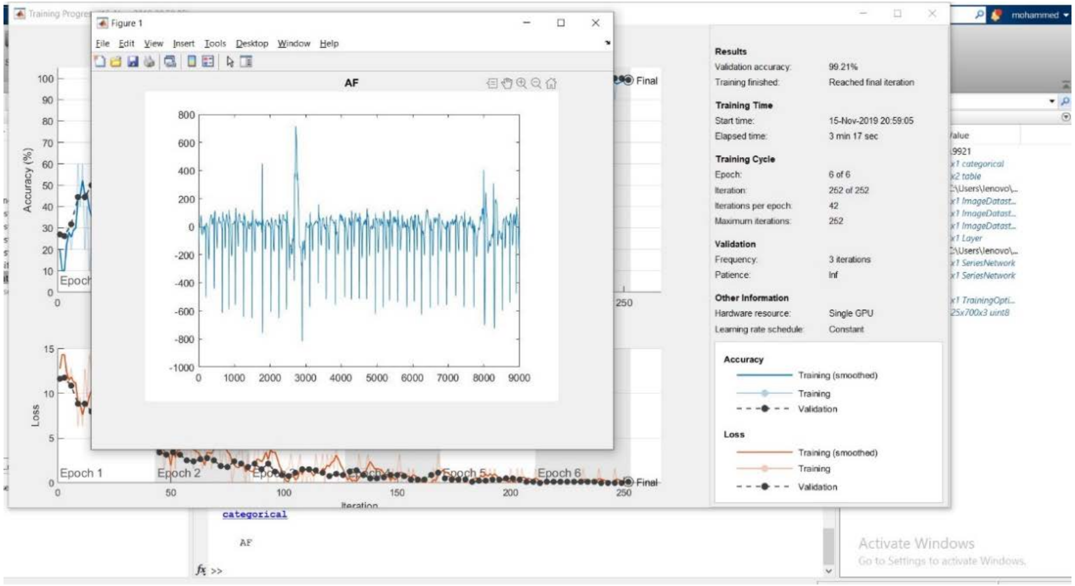


Figure 4.10 Samples of Objects Categories from Training Set:
(A) AFib. (B) Normal. (C) Noisy. (D) Other

The proposed method was fully supervised for AFib prediction. Figure 4.10 viewed samples of objects categories from the training et. Figure 4.11 illustrated the result of testing stage where the used test sample is unsupervised and separate from the training and validation sets. The result was predicted AFib correctly. Figures 4.12, 4.13, and 4.14 show the results of the other cases.



Results
Validation accuracy: 99.21%
Training finished: Reached final iteration

Training Time
Start time: 15-Nov-2019 20:59:05
Elapsed time: 3 min 17 sec

Training Cycle
Epoch: 6 of 6
Iteration: 252 of 252
Iterations per epoch: 42
Maximum iterations: 252

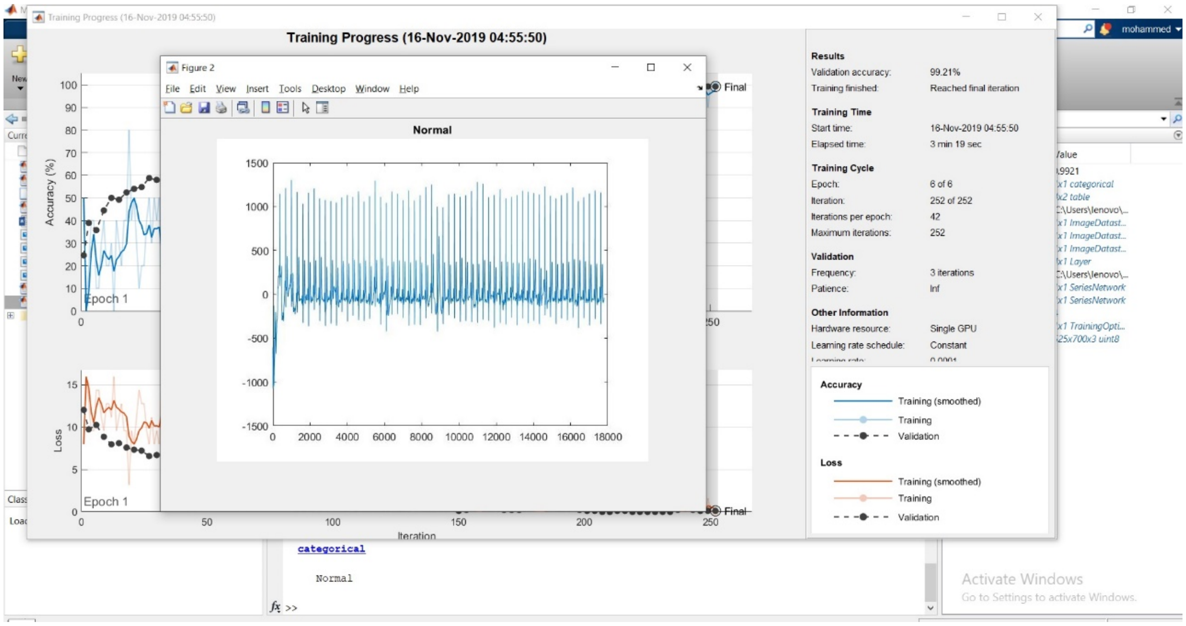
Validation
Frequency: 3 iterations
Patience: Inf

Other Information
Hardware resource: Single GPU
Learning rate schedule: Constant

```
categorical

    AF
```

Figure 4.11 Result of testing - AF Auto-Predicted



Results
Validation accuracy: 99.21%
Training finished: Reached final iteration

Training Time
Start time: 16-Nov-2019 04:55:50
Elapsed time: 3 min 19 sec

Training Cycle
Epoch: 6 of 6
Iteration: 252 of 252
Iterations per epoch: 42
Maximum iterations: 252

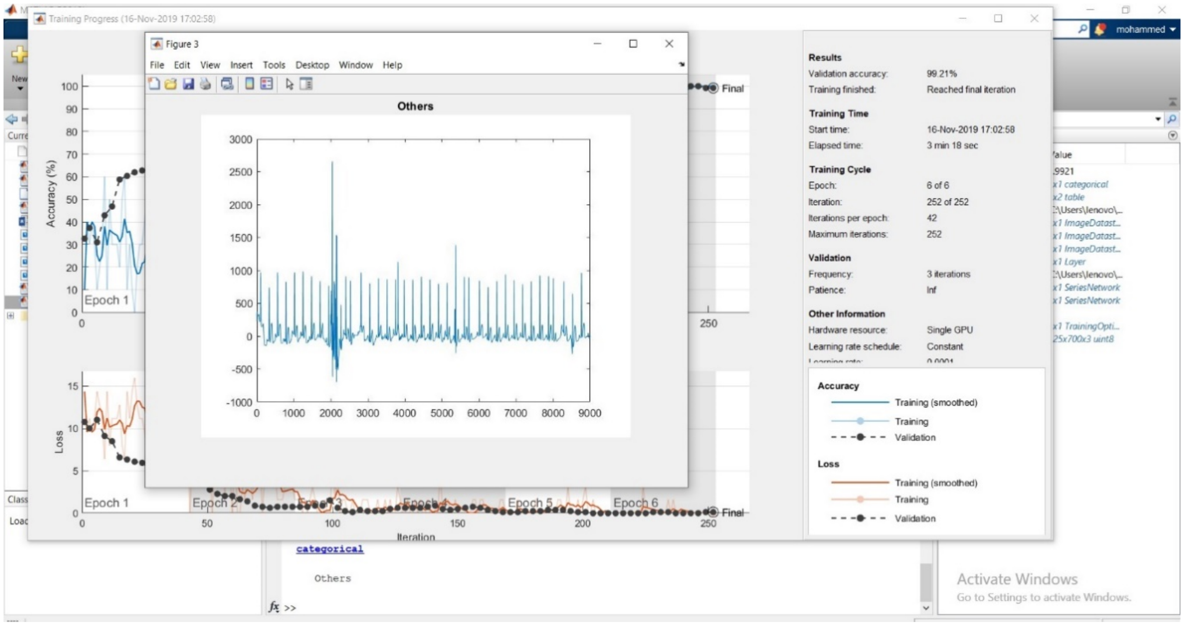
Validation
Frequency: 3 iterations
Patience: Inf

Other Information
Hardware resource: Single GPU
Learning rate schedule: Constant
Learning rate: 0.0001

```
categorical

  Normal
```

Figure 4.12 Result of testing - Normal Case was Auto-Predicted



Results
Validation accuracy: 99.21%
Training finished: Reached final iteration

Training Time
Start time: 16-Nov-2019 17:02:58
Elapsed time: 3 min 18 sec

Training Cycle
Epoch: 6 of 6
Iteration: 252 of 252
Iterations per epoch: 42
Maximum iterations: 252

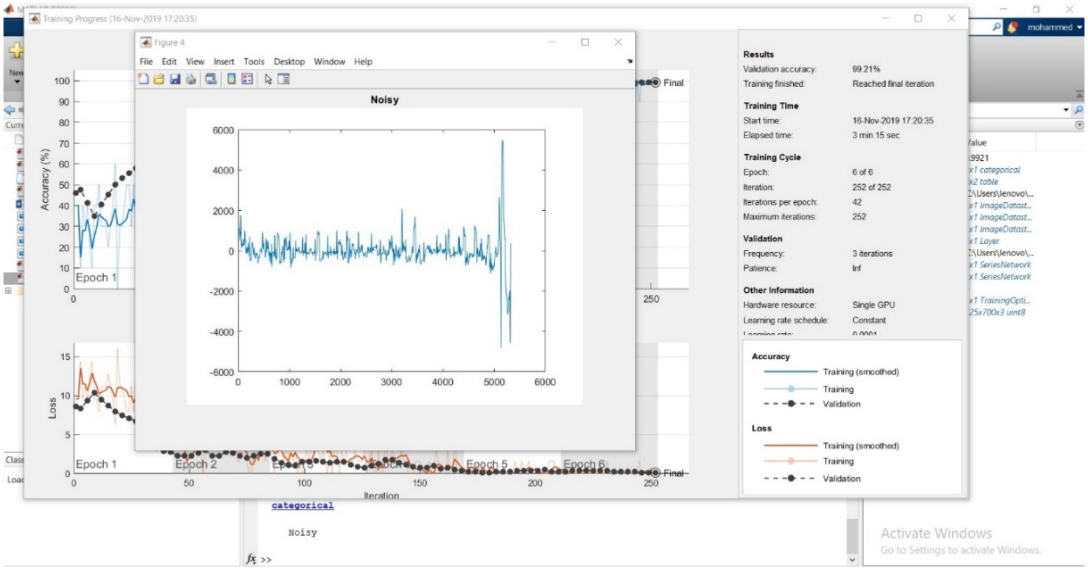
Validation
Frequency: 3 iterations
Patience: Inf

Other Information
Hardware resource: Single GPU
Learning rate schedule: Constant
Learning rate: 0.0001

```
categorical

  Others
```

Figure 4.13 Result of testing - Other Case was Auto-Predicted



Results
Validation accuracy: 99.21%
Training finished: Reached final iteration

Training Time
Start time: 16-Nov-2019 17:20:35
Elapsed time: 3 min 15 sec

Training Cycle
Epoch: 6 of 6
Iteration: 252 of 252
Iterations per epoch: 42
Maximum iterations: 252

Validation
Frequency: 3 iterations
Patience: Inf

Other Information
Hardware resource: Single GPU
Learning rate schedule: Constant
Learning rate: 0.0001

```
categorical

   Noisy

>>
```

Figure 4.14 Result of testing - Noisy Case was Auto-Predicted

4.6 Conclusion

In this chapter, we proposed to explore the Transfer Learning approach in the Deep Learning field using pre-trained Convolutional Neural Network to improve the accuracy of Atrial Fibrillation classification based on the Short-term recorded ECG datasets. The pre-trained AlexNet model has been used in our experiments due to different reasons as illustrated in section 4.3.4 where the network was fully supervised, and the parameters of the model were optimized utilizing the function of cross-entropy loss in the classification layer that used stochastic gradient descent with momentum (SGDM). Also, Mini-Batch Gradient Descent (MBGD) was utilized in the model with 10 observations at each iteration to train the network faster. Multiclass SVM classifier was used to extract features by knowledge transfer from the pre-trained CNN model in which the features are used to connect the ECG signals to their classifications (AFib, Normal, Other, and Noisy). This study was based on three experiments: feature extraction, transfer learning with data augmentation, transfer learning without data augmentation where transfer learning without data augmentation obtained the top result with 99.21% of accuracy as explained in section 4.5. Thus, the proposed method for automatic prediction of atrial fibrillation has proved to provide robust results.

CHAPTER 5. DESIGN HCARE WEB APPLICATION FOR EHEALTH MONITORING SYSTEM

5.1 Introduction

Different health applications have been developed for mobile devices and vastly utilized by patients and medical personnel [128]. These applications lead to improve communication between doctors and patients thus assist to enhance the quality of treatment in general, therefore the utilization of these applications is quite useful. Generally, people prefer to access their information including medical information, in an effortless and flexible way with the current speedy development of mobile devices, therefore it became necessary to prepare fitting interfaces according to these different devices with use of Responsive Web Design (RWD) to develop a modern web-application [129].

Building an interactive healthcare environment became an essential need to improve and increase the effectiveness of professionals in the health field, along with the enhancement of security and confidentiality of medical data, as well as the improvement of quality of healthcare services.

Nowadays, various wearable mini-biosensors had become broadly available, allowing comfortable and non-intrusive monitoring of the activities of patients' lives. With the use of these biosensors that connect to mobile devices, we will be able to collect the medical data from the patients while they do daily life activities, fact that allow us to identify and understand the patient's medical conditions.

Professionals in the health field attempt to benefit from analyzing and investigating these health data in order to comprehend the diseases and conditions that affect a specific country or community [130], taking into consideration the confidentiality and security of these health data as sensitive data. The medical cases and health data of patients have to be tracked by the doctors when the patients being outside hospitals with the potential to access their recorded data and the ability to record the diagnosis and treatment data to their health profiles.

This chapter presents the design and implementation of an enhanced healthcare monitoring system based on the web application framework and the cloud platform using various vital signs such as blood pressure, SPO2, body temperature, and electrocardiogram ECG. This web application system, called *Hcare*, provides the physicians with the ability to monitor the health of their patients as well as it provides health and medical consultation to them and allows the patients to observe their health activities. Hcare provides different functionalities for the patients and medical professionals. The application also includes modules for the previous developed filtering model and risk prediction and diagnose model in case of atrial fibrillation described in chapters 3 and 4.

As it will be remarked further, we highlighted and illustrated the requirements of healthcare monitoring systems based on a previous survey published in a previous phase [127]. The database approach of the proposed system was illustrated in this chapter as well. UML modeling diagrams for the proposed system were presented and discussed such as the Use-Case diagram of the entire system plus system administrator Use-Case diagram, as well as the sequence diagram of the appointment scheduling scenario and sequence diagram of the new registration and login scenario.

We have also investigated the information security issues represented by healthcare information threats in the system, information consent, and information sharing, to obtain better protection of patient information. Also, the techniques and approaches of security and privacy of our Hcare web-app were explained along with the confidentiality of the patient's information. The system provides appointments schedule management between patients and doctors and also provides Alert Mechanism as system notifications or SMS according to the severity of the medical condition of the patient.

This system is considered the best compared to its counterparts from the systems due to the use of enhanced and advanced techniques to filter and classify the vital signs of patients especially the ECG signal where these techniques were previously published in the articles [5] [6].

5.2 System Requirements

The requirements of users were determined for the healthcare monitoring systems through a survey conducted previously in our published article [127]. This survey was intended to take a comprehensive look at the requirements that are essential for the platform of healthcare monitoring systems from the viewpoint of users. The questionnaire was conducted online by distributing it directly to a set of people who have jobs in the information technology fields or the medical fields and others.

The identified requirements can cover the essential demands for different divisions of users such as regular or elderly patients, in addition, the patients who suffer from various illnesses. Medical professionals and normal people (non-medical) are agreed that online healthcare monitoring systems will be extremely significant and the demand for it will increase in the market.

The survey results are considered necessary to determine the system development priorities for the ultimate product. The product will develop a platform of unified software serving healthcare that saves the users from multiple programs problem and also the websites of specialized healthcare which distract users and doctors. These requirements are listed below:

- The potential of obtaining medical counsel from a doctor.
- The potential to present the results of lab.

- The potential to view and read the medical articles in the web application.
- The potential to interact the medical staff (doctors and Emergency staff) with patients.
- System security.
- System efficiency.
- System reliability.
- System performance.
- System usability.
- System portability.

5.3 System Architecture

The general architecture of the proposed e-health system is illustrated in Figure 5.1. Various users are utilizing this system such as patients, doctors, and the emergency staff along with the administrator who control and manage the system. The system architecture is composed of the following components:

- **Sensor-based eHealth wearable devices**: various types of biosensors are measuring significant physiological parameters of a patient such as blood pressure, electrocardiogram (ECG), oxygen in the blood (SPO2), and body temperature. The aggregated data from the biosensors are transferred into the system for preprocessing and decision making.

- **ECG module for automatic diagnose**: The received ECG signals pass through two innovative modules: the ECG filtering module to denoise the noises from the signal and the DCNN-based ECG classification module for automatic prediction. Both modules were designed, developed and tested previously, the details being published [5] and [6].

- **Hcare web application**: provides various functionalities and privileges for the users in order to facilitate the work of doctors or emergency staff to monitor patients in order to provide medical support in a timely manner. Also, it supports patients by providing them with medical assistance through the remote interaction with medical professionals taking into consideration the security and privacy of sensitive medical data.

- **Cloud server**: The Hcare web-application runs on Microsoft Azure cloud in the form of Software as a Service (SaaS).

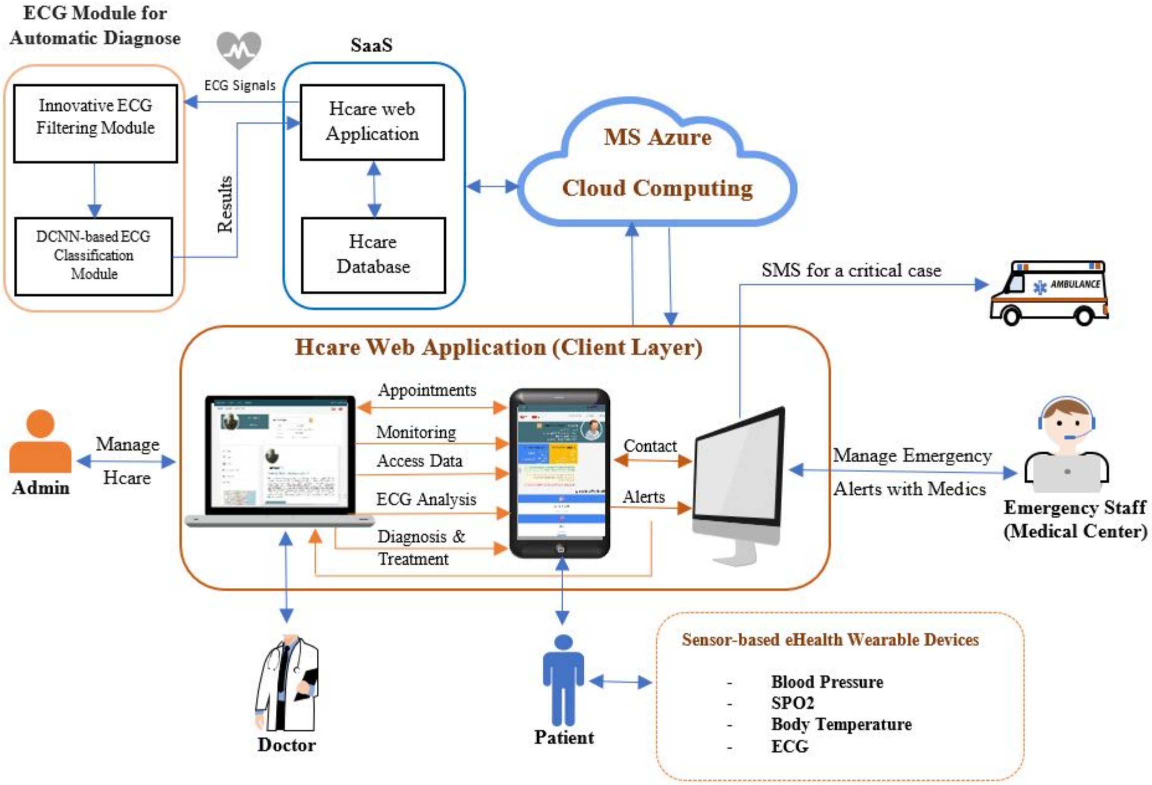


Figure 5.1 System General Architecture Diagram

5.4 Design of System Database

The proposed system consisted of varied components as shown in figure 5.2. The Graphical User Interface (GUI) allows the end-users who are administrator, doctor, patient, ambulance staff, and other to interact with different activities in the system.

Identity framework API supports GUI login functionality such as manage usernames, passwords, email confirmation, and others. The users have the possibility to create a login account in which the login details will be stored in identity or they can utilize login information from external providers such as Google, Facebook, etc. [122]. Whilst, the entity framework which also called Object Relational Mapper (ORM) is an open-source framework provided by Microsoft that maps the entities with the tables of the database automatically. It allows us as developers to utilize .NET objects for operating with a database [123].

At the end of the database design scheme is figured the database storage component which stores doctor profile, patient profile, medical history of patient, appointment details, contact details, and medical activities information.

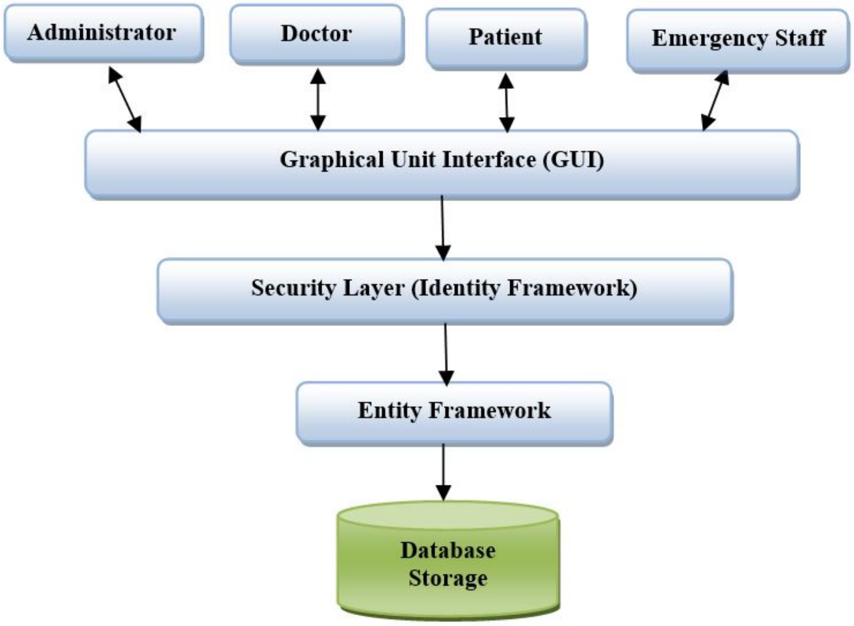


Figure 5.2 Database Design Scheme

Data coherence, a key factor in data transparency, is a necessity for high-quality data systems without faults for the data collected and it affects how users can make the best use of available medical data. Therefore, data coherence of Hcare system is proved by the following features: highly user-friendly, easily accessible, and consistent over time.

The definition of entities in our web application design are listed as follows:

- **Home**: contains the information of the designed system and general medical news.
- **Admin**: the administrator can help to manage and control information regarding hospitals, doctors, and ambulance staff from the administrator page of healthcare system.
- **Profile**: contains common information about the user.
- **Patient medical history:** contains patient medical data or previous treatments and diagnoses, and tests that enable the description of the patient condition.
- **ECG Analysis:** provides a doctor with the ability to view the ECG signal and analyze it to predict the result in case it is Normal, AFib, another disease, or very noisy based on two innovative modules.
- **Appointment**: enables appointment self-scheduling service for the patients by providing the patients with the ability to manage the appointment time and date online by themselves at any time.
- **Health monitoring**: allows the users to monitor the medical activities for the patients such as ECG, SPOs, blood pressure, and body temperature.

- **Alerts:** Alarming users for the abnormal health conditions.
- **Contact**: provides the contact details to facilitate the connection among the patients, doctors, and ambulance staff.

5.4.1 Database Design Scheme

The database of our web application stores all the records of the users, the healthcare organizations, and medical activities. Different tables were created according to the requirements of the system entities and these tables are linked together with the foreign keys. Tables 5.1, 5.2, 5.3, 5.4, and 5.5 are typical tables of the system database which are Patient Information table, Address details, Doctor's Specialization, Appointment Details, and Contact Details table respectively. Figure 5.3 illustrates the scheme of database relationship where there are three keys parts of this scheme: first, the table of "Patient Information" that the general tables linked to it, second is "AspNet Users" table where all security-related tables are connected to it, third key part is the "Session" table where the connection tables are linked to it.

TABLE 5.1 PATIENT INFORMATION

Item	**Data Type**
PsnID	Nvarchart (250)
PsnFname	Nvarchart (250)
PsnLname	Nvarchart (250)
PsnDob	int
PsnBloodTy	int
PsnGender	int
PsnLength	int
PsnWeight	int
PsnSpecilist	int
PsnImgPath	Nvarchart max
PsnTy	int
PsnStatus	bit

TABLE 5.2 APPOINTMENT DETAILS

Item	**Data Type**
AppID	int
PatientID	Nvarchart (250)
DrID	Nvarchart (250)
AppDate	Data time
AppTime	Nvarchart (50)
AppReason	Nvarchart max
AppConfirm	bit

TABLE 5.3 ADDRESS DETAILS

Item	**Data Type**
AddID	int
PsnID	Nvarchart (250)
AddCity	Nvarchart (150)
AddStreetNM	Nvarchart (150)
AddHomeNum	int
AddNearLocation	Nvarchart (150)

TABLE 5.4 CONTACT DETAILS

Item	**Data Type**
ContID	int
PsnID	Nvarchart (250)
ContPsnPhone	int
ContPsnEmail	Nvarchart (50)
ContPerson1Nm	Nvarchart (50)
ContPerson1Phone	int
ContPersonEmail	Nvarchart (50)

TABLE 5.5 DOCTOR'S SPECIALIZATION

Item	**Data Type**
SpecialID	Int
SpecialNM	Nvarchart (50)

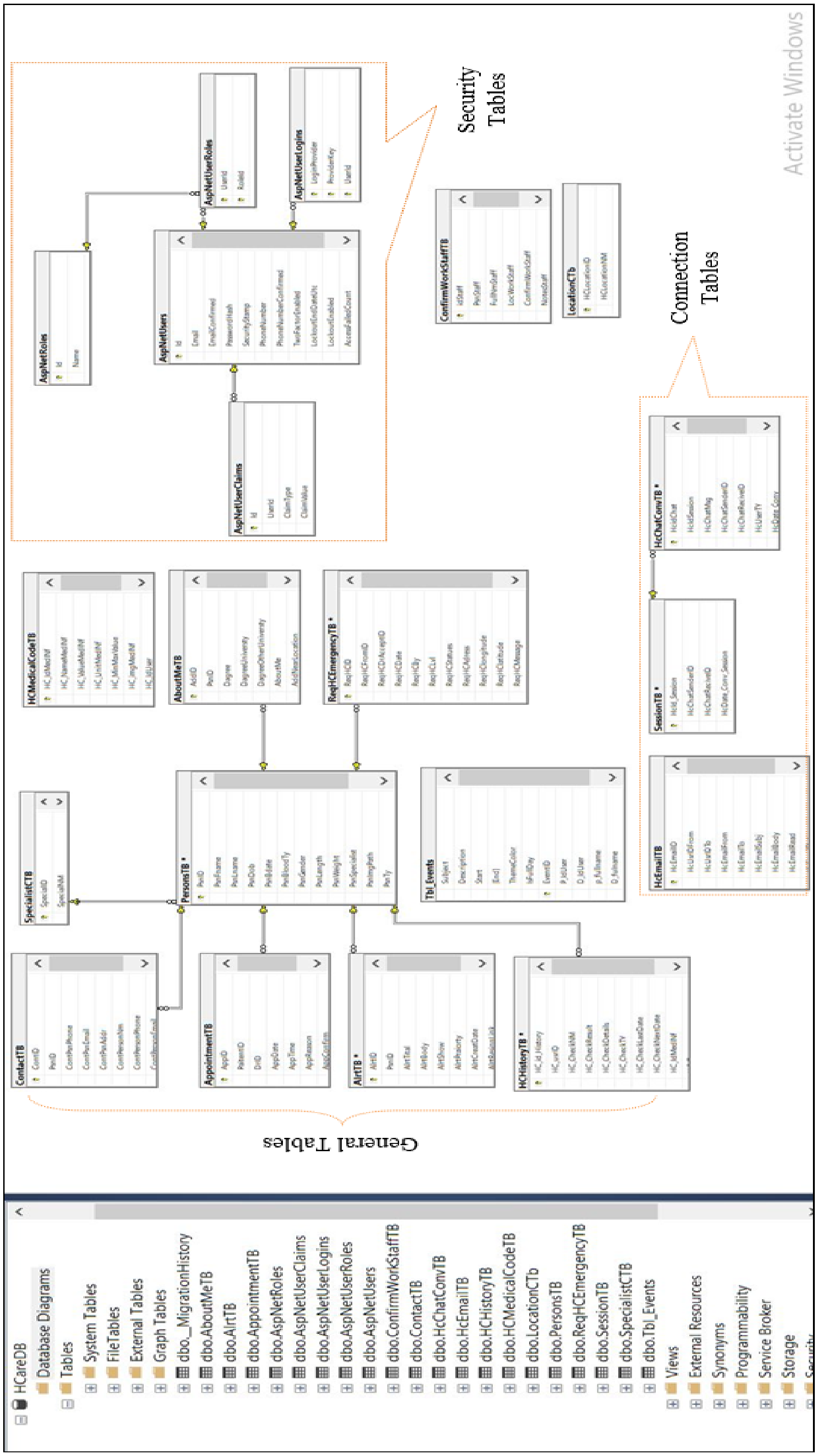


Figure 5.3 Database Relationship Schema

5.5 Modeling Diagrams of System Services

Unified Modeling Language (UML) was appropriated in this work to represent our proposed healthcare system visually through modeling diagrams such as Use Case Diagrams and Sequence diagrams.

5.5.1 Use Case Diagrams of System

Use Case diagrams were employed to illustrate the functional requirements of the system. Chief components of this diagram are users, the functionalities of system (use cases), and the relationship of them, these components were analyzed in these UML diagrams.

The qualification of the system administrator is extremely significant to give him all the powers to manage the system. Figure 5.4 shows the use case diagram of the services provided to the administrator by the system. The administrator after accessing the system will have the authority to manage the records of medical staff (Doctors, Emergency\ambulance staff) and the records of medical centers (Hospitals, Clinics) by add, delete, modify for the existing records. Also, he can make reports and print them.

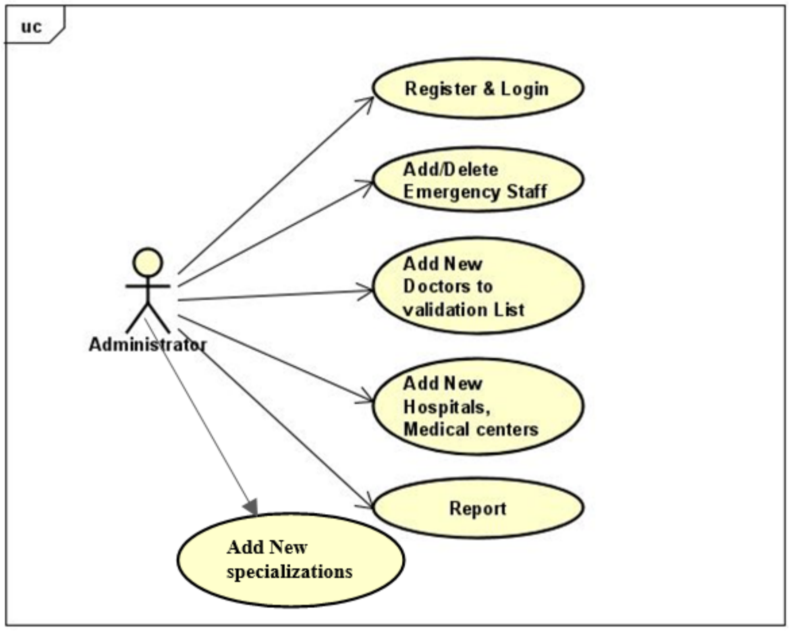


Figure 5.4 Administrator Use Case Diagram

Figure 5.5 demonstrates the other users, namely patients, doctors, and emergency staff. Each kind of user has privileges to do multiple and specific functionalities, as illustrated below:

- **Functionalities and privileges of doctor:**
  - ✓ He can view his profile information and patients' profile and search for the patient through his ID or name.

- ✓ Access the patient medical history with the ability to edit and add medical information such as diagnoses and treatments (prescriptions). Also, he can upload documents or images related to test results, ECG, X-Ray, and so on to be part of the patient medical history.
- ✓ Manage the appointment scheduling with the patients.
- ✓ Ability to monitor the patient's health activities (ECG, SPO2, Blood Pressure, & Body Temperature) and receive a notification and SMS from the user-end for the abnormal conditions.
- ✓ A doctor can perform an electronic diagnosis of an ECG signal that are received from his patients through the system to detect whether the patient has Atrial Fibrillation or suffering from other arrhythmias. The automatic diagnose model for atrial fibrillation has been discussed and presented in Chapter 4. Hcare app is connected to this model. The hybrid filtering model proposed and presented in Chapter 3 has also been implemented and connected to Hcare web-app to remove the noises from the signal before diagnosing. This model was published in our previous work [5].
- ✓ Can make reports and print them.
- ✓ Contacts with patients.

❖ **Functionalities and privileges of patient:**

- ✓ View his profile and medical history.
- ✓ Search for a doctor according to his specialization, address, and hospital/clinic.
- ✓ The system provides the patients with the ability to manage the appointment time and date with the doctor and confirm\cancel the appointment.
- ✓ View and monitor his medical activities and receive a notification or SMS from the system or doctor for the abnormal conditions.
- ✓ Able to contact doctors and emergency\ambulance staff.

❖ **Functionalities and privileges of Emergency Staff:**

- ✓ View his profile.
- ✓ View patient profile and his medical history.
- ✓ Receiving calls and emails from the patients.
- ✓ Receive an auto SMS from the system in case the condition of the patient is critical, and able to detect his location from the GPS.

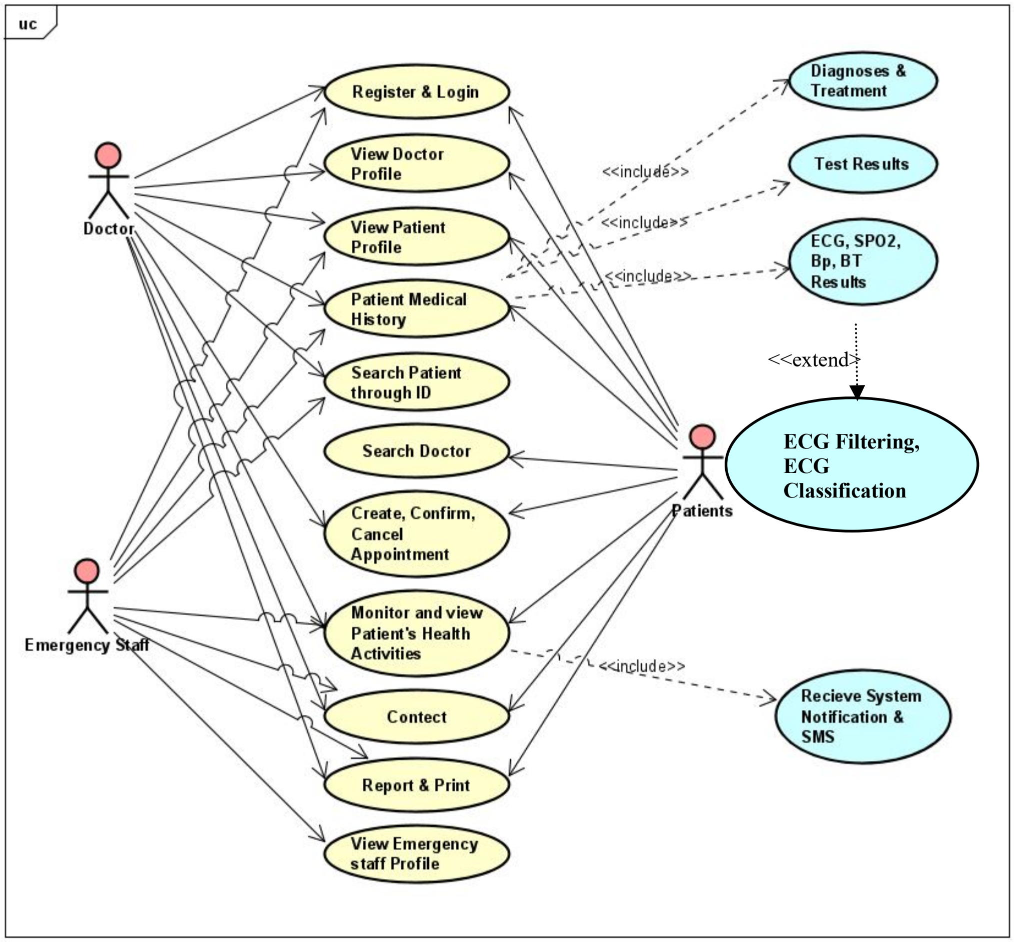


Figure 5.5 Use Case Diagram of the Proposed System

5.5.2 Sequence Diagrams of System

The sequence diagrams represent the sequence of interactions that occur between users and objects, organized in a time sequence. Figure 5.7 displays a sequence diagram for the New Registration and Login scenario.

Figure 5.6 shows the sequence diagram of the appointment scheduling scenario. The system provides the patients self-management of appointments where the patient sends an appointment request to a doctor through the system, the doctor, in turn, makes an appointment and sends it to the patient and the patient will have the choice to confirm or cancel the appointment.

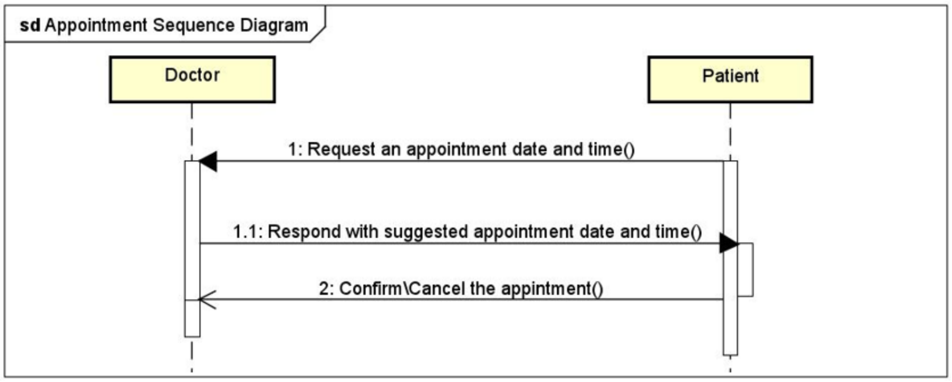


Figure 5.6 Appointment Sequence Diagram

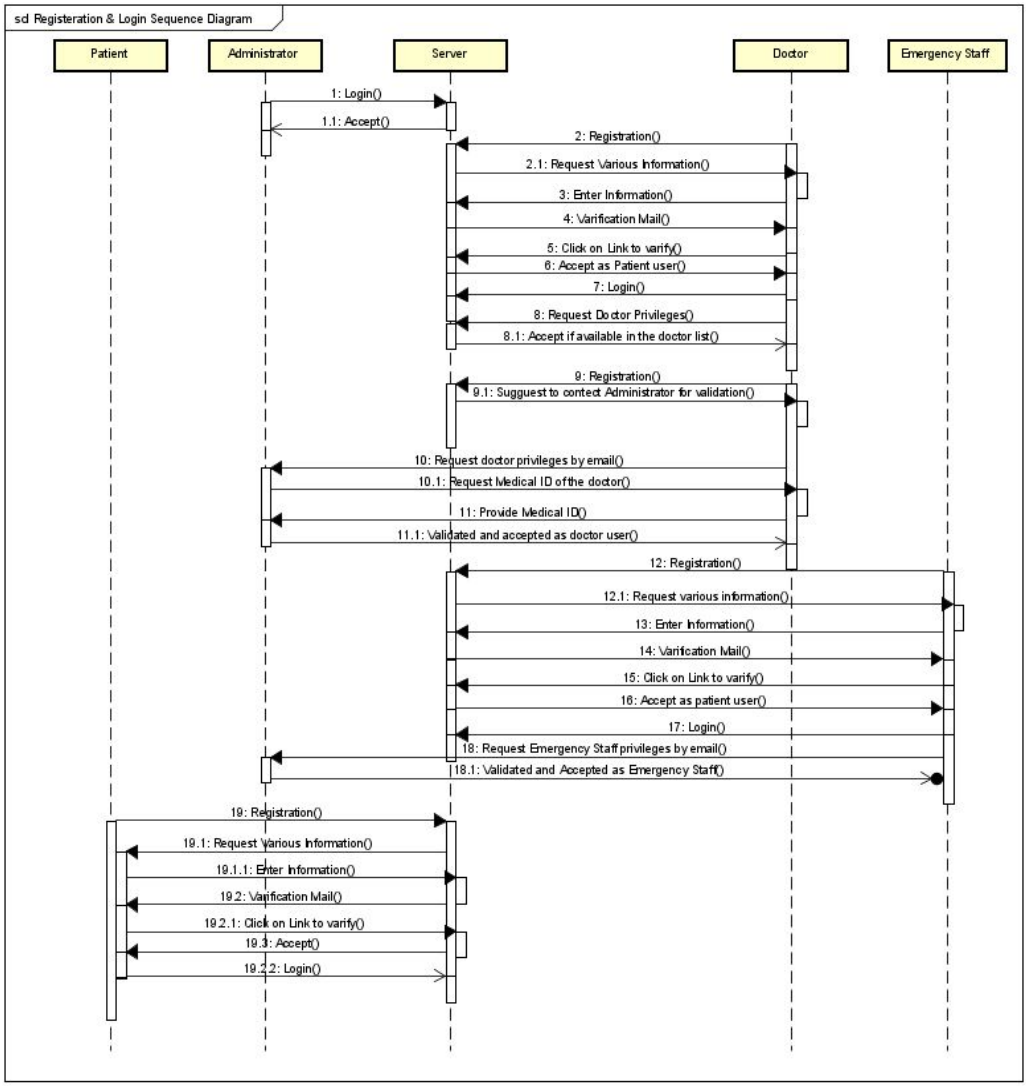


Figure 5.7 Sequence diagram of the New Registration and Login scenario

5.6 Alert processes of Proposed System

The healthcare monitoring system comprises an alerting part. The alerting part can either be a notification through HCare web application or via SMS in order to notify the patients themselves and the medical professionals (Doctors and ambulance staff) about the abnormal and critical health conditions of the patients. Regarding alerting through SMS, it is sent either to the patient's phone, the doctor's phone, or the ambulance phone, according to the level of health condition severity. The alerting SMS contains Patient ID, levels of vital signs, and along with GPS coordinates (sent to ambulance staff).

Figures 5.8 illustrates the decision making of sending alarming SMS in the system according to the vital signs levels for both systolic and diastolic blood pressures. Figure 5.9 shows the flowchart of decision process of sending alarming SMS to the system according to the vital signs levels for SPO2 in the blood. where the SMS will be sent in case the data measured exceed the normal thresholding value.

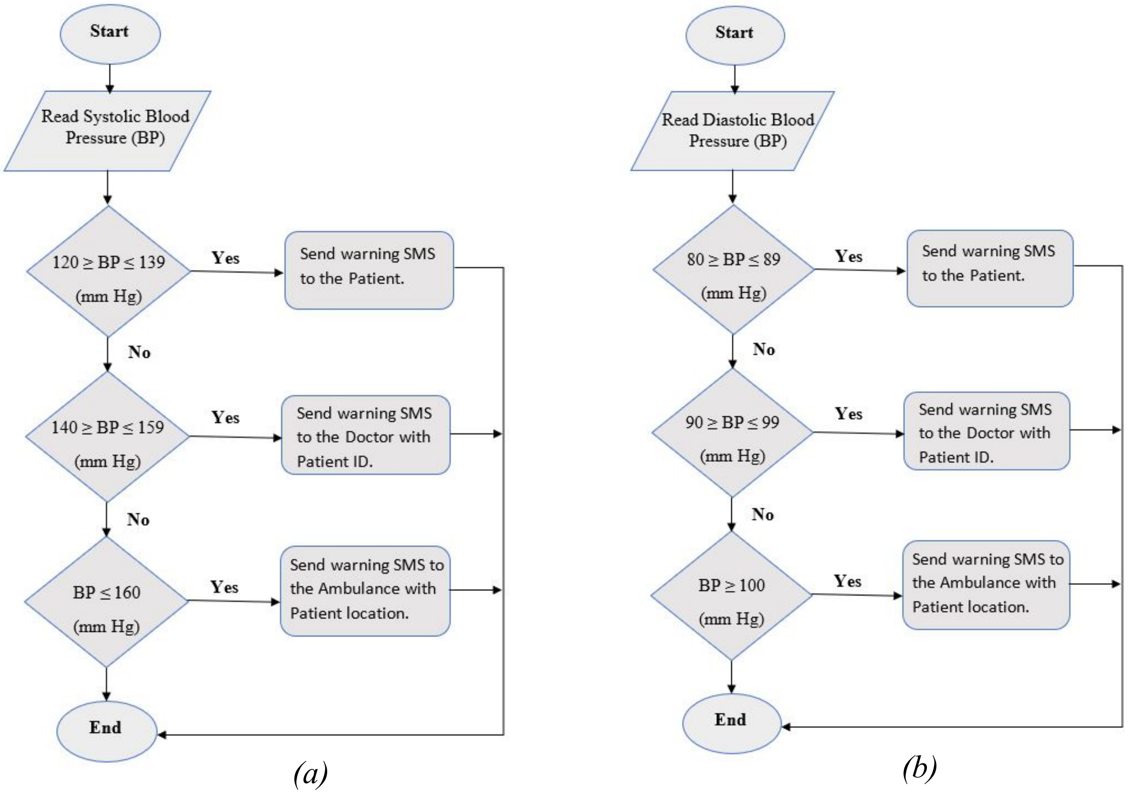


Figure 5.8 Flow chart of the alarming system based on (a) systolic blood pressure and (b) diastolic blood pressure

Figure 5.10 presents the flowchart for the alarming SMS process when measuring the body temperature level. Figure 5.11 illustrates the flowchart of ECG diagnosing results. The alert will be sent when the ECG diagnosing result is AFib case or if there is another arrhythmia case.

The alerting messages will not be sent to all users (patients, doctors, and ambulance staff) for any abnormal case but the system will send the alert message according to the severity level of vital signs. If the severity level is medium, the message will be sent to the patient only, and if severity level is high then the message will be sent to patient and doctor. In the case in which the severity level is reaching a critical level, then the alert message will be sent to all users like patients, doctors, and ambulance staff. The purpose of this distribution based on risk-priority levels is to avoid inconveniences for doctors and emergency personnel due to a large number of alert messages that perhaps are sometimes unnecessary to them, as explained in tables 5.7, 5.8 and 5.9. Except for ECG, the alerts will be sent to the doctor and emergency staff for any kind of arrhythmias because arrhythmia could be considered critical in all cases from the medical perspective as explained in table 5.6.

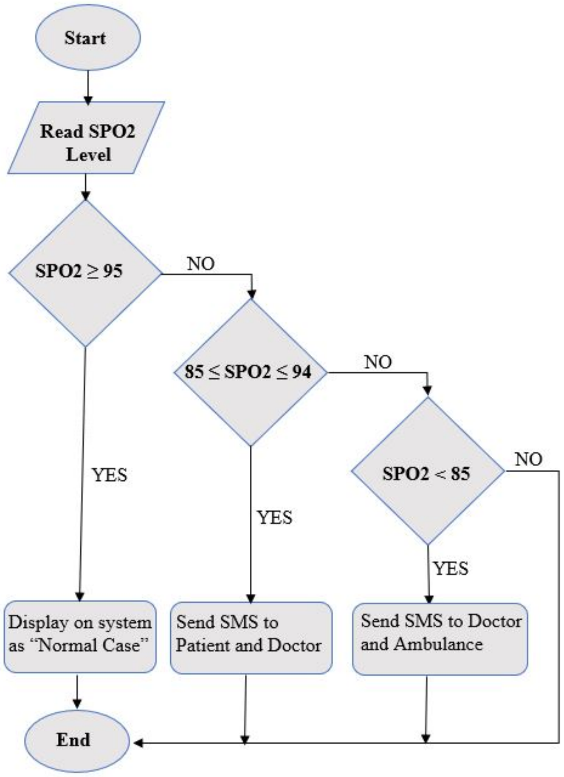


Figure 5.9 Flow chart of the alarming system based on SPO2 level in blood

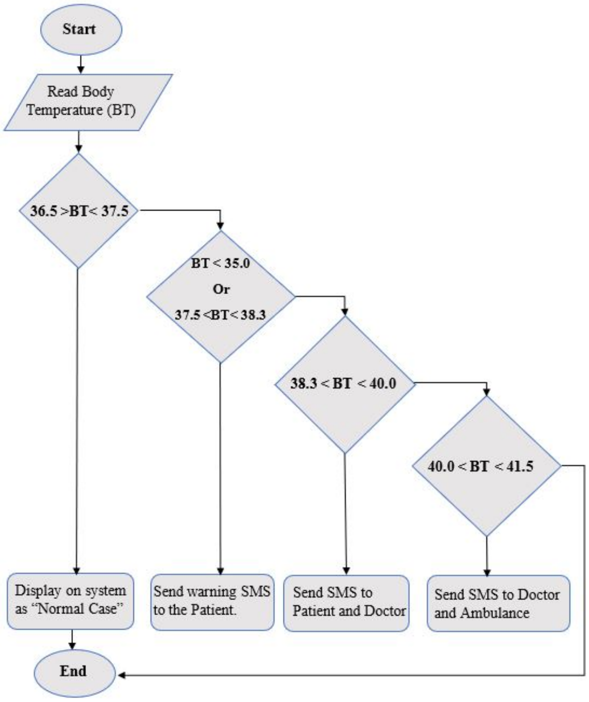


Figure 5.10 Flow chart of the alarming system based on body temperature level

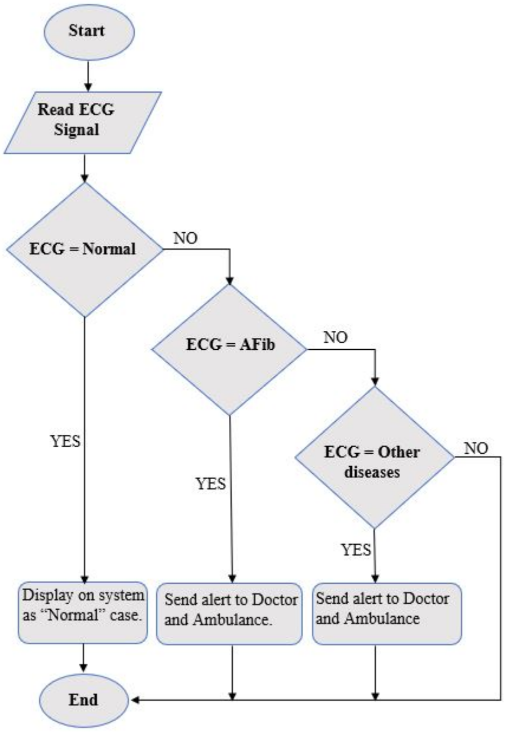


Figure 5.11 Flow chart of the alarming system based on ECG AFib Disease

TABLE 5.6 ECG - AFIB IN THE ALERTING SYSTEM

ECG Diagnosis	**Disease level**	**Sent to**	**Alert Message**
ECG = AFib	Critical	Doctor & Ambulance staff	Please attention, Hcare system has detected an AFib case in the patient's heart; the doctor must check the condition and gives an immediate treatment. Patient ID: xxxxxxx Location coordinates: xxxxxx
ECG = Other disease	Critical	Doctor & Ambulance staff	Please attention, Hcare system has detected an arrhythmia case in the patient's heart; first aid should be performed urgently. Patient ID: xxxxxxx Location coordinates: xxxxxx

TABLE 5.7 BLOOD PRESSURE IN THE ALERTING SYSTEM

Blood Pressure (BP)		**Severity level**	**Sent to**	**Alert Message**
Systolic	*Diastolic*			
120 ≥BP≤ 139	80 ≥BP≤ 89	Medium	Patient	Please take a precaution because your blood pressure is 120/80 mm Hg.
140 ≥BP≤ 159	90 ≥BP≤ 99	High	Patient and Doctor	Please take care the blood pressure is 140/90 mm Hg; the doctor must check the condition and gives an immediate treatment. Patient ID: xxxxxxx
BP≥ 160	BP≥ 100	Critical	Patient, Doctor & Ambulance staff	Blood pressure reached the critical level 160/100 mm Hg; first aid should be performed urgently. Patient ID: xxxxxxx Location coordinates: xxxxxx

TABLE 5.8 SPO2 IN THE ALERTING SYSTEM.

SPO2	**Severity level**	**Sent to**	**Alert Message**
85 ≤ SPO2 ≤ 94	High	Patient and Doctor	Please take care, SPO2 level is 90; the doctor must check the condition and gives an immediate treatment. Patient ID: xxxxxxx
SPO2 < 85	Critical	Patient, Doctor & Ambulance staff	SPO2 reached the critical level: 80; first aid should be performed urgently. Patient ID: xxxxxxx Location coordinates: xxxxxx

TABLE 5.9 BODY TEMPERATURE IN THE ALERTING SYSTEM

Body Temperature	**Severity level**	**Sent to**	**Alert Message**
BT < 35.0 or 37.5 < BT < 38.3	Medium	Patient	Please take a precaution because your body temperature is 38.
38.3 < BT < 40.0	High	Patient and Doctor	Please take care, body temperature is 39; the doctor must check the condition and gives an immediate treatment. Patient ID: xxxxxxx
40.0 < BT < 41.5	Critical	Patient, Doctor & Ambulance staff	Body temperature reached the critical level: 41; first aid should be performed urgently. Patient ID: xxxxxxx Location coordinates: xxxxxx

5.7 System Security Measures

5.7.1 Information Security

Information security of the healthcare field is extremely significant due to high health security threats. Healthcare systems face many hazards to the security of health information arising from ransomware, IoT devices that were insufficiently secured, and human elements as well [124].

The entire communication stages that is performed by users in a healthcare system in a sequence to achieve a certain targeted mission must be secured and protected [125]. In order to obtain better protection of patient information, information security is obligated to have the ability for further classification of patient information confidentiality and to broaden the scope of safety measures in the same system [126].

Previous researches presented different security concerns in the healthcare field, as it is illustrated below:

A. Healthcare information threats in the system:

Threats activities are one of the most dangerous issues that attack the sensitive information of the healthcare system and could affect it badly. The changed health information after the threat attack could lead to deceive the professionals of healthcare. Therefore, analysis of threats possibilities has to be conducted by gather and evaluate the information and specific options that face a particular organization or individual at a certain time.

B. Information Consent:

The confidentiality of healthcare records and its used materials are subjected to many laws imposed within a specified country. Controlling the authorization to access a patient's health records is part of Information Consent that the patient has the right to provide to the authority regarding accessing his/her medical data in an electronic method. The identification of consent on a patient medical data practice means that the disclosure of patient's information is considered very significant to protect the information of patients and guarantee its integrity.

C. Information Sharing

Medical information sharing in the healthcare systems had become part of it and it could change the delivered mothed of care. To ensure that the health-related information is not misused, it permits visibility and flows of this information that is exposed among the users, taking into account the ability to control and monitor it.

5.7.2 Security and Privacy of HCare Web App

Different protection steps were applied to patient-sensitive data through the safe points of web application to ensure integrity and privacy. The following steps are further details regarding security and privacy in the Hcare Web Application [138]:

- Access of System: the users must have credentials in order to confirm the authority of system access.
- Control Access: confirm whether the user already exists in the system or requires creating a new account to access the system.
- Kind of Access: each user has different permission and specific privileges and it is controlled and managed by the system and the administrator of the system where the kind of access will be provided after verifying the user role - if the user is patient, doctor, or from emergency staff.
- Anonymity: is realized partly in the case of personal information of doctors since only the necessary details will be visible for the patients and Hcare maintains the other personal details as private, or wholly anonymity in case of patient information as described in the next sub-section (Confidentiality).

5.7.3 Confidentiality

Confidentiality is quite comparable to privacy. Confidentiality can be defined as an individual's right to retain his personal medical information as private info. Measures must be taken to prevent sensitive data of the patients to be reached by the wrong persons and restrict the access to authorized users only. The sharing of medical information is subject to the decision of the patient himself. The patient decides to whom will share his medical information with the medical staff and as necessary need. Medical professionals have the responsibility to protect the patient's health information when received it from them.

In our proposed system, the doctor will not be able to access the patient medical information until the patient requests an appointment with this doctor and the appointment must be confirmed by the patient. In this case only, the medical information of this patient will be reachable by the doctor, otherwise the information will maintain on its private status. Figure 5.12 illustrates this scenario.

Two-factor authentication (2FA) method was applied to improve the security layer in order to protect the users accounts. Data Encryption technique of the identity framework has been used to ensure the confidentiality by encrypting user’s ID and the information of the user.

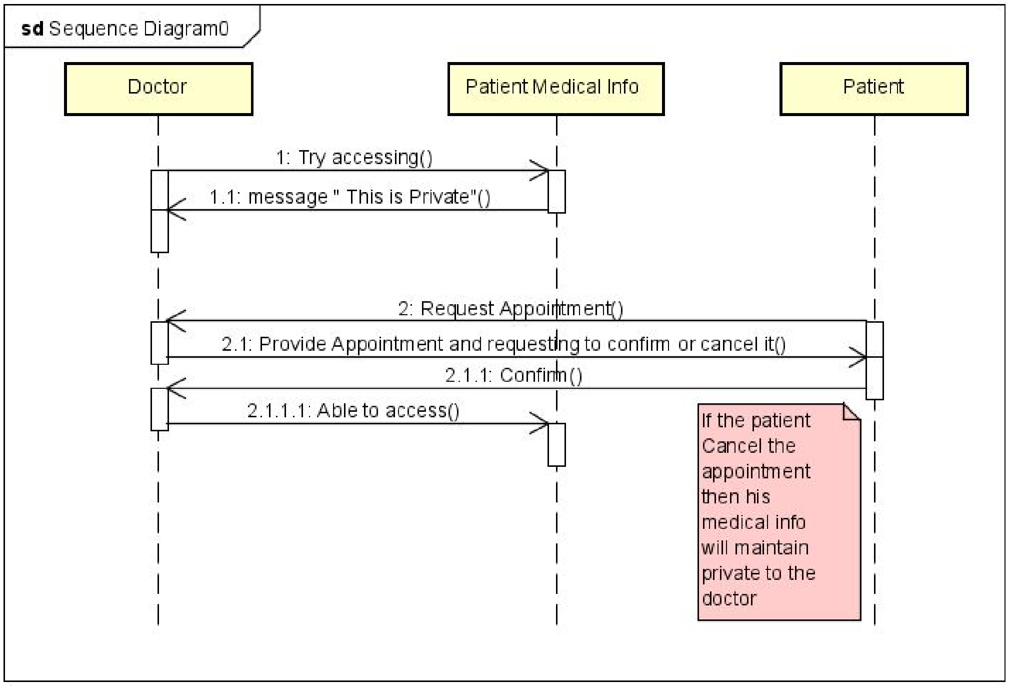


Figure 5.12 Privacy Scenario of Patient's Medical Info through Appointment

5.8 Cloud Computing Approach for ECG Diagnose Module

5.8.1 Cloud Computing – Concept and Models

Cloud computing is known as a technology that allows us to carry out the computation by offering various types of services and the method of exchanging data through the Internet. The sources of cloud computing involve applications and tools such as data storage, databases, servers, software, and networking. It has already attracted global interest in delivering services such as DropBox, Gmail, etc. Quick access to data across a widespread and cost-effective network has made cloud computing the most advanced Internet technologies. It was developed as an accessory to network computing as resources and services accumulate on the infrastructure of hardware. In general, the applications of cloud computing are developed utilizing internet technologies such as AJAX.Net, PHP, CSS, SOAP, and HTML [131].

The cloud of health has been designed as a correlation between numerous PCs and servers assigned particularly to fit the demands of the healthcare manufacture. The services of healthcare are offered to users who can be health professionals or patients over an internet network. User registration is mandatory to enable cloud services and access the software and hardware that are managed remotely by the vendors. The method of store and access information has been grown with the employ of cloud computing. Cloud computing mechanism is the payment for the services that the user consumes only, and it provides self-servicing by allows the users to increase the sources of computing on-demand according to the workloads level, and also, it has the flexibility to scale up or down the resources [132].

Cloud server usage is a key factor to avoid component failure in the system by providing high flexibility in receiving, storing and using data.

The cloud services consist of three models and ordinarily called SPI models which referred to the services software, platform or infrastructure. Figure 5.13 shows the diagram of cloud service models.

i. SaaS Model

SaaS stands for Software as a Service, which means the client will be provided with complete software running on the infrastructure of cloud in the form of service afforded by the vendor. This software can be reachable by the different devices of the users via a particular interface or an API using the internet [133]. The users are restricted to utilize this service, they don't have the capability to control or manage the underlying infrastructure of cloud such as operating system, storage, servers, and network [134].

- Advantages of SaaS:
  - Can be accessed Globally from any platform.
  - It is great for collective working.
  - Different simple software tools are provided by the vendor.
  - The multi-Tenancy option is available.

- Disadvantages of SaaS:
  - Problems of browser.
  - The restrictions of compliance.
  - The overall performance is controlled by the internet.
  - Portability.

ii. PaaS Model

PaaS stands for Platform as a Service, which indicates that the applications are created by developers using a hosted programming language in the cloud infrastructure through the provider of cloud service. It allows clients creating or developing software (SaaS) and cloud services directly on the PaaS cloud whereas SaaS is already available and ordinarily administered by the cloud service provider. The hosting can also be for complete or in progress software [135]. In other word, PaaS is used by developers, they can create, compile and operate programs, and users can manage and control the sources of application and its data. A good example of PaaS is Google AppEngine [134] [135].

- Advantages of PaaS:
  - scalability and cost-effectively is extremely high.
  - A quicker market for designers and developers.
  - The flexibility of web applications deployment.
  - The deployment available with the private and public options.

- Disadvantages of PaaS:
  - Use certain programming languages that predefined by the provider only.
  - The capability made limited for developers by the vendor.
  - The issues of migration.
  - Vendor locked-in.

iii. IaaS Model

IaaS stands for Infrastructure as a Service and provides a computing architecture and infrastructure which include resources of virtualization, data storage, servers, and networking. These resources are managed by vendors while the users will handle the data and middleware only. The virtualization resource of IaaS cloud is broadly utilized to exploit physical resources by decomposing and integrating it in a way that is customized to meet the increasing or decreasing demand for resources from cloud customers and that is by setting up virtual machines (VM) independently [135]. IaaS cloud model is considered as a foundation layer for the other models and is usually used by system administrators [136]. Running multiple VMs on a single physical server simultaneously became possible with the use of virtualization [137]. Amazon's EC2 is a well-known instance of the IaaS cloud model [135].

- Advantages of IaaS:
  - It provides infrastructure.
  - Normally the cloud scalability feature is enhanced.
  - Dynamic workloads are underpinned.
  - Very flexible.

- Disadvantages of IaaS:
  - Problems of security.
  - The delays of service.
  - The delays of network.

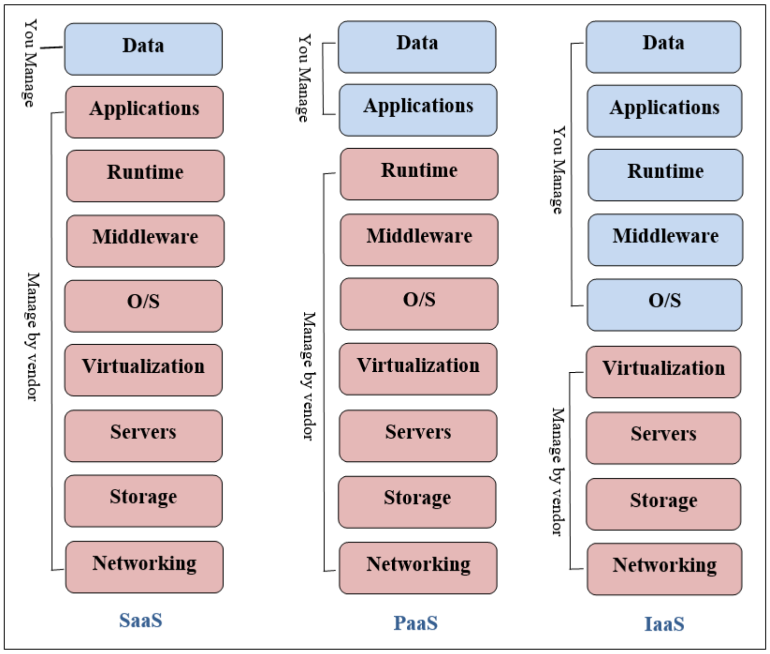


Figure 5.13 Comparison of Cloud Service Models

5.8.2 Implementation Details of ECG Diagnose Module in Cloud

The ECG filtering and automatic diagnosis modules were created with the use of MATLAB programming environment as discussed in the previous chapters. Microsoft Visual Studio v.2016 has been used to deploy Hcare web-app on the MS Azure cloud. Since Hcare web application that runs on Microsoft Azure cloud in the form of SaaS is designed using another programming language C# and .NET framework, therefore to avoid re-coding the algorithms in another language, we have used MATLAB Compiler™ SDK approach to generate software components such as assembly libraries called Dynamic Link Library (DLL). The header files were linked with the Hcare web application through integration connection. The shared libraries (DLL) enable an in-process approach in which the library and the code that invokes it are a portion of a single operating system process. The whole point of DLL is the reusability, we can create DLL once then we can host it inside our application where the DLL will run inside the address space of the hoster (Hcare). In the end, these modules will be available to use by various clients who are accessing our Hcare web application. Figure 5.14 illustrates the process of simultaneous interaction between the algorithms of ECG filtering and automatic diagnosis that were implemented in MATLAB to perform the filtering and classification process. The results are then transferred to the intermediate storage centers (Shared Folder) and the new results are fetched by the Hcare system that is acted in parallel with the mentioned algorithms to be used by the users. In other words, the results will be saved at each update time in a shared folder on the MS Azure cloud and these results will be fetched by the system simultaneously.

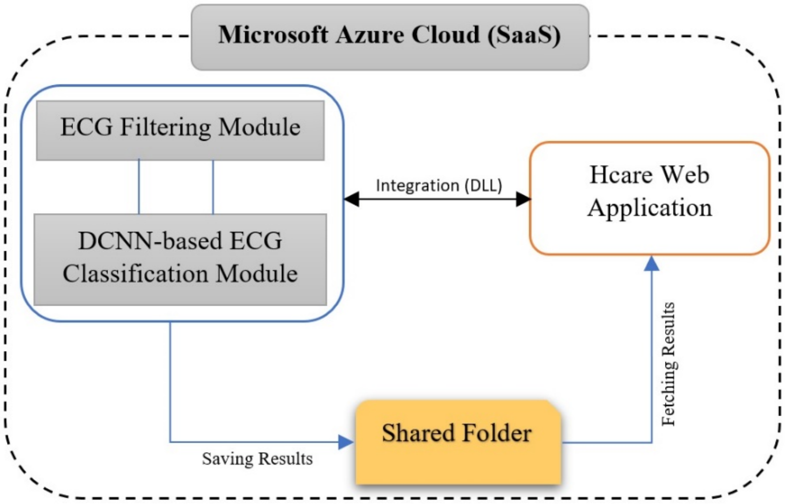


Figure 5.14 Results synchronization between the ECG filtering, the automatic diagnosis modules and the Hcare Web Application

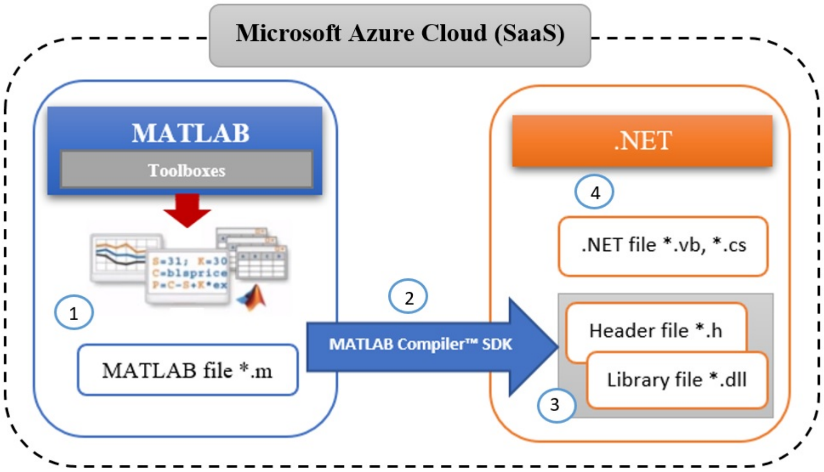
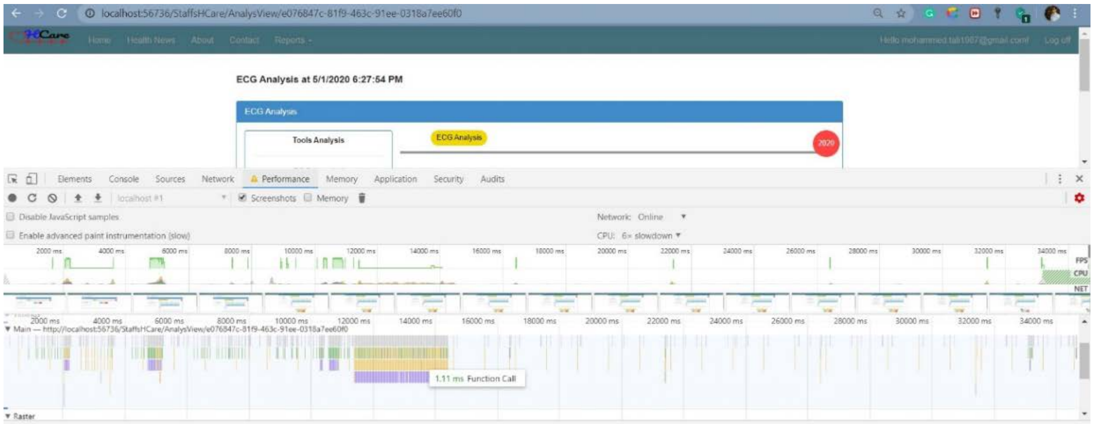


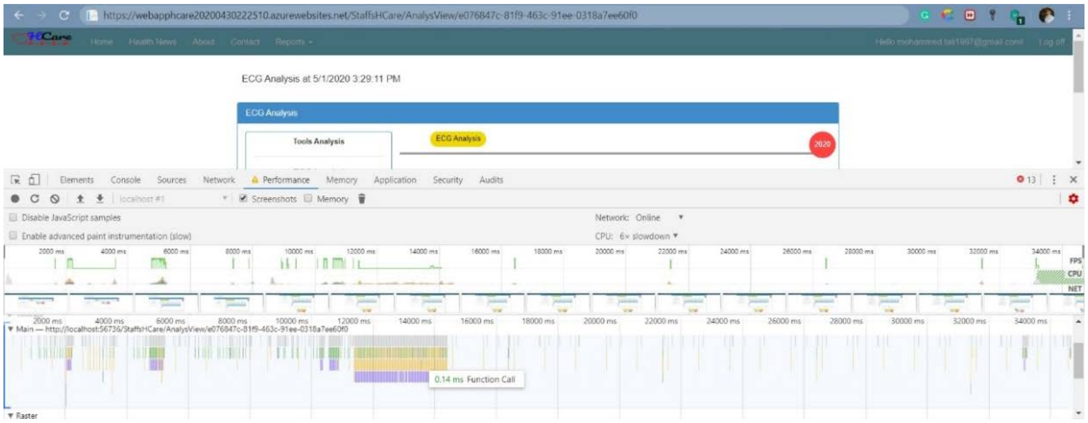
Figure 5.15 General Diagram for MATLAB Algorithms deployment on .NET Platform

Figure 5.15 illustrates the MATLAB algorithms integration steps with .NET Platform that have been utilized to link the MATLAB files of the innovative ECG filtering and automatic diagnosis modules with our Hcare web application. First, the MATLAB files (*.m) of our modules are created by using MATLAB toolboxes. Second, the MATLAB Compiler™ SDK runs to generate a DLL and header file (contain a C# code). Finally, the generated files will be integrated with all .NET files.

In this work, we had run the Hcare web app on two servers - the host server (Normal) and the cloud server - to monitor the performance difference between them. By this test, we emphasized one more contribution regarding ECG Analysis in the Hcare Web application since the application was tested with the use of modern DevTools which is a set of web development tools that helps developers to test and debug their websites or web applications [141]. We started the test by opening the DevTools and navigated to the ECG Analysis page and run it to diagnose a certain ECG signal of a patient. On the other side, on the Performance tab of the DevTools, we started recording the performance simultaneously until obtaining a result. The recording results are shown in the figure 5.16 that illustrates the performance difference through a function call durations between (a) implementing ECG diagnose of the Hcare web-app in a host server and (b) implementing ECG diagnose of the Hcare web-app in a cloud (MS Azure). We can observe from the test that the duration of the function call is 1.11 ms on the local host while on the Azure cloud is 0.14 ms. This means that calling a function on the cloud is faster than on the host server.



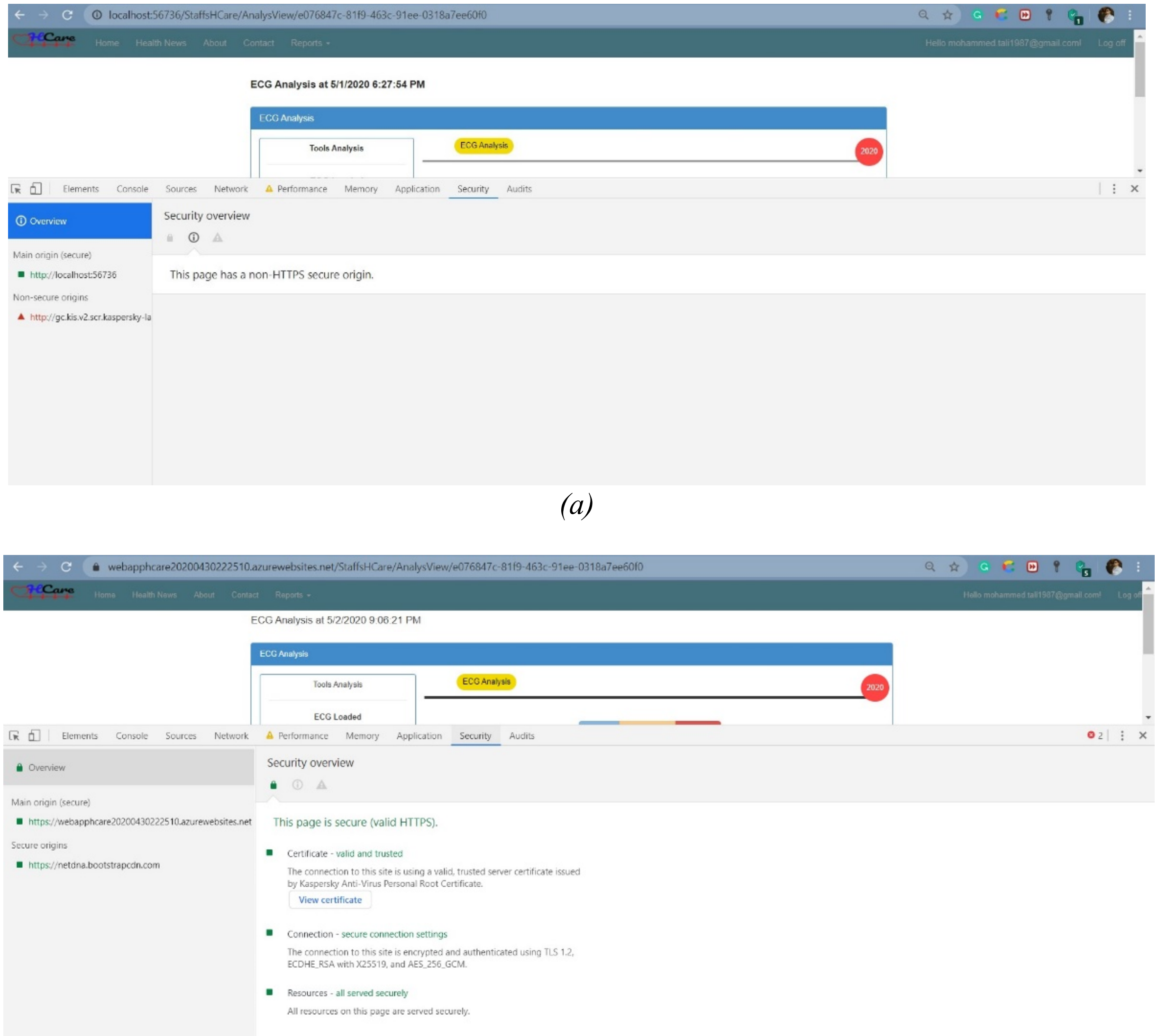
a -Implementing the ECG Diagnose on host server



b -Implementing the ECG Diagnose on Azure cloud server

Figure 5.16 Performance difference by function call durations between (a) Hcare web-app in host server and (b) Hcare web-app in Azure Cloud server

Figure 5.17 presents an overview of Hcare web application security. We can observe that the web application running on the cloud server is secured and trusted where the validation of HTTPS is enabled, the connection to the web app is encrypted and authenticated using different security techniques such as TLS 1.2, ECDHE_RSA with X25519, and AES_256_GCM, as well as all resources of Hcare on the cloud server are served securely. Whilst, Hcare web-app that running on a host server is not secured at this standard.



localhost:56736/StaffsHCare/AnalysView/e076847c-81f9-463c-91ee-0318a7ee60f0

Hello mohammed.tali1987@gmail.com!

ECG Analysis at 5/1/2020 6:27:54 PM

Main origin (secure)

http://localhost:56736

Non-secure origins

http://gc.kis.v2.scr.kaspersky-la

This page has a non-HTTPS secure origin.

(a)

webapphcare20200430222510.azurewebsites.net/StaffsHCare/AnalysView/e076847c-81f9-463c-91ee-0318a7ee60f0

Hello mohammed.tali1987@gmail.com!

ECG Analysis at 5/2/2020 9:06:21 PM

Main origin (secure)

https://webapphcare20200430222510.azurewebsites.net

Secure origins

https://netdna.bootstrapcdn.com

This page is secure (valid HTTPS).

- Certificate - valid and trusted

  The connection to this site is using a valid, trusted server certificate issued by Kaspersky Anti-Virus Personal Root Certificate.

- Connection - secure connection settings

  The connection to this site is encrypted and authenticated using TLS 1.2, ECDHE_RSA with X25519, and AES_256_GCM.

- Resources - all served securely

  All resources on this page are served securely.

(b)

Figure 5.17 Security Overview of Hcare Web App on: (a) Host server and (b) Cloud server

5.9 Design and Implementation

5.9.1 Software Tools

The web application designing consists of several parts such as interfaces, databases, the interaction between them, and a security part in which these parts need to be built utilizing different design environments and tools, as listed and illustrated below:

- **C# Programming Language:** is a common-objective language created for application development using the platform of Microsoft that needs the .NET framework in order to operate. C# was used to program our web application system.

- **ASP.Net MVC:** a common open-source environment for web development utilized to design a websites or web applications along with other techniques. Incipiently, the platform of ASP.NET was developed for Web Form use and it supports several programming models and, in this work, the model-view-controller (MVC) design pattern was used to design dynamic web pages. The principle of MVC pattern is to join it with components that contain a set of user interface (UI) elements and each single UI element considers a higher-level component that joins the required three components of MVC into one package. This mechanism provides developers with the ability to reuse the components in different applications quickly and comfortably. Additionally, ASP.Net MVC provides a jQuery feature for easier and best web development. ASP.Net MVC was used to build the dynamic web pages of Hcare web application.

- **JQuery:** is a JavaScript library that makes the utilization of JavaScript easier for developers to build web pages. Instead of writing a lot of codes and in many lines in JavaScript for a particular task, the JQuery takes these codes and converts it into a single method and this method can be called in a code of single line. Many features are contained in JQuery library such as HTML/DOM manipulation, CSS manipulation, HTML event methods, effects and animations, and AJAX.

- **Bootstrap:** is a most common open-source HTML, CSS, and JS framework directed at developing highly-responsive projects on the websites. Moreover, the JQuery is required in order to make the Bootstrap operating. Bootstrap functionalities helped me to the front-end design of Hcare web application quickly due to the availability of various element styles. Also, it helped to make Hcare a responsive web application.

- **Identity Framework:** supports GUI login functionality such as manage usernames, passwords, email confirmation, and others. The users have the possibility to create a login account in which the login details will be stored in identity or they can utilize login information from external providers such as Google, Facebook, etc.

- **Entity Framework:** is also called Object Relational Mapper (ORM) is an open-source framework provided by Microsoft that maps the entities with the tables of the database automatically. It allows us as developers to utilize .NET objects for operating with a database.

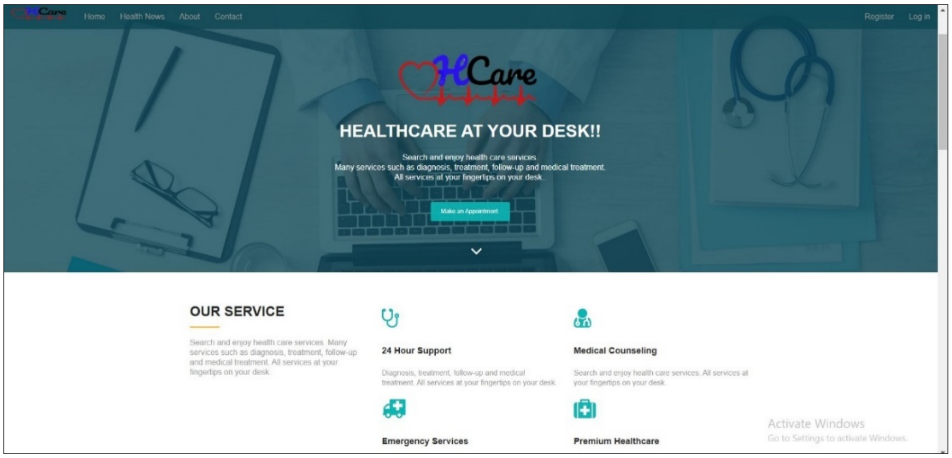
- **SQL Server:** it stands for Structured Query Language, which is one of the most popular database technologies in the programming market used to manage the databases and its relations. The SQL Server is applied in our system to store all the healthcare and medical data.

- **Microsoft Azure Cloud:** A set of cloud computing services built by Microsoft to create, deploy and manage applications through its data centers on a huge global network. These services are SaaS, PaaS, and IaaS. Azure deals with various programming languages, frameworks, and tools. We have used SaaS of the cloud to run the Hcare web-application.

- **MATLAB Compiler™ SDK:** an expands MATLAB Compiler™ functionality to allow creating different components from MATLAB programs such as shared libraries from C/C++, Microsoft .NET assemblies, and packages and classes from Python and Java. These components allow the developers to integrate it with custom applications written in other programming languages, and then deploy it to desktop and web systems. MATLAB Compiler™ SDK was very important for implementation by integrating the MATLAB algorithms (the ECG filtering and automatic diagnosis algorithms) with the Hcare Web Application.

5.9.2 Design of Hcare Web Application

Web application design sequences have been described in this section. The web pages are designed to cover the requirements of health services, and this design is included with different sub-web pages also. Figure 5.18 shows the home page of Hcare web application. From the home page the user can scroll down and read the latest three health news as shown in figure 5.19 the system display the most three interested news and if the users want to read more health new then they can click on the button (See more) or Health New option from the top bar of the page to view all the recent health news as shown in figure 5.20.



HEALTHCARE AT YOUR DESK!!

Search and enjoy health care services.
Many services such as diagnosis, treatment, follow-up and medical treatment.
All services at your fingertips on your desk.

OUR SERVICE

Search and enjoy health care services. Many services such as diagnosis, treatment, follow-up and medical treatment. All services at your fingertips on your desk.

24 Hour Support

Diagnosis, treatment, follow-up and medical treatment. All services at your fingertips on your desk.

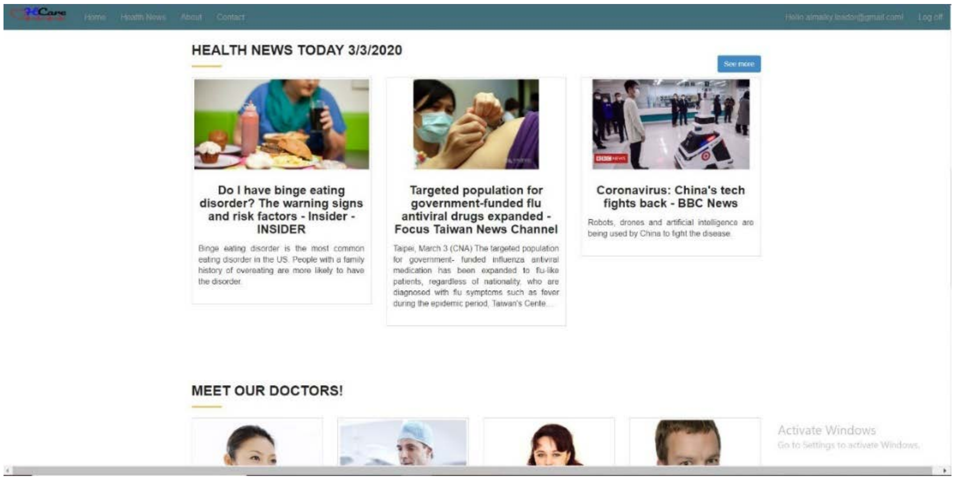
Medical Counseling

Search and enjoy health care services. All services at your fingertips on your desk.

Emergency Services

Premium Healthcare

Figure 5.18 Home Page of Hcare Web App



HEALTH NEWS TODAY 3/3/2020

Do I have binge eating disorder? The warning signs and risk factors - Insider - INSIDER

Binge eating disorder is the most common eating disorder in the US. People with a family history of overeating are more likely to have the disorder.

Targeted population for government-funded flu antiviral drugs expanded - Focus Taiwan News Channel

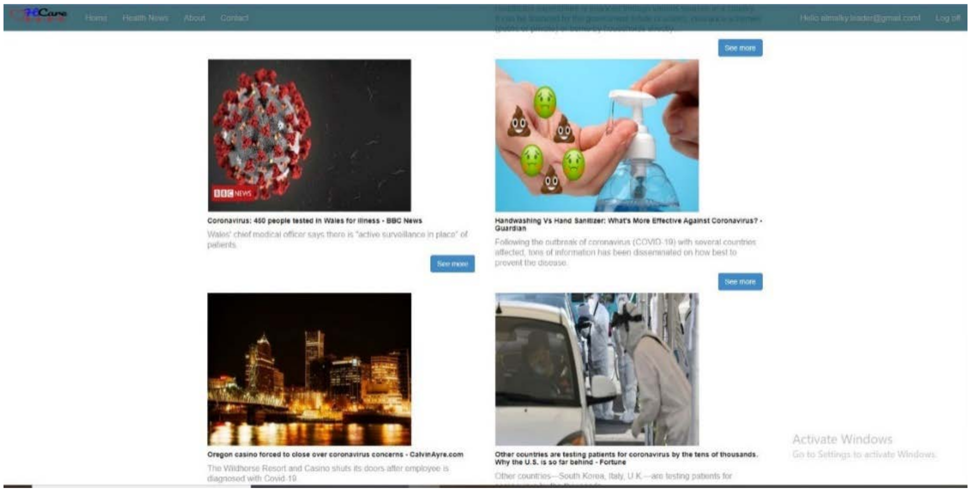
Taipei, March 3 (CNA) The targeted population for government- funded influenza antiviral medication has been expanded to flu-like patients, regardless of nationality, who are diagnosed with flu symptoms such as fever during the epidemic period, Taiwan's Cente...

Coronavirus: China's tech fights back - BBC News

Robots, drones and artificial intelligence are being used by China to fight the disease.

MEET OUR DOCTORS!

Figure 5.19 Home Page - Health News (Scroll Down)



Coronavirus: 450 people tested in Wales for illness - BBC News

Wales' chief medical officer says there is "active surveillance in place" of patients.

Handwashing Vs Hand Sanitizer: What's More Effective Against Coronavirus? - Guardian

Following the outbreak of coronavirus (COVID-19) with several countries affected, tons of information has been disseminated on how best to prevent the disease.

Oregon casino forced to close over coronavirus concerns - CalvinAyre.com

The Wildhorse Resort and Casino shuts its doors after employee is diagnosed with Covid-19.

Other countries are testing patients for coronavirus by the tens of thousands. Why the U.S. is so far behind - Fortune

Other countries—South Korea, Italy, U.K.—are testing patients for

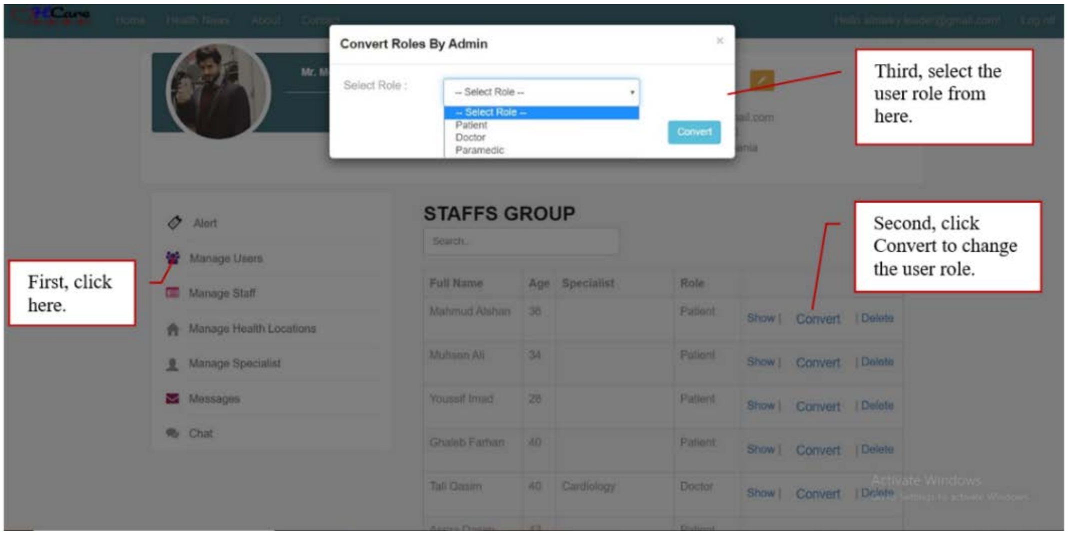
Figure 5.20 Health News Page

5.9.2.1 Design of Registration and Login Pages

User must do registration in order to login and use the Hcare web-app. The registration consists of two steps, first creates un unique account with user email address and password, on another form as a second step the user should fill in the personal information to create his own profile. This personal information includes (first name, second name, age, gender, blood type, specialist, length, weight, and upload image person). The created account will be activated after verifying it through mail sent to his email by system as part of a security system. The user will be authenticated using his new account (email address and password) and will be authorized to login the system through the main login page as a normal patient.

5.9.2.2 Design of Administrator Section

In this section, the administrator has privileges to manage all the users in general and control their roles by keeping the user as a patient or convert him to be a doctor or paramedic as shown in figure 5.21. Administrator allows managing the medical staff by adding their names, location work (Hospital, clinic, etc.), specializations, and confirm their roles as shown in figure 5.22. Also, he can add the required medical specializations and health locations to the system. Additionally, an administrator has options to communicate with all the users by chat or send\receive messages. He can create reports and print them as well.



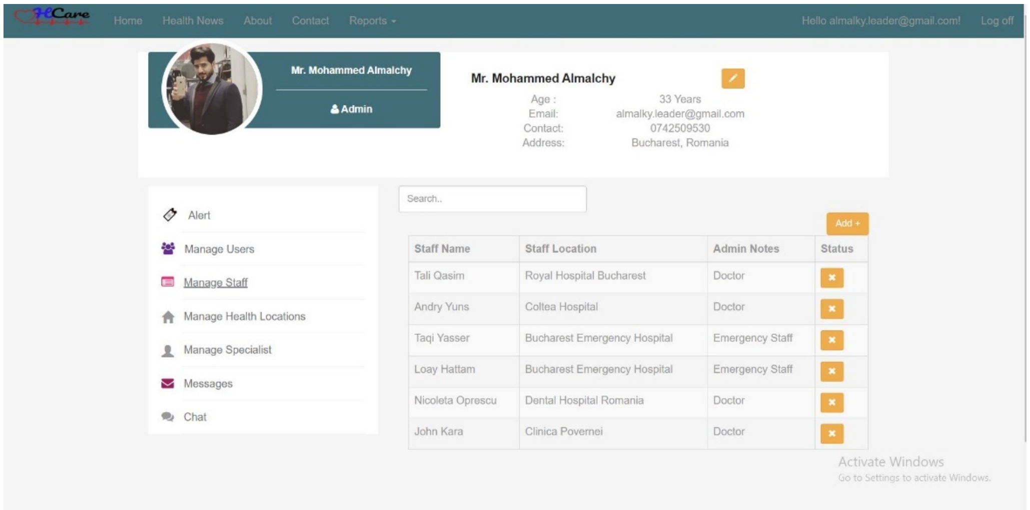
Full Name	Age	Specialist	Role	
Mahmud Alshan	36		Patient	Show | Convert | Delete
Muhsen Ali	34		Patient	Show | Convert | Delete
Youssif Imad	28		Patient	Show | Convert | Delete
Ghaleb Farhan	40		Patient	Show | Convert | Delete
Tali Qasim	40	Cardiology	Doctor	Show | Convert | Delete

Third, select the user role from here.

Second, click Convert to change the user role.

First, click here.

Figure 5.21 Manage Users by Administrator



Mr. Mohammed Almalchy

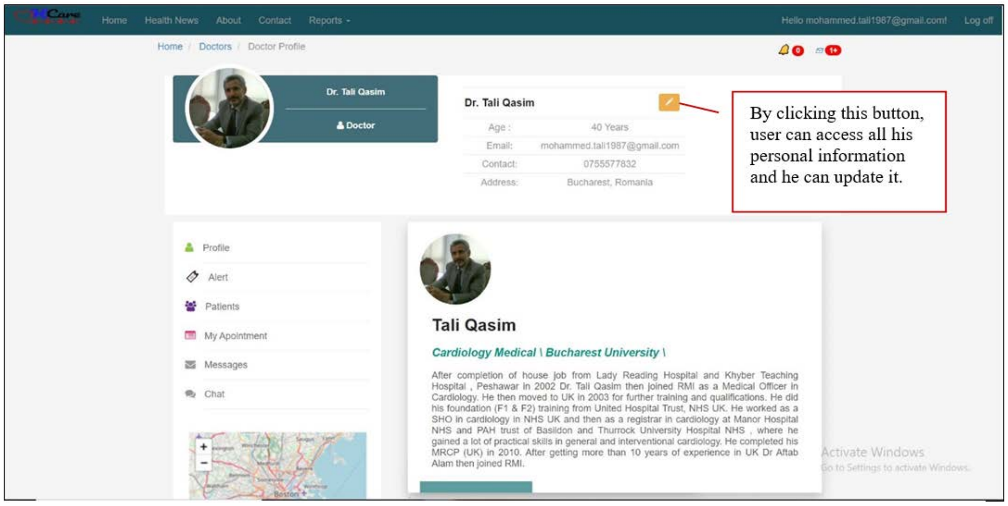
Age : 33 Years
Email: almalky.leader@gmail.com
Contact: 0742509530
Address: Bucharest, Romania

Staff Name	Staff Location	Admin Notes	Status
Tali Qasim	Royal Hospital Bucharest	Doctor	×
Andry Yuns	Coltea Hospital	Doctor	×
Taqi Yasser	Bucharest Emergency Hospital	Emergency Staff	×
Loay Hattam	Bucharest Emergency Hospital	Emergency Staff	×
Nicoleta Oprescu	Dental Hospital Romania	Doctor	×
John Kara	Clinica Povernei	Doctor	×

Figure 5.22 Manage Staff by Administrator

5.9.2.3 Design of Doctor Section

This section provides the doctor different functionalities such as view his profile and edit it if require as shown in figure 5.23. He can manage the appointment schedules with patients, access the profile of their patients along with their medical history. In addition, a doctor can monitor medical activities (SPO2, blood pressure, body temperature, and ECG) of a patient and receive alerts for the abnormal statuses where the doctor can diagnose the patient and suggest prescriptions by adding treatment and medicines according to that as shown in figure 5.24. The system provides additional services to doctors such as correspondence with the patients by messages and chat, and they can make reports and print them as shown in figure 5.25.



Dr. Tali Qasim

Age : 40 Years
Email: mohammed.tali1987@gmail.com
Contact: 0755577832
Address: Bucharest, Romania

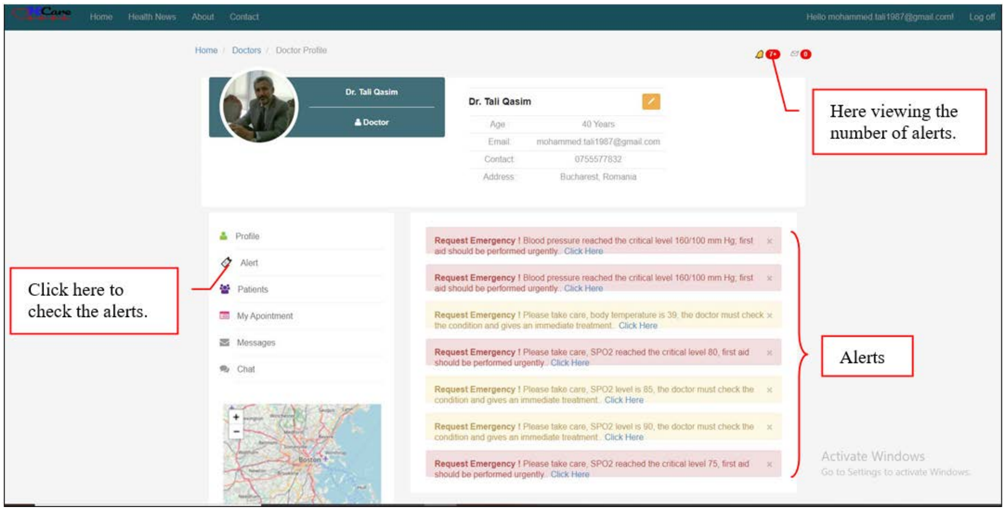
By clicking this button, user can access all his personal information and he can update it.

Tali Qasim

*Cardiology Medical \ Bucharest University *

After completion of house job from Lady Reading Hospital and Khyber Teaching Hospital , Peshawar in 2002 Dr. Tali Qasim then joined RMI as a Medical Officer in Cardiology. He then moved to UK in 2003 for further training and qualifications. He did his foundation (F1 & F2) training from United Hospital Trust, NHS UK. He worked as a SHO in cardiology in NHS UK and then as a registrar in cardiology at Manor Hospital NHS and PAH trust of Basildon and Thurrock University Hospital NHS , where he gained a lot of practical skills in general and interventional cardiology. He completed his MRCP (UK) in 2010. After getting more than 10 years of experience in UK Dr Aftab Alam then joined RMI.

Figure 5.23 The Profile Page of Doctor



Dr. Tali Qasim

Age: 40 Years
Email: mohammed.tali1987@gmail.com
Contact: 0755577832
Address: Bucharest, Romania

Request Emergency ! Blood pressure reached the critical level 160/100 mm Hg, first aid should be performed urgently. Click Here

Request Emergency ! Blood pressure reached the critical level 160/100 mm Hg, first aid should be performed urgently. Click Here

Request Emergency ! Please take care, body temperature is 39, the doctor must check the condition and gives an immediate treatment. Click Here

Request Emergency ! Please take care, SPO2 reached the critical level 80, first aid should be performed urgently. Click Here

Request Emergency ! Please take care, SPO2 level is 85, the doctor must check the condition and gives an immediate treatment. Click Here

Request Emergency ! Please take care, SPO2 level is 90, the doctor must check the condition and gives an immediate treatment. Click Here

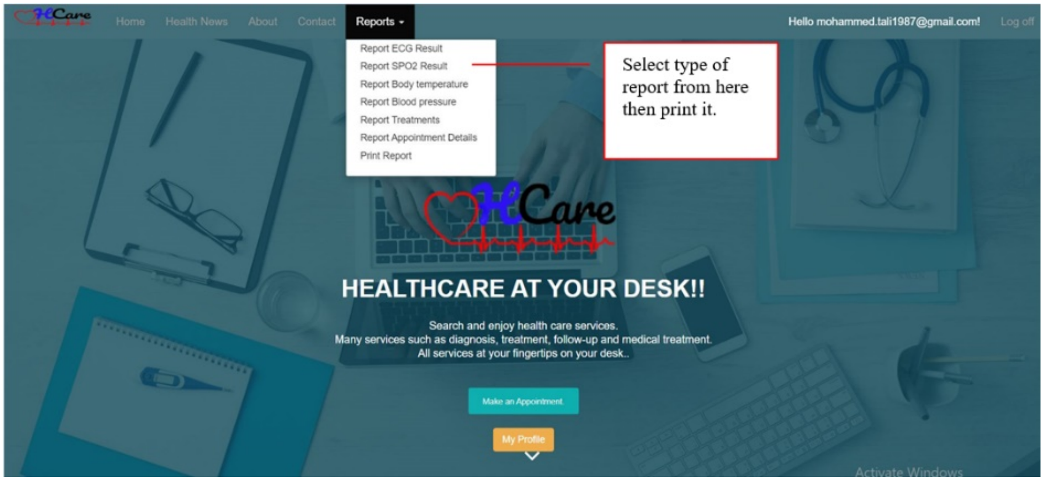
Request Emergency ! Please take care, SPO2 reached the critical level 75, first aid should be performed urgently. Click Here

Here viewing the number of alerts.

Click here to check the alerts.

Alerts

Figure 5.24 Alerts Received from the Patients of Doctor



Search and enjoy health care services.
Many services such as diagnosis, treatment, follow-up and medical treatment.
All services at your fingertips on your desk..

Select type of report from here then print it.

Figure 5.25 Reports Page

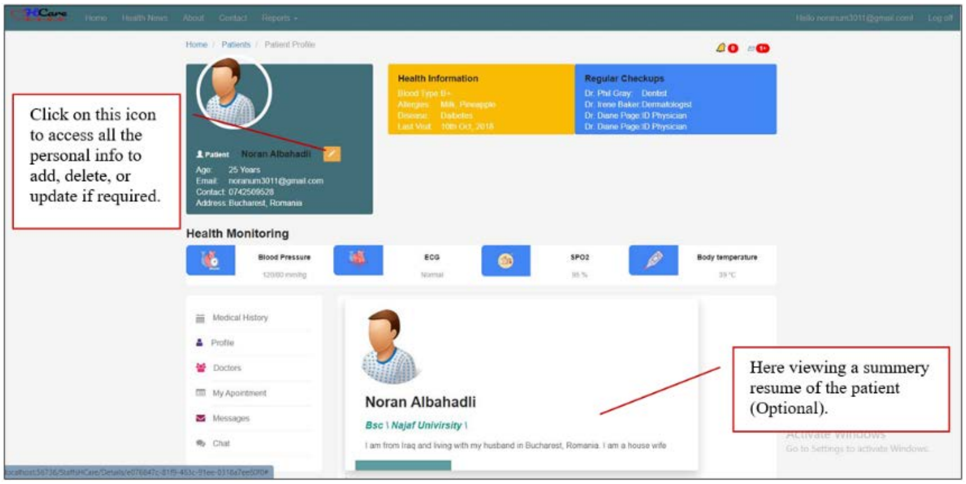
5.9.2.4 Design of Patient Section

The patient will be provided with various functionalities in this section of the system such as view his profile, medical history, health information. He can read digital diagnoses and prescriptions that are given by a doctor. Also, he can monitor the levels of his medical activities and receive alerts as notifications or SMS from the system or doctor for irregular conditions where the alerts notifications will be on three levels as illustrated in figure 5.27 and listed below:

- Medium level: green color.
- High level: yellow color.
- Critical level: red color.

Presenting the activity chart for each of SPO2, Blood Pressure, and Body temperature of a patient is significant for an accurate diagnosis. Therefore, it is included in the system by clicking on any of them from the Health Monitoring bar. Figure 5.28 shows the activity chart of SPO2 as a sample of these charts.

The system provides patients with the ability to search for a doctor and manage the appointments (time and date) with him and confirm or cancel the appointment as well. Additionally, the patient able to contact doctors and emergency services at any time through messages, chat, and phone numbers that are available in the system as illustrated in figure 5.29. Figure 5.26 presents the patient page in the Hcare system.



Click on this icon to access all the personal info to add, delete, or update if required.

Patient Noran Albahadli
Age: 25 Years
Email: noranum3011@gmail.com
Contact: 0742509528
Address: Bucharest, Romania

Health Information
Blood Type: B+
Allergies: Milk, Pineapple
Disease: Daibetes
Last Visit: 10th Oct, 2018

Regular Checkups
Dr. Phil Gray: Dentist
Dr. Irene Baker: Dermatologist
Dr. Diane Page: ID Physician
Dr. Diane Page: ID Physician

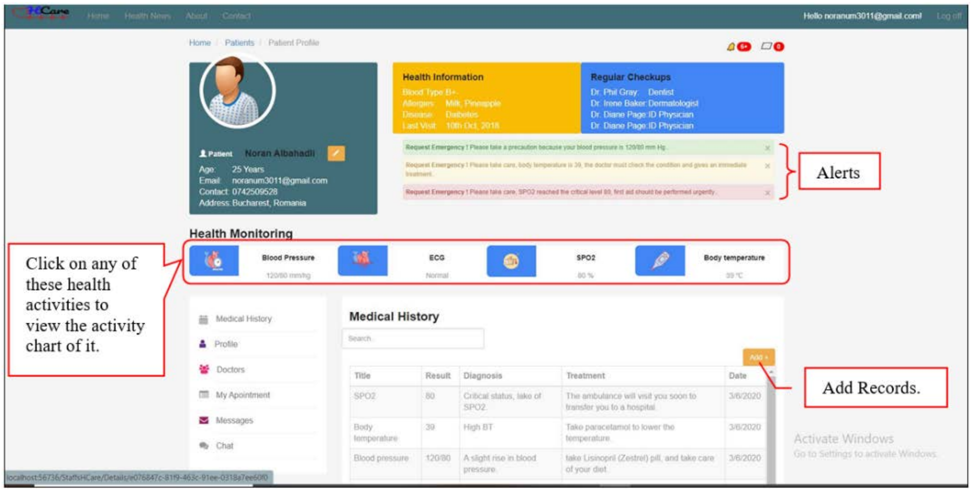
Blood Pressure 120/80 mmHg
ECG Normal
SPO2 95 %
Body temperature 39 °C

Noran Albahadli
Bsc \ Najaf Univirsity \
I am from Iraq and living with my husband in Bucharest, Romania. I am a house wife

Here viewing a summery resume of the patient (Optional).

localhost:56736/StaffsHCare/Details/e076847c-81f9-463c-91ee-0318a7ee60f0#

Figure 5.26 Patient Page



Patient Noran Albahadli
Age: 25 Years
Email: noranum3011@gmail.com
Contact: 0742509528
Address: Bucharest, Romania

Health Information
Blood Type: B+
Allergies: Milk, Pineapple
Disease: Daibetes
Last Visit: 10th Oct, 2018

Regular Checkups
Dr. Phil Gray: Dentist
Dr. Irene Baker: Dermatologist
Dr. Diane Page: ID Physician
Dr. Diane Page: ID Physician

Request Emergency ! Please take a precaution because your blood pressure is 120/80 mm Hg.
Request Emergency ! Please take care, body temperature is 39, the doctor must check the condition and gives an immediate treatment.
Request Emergency ! Please take care, SPO2 reached the critical level 80, first aid should be performed urgently.

Alerts

Blood Pressure 120/80 mm/hg
ECG Normal
SPO2 80 %
Body temperature 39 °C

Click on any of these health activities to view the activity chart of it.

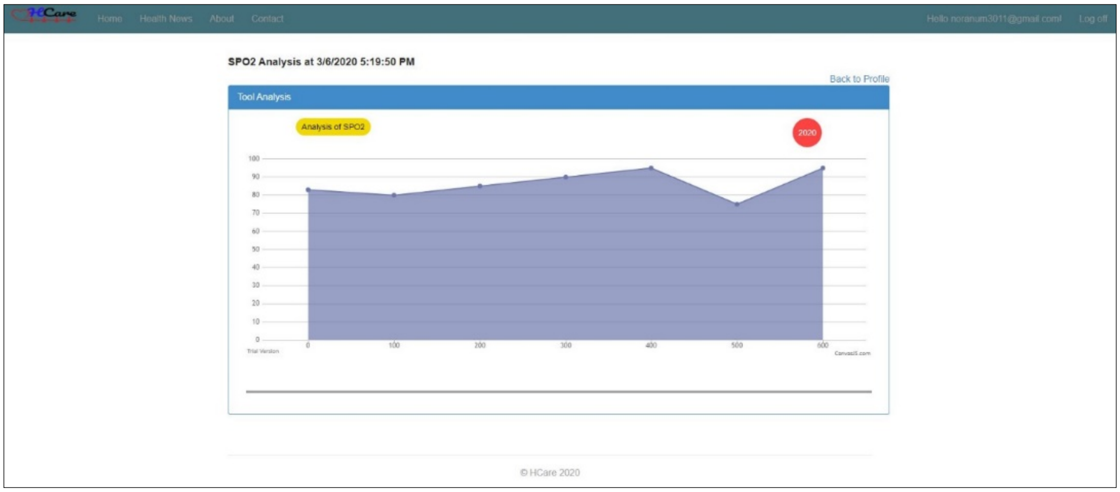
Medical History

Title	Result	Diagnosis	Treatment	Date
SPO2	80	Critical status, lake of SPO2.	The ambulance will visit you soon to transfer you to a hospital.	3/6/2020
Body temperature	39	High BT	Take paracetamol to lower the temperature.	3/6/2020
Blood pressure	120/80	A slight rise in blood pressure.	take Lisinopril (Zestril) pill, and take care of your diet.	3/6/2020

Add Records.

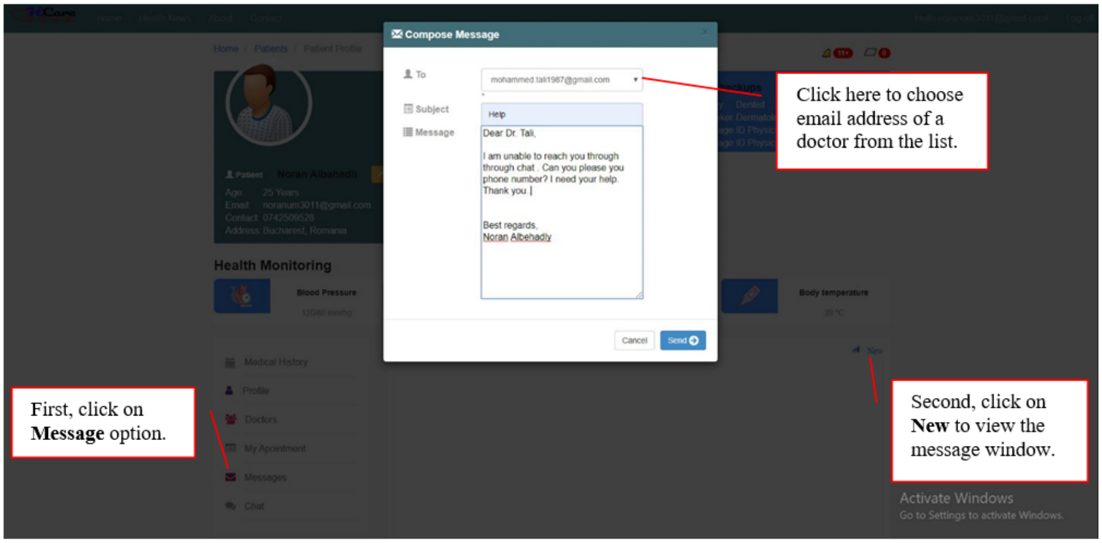
localhost:56736/StaffsHCare/Details/e076847c-81f9-463c-91ee-0318a7ee60f0

Figure 5.27 Health Activities and its Records and Alerts



SPO2 Analysis at 3/6/2020 5:19:50 PM

Figure 5.28 The Activity Chart of SPO2



To: mohammed.tali1987@gmail.com

Subject: Help

Message:

Dear Dr. Tali,

I am unable to reach you through through chat . Can you please you phone number? I need your help. Thank you.

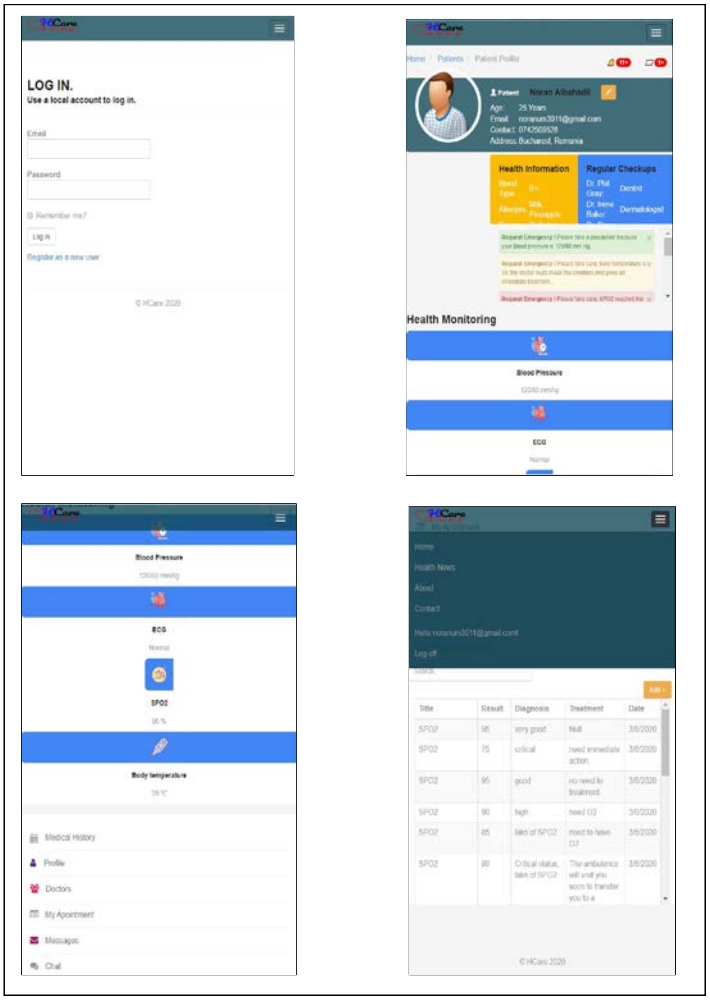
Best regards,
Noran Albehadly

Click here to choose email address of a doctor from the list.

First, click on **Message** option.

Second, click on **New** to view the message window.

Figure 5.29 Message Window



Noran Albahadli
Age: 25 Years
Email: noranum3011@gmail.com
Contact: 0742509528
Address: Bucharest, Romania

Blood Type: B+
Allergies: Milk, Pineapple

Dr. Phil Gray: Dentist
Dr. Irene Baker: Dermatologist

Blood Pressure: 120/80 mmHg
ECG: Normal
SPO2: 98 %
Body temperature: 38 °C

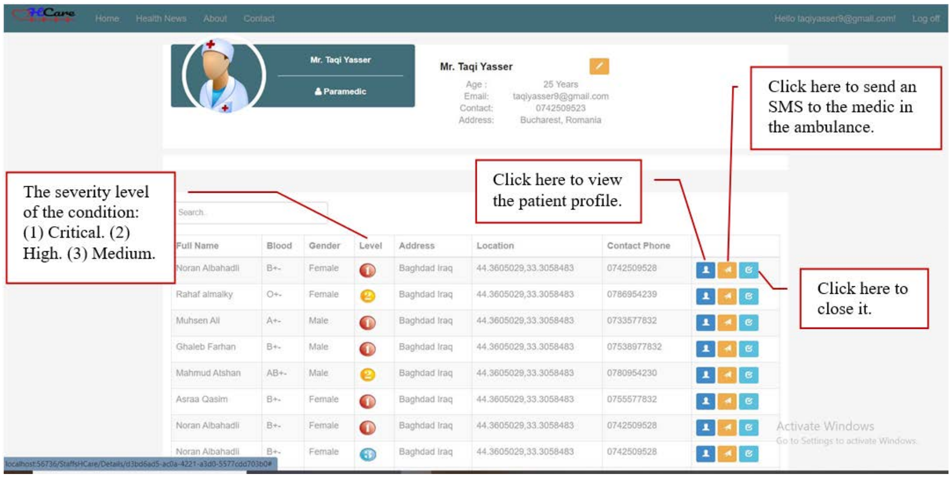
Hello noranum3011@gmail.com!

Title	Result	Diagnosis	Treatment	Date
SPO2	98	very good	Null	3/6/2020
SPO2	75	critical	need immediate action.	3/6/2020
SPO2	95	good	no need to treatment.	3/6/2020
SPO2	90	high	need O2	3/6/2020
SPO2	85	lake of SPO2	need to have O2	3/6/2020
SPO2	80	Critical status, lake of SPO2	The ambulance will visit you soon to transfer you to a	3/6/2020

Figure 5.30 Hcare Web App in Smartphone Form

5.9.2.5 Design of Emergency Section

This section deals with the critical statuses of the patients and it manages by an emergency center where all the critical conditions will be received including patient information like (patient name, blood type, gender, address, the coordinates of location, and health status) and listed it according to severity level then send it to the mobile of ambulance staff to take the necessary action. Patients can reach the emergency center via various means of communication provided by the system like emails, chats, and phone calls. Figure 5.31 illustrates the emergency center page in the Hcare system.



Mr. Taqi Yasser

Age : 25 Years
Email: taqiyasser9@gmail.com
Contact: 0742509523
Address: Bucharest, Romania

Full Name	Blood	Gender	Level	Address	Location	Contact Phone
Noran Albahadli	B+-	Female	1	Baghdad Iraq	44.3605029,33.3058483	0742509528
Rahaf almalky	O+-	Female	2	Baghdad Iraq	44.3605029,33.3058483	0786954239
Muhsen Ali	A+-	Male	1	Baghdad Iraq	44.3605029,33.3058483	0733577832
Ghaleb Farhan	B+-	Male	1	Baghdad Iraq	44.3605029,33.3058483	07538977832
Mahmud Atshan	AB+-	Male	2	Baghdad Iraq	44.3605029,33.3058483	0780954230
Asraa Qasim	B+-	Female	1	Baghdad Iraq	44.3605029,33.3058483	0755577832
Noran Albahadli	B+-	Female	1	Baghdad Iraq	44.3605029,33.3058483	0742509528
Noran Albahadli	B+-	Female	3	Baghdad Iraq	44.3605029,33.3058483	0742509528

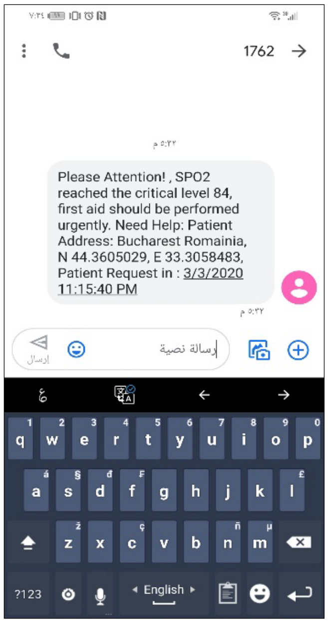
The severity level of the condition: (1) Critical. (2) High. (3) Medium.

Click here to view the patient profile.

Click here to send an SMS to the medic in the ambulance.

Click here to close it.

Figure 5.31 Emergency Center Page



Please Attention! , SPO2 reached the critical level 84, first aid should be performed urgently. Need Help: Patient Address: Bucharest Romainia, N 44.3605029, E 33.3058483, Patient Request in : 3/3/2020 11:15:40 PM

Figure 5.32 Sample of SMS Sent from Emergency Center to Medic

5.9.2.6 Design of Appointment Section

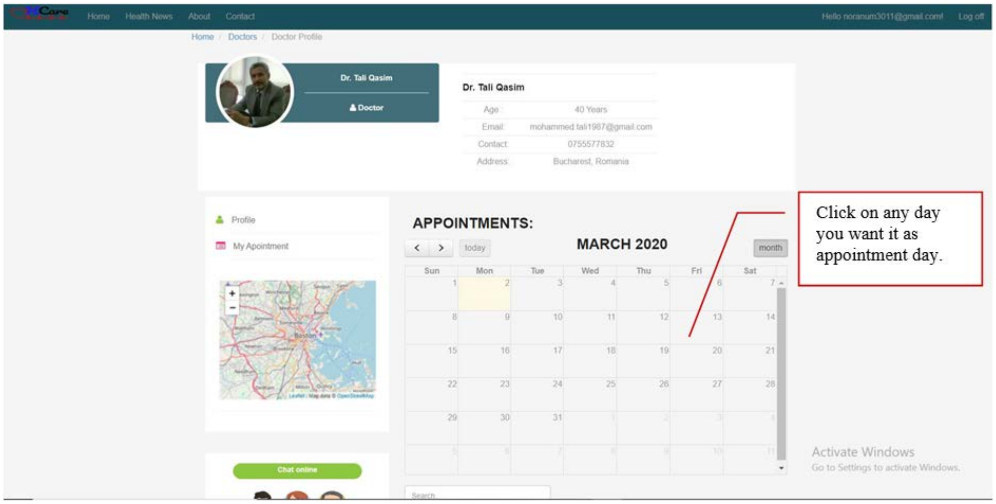
This section illustrates the appointment scenario between doctor and patient as explained below:

- Patient can make appointment with a doctor from his page by following the below steps:
  - From the options menu of his page, he must click on (Doctor) option to display his doctors or search for another doctor.

- From doctor subpage click on the option (My appointment) to view a calendar as shown in figure 5.33.
- When the patient clicks on any date from the calendar a small window will appear to create an appointment by entering the suitable appointment time and the purpose of appointment then click save.
- A patient has an ability to modify or delete the appointment by clicking on the highlighted date of that appointment, a small window will display which has options for editing or deleting an appointment.
- By clicking on the option (My appointment) from the patient page it will view a list of created appointments as shown in the figure 5.34. Once the patient clicks on (Confirm) button he will provide permission to the doctor to access his profile, medical history, monitoring his health activities, and receiving alarms for abnormal statuses.

❖ From doctor side:

- The doctor can click on (My appointment) option to view the list of appointments with his patients.
- The doctor must click on the (Patients) option to display a list of his patients as shown in the figure 5.35, and by clicking on the (Show Profile) of any patient it will shift to the patient's profile then the doctor can see the medical history and observe the medical activities of the patient.

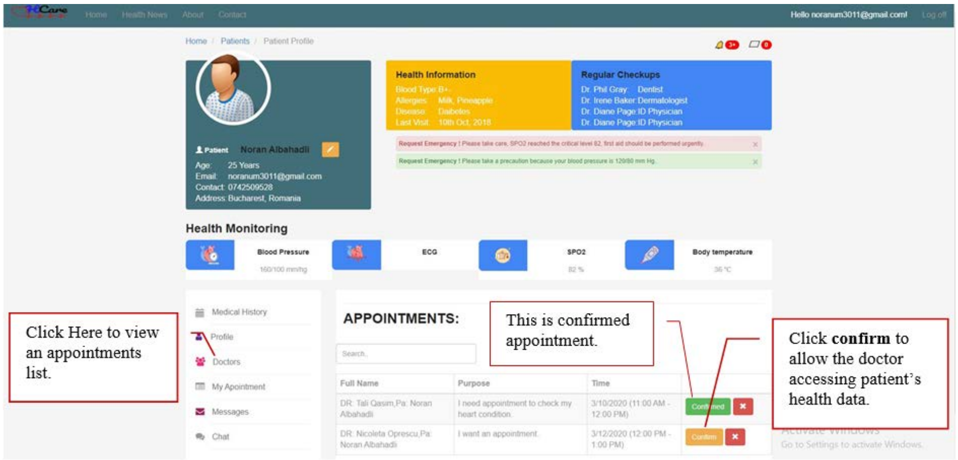


Dr. Tali Qasim

Age: 40 Years
Email: mohammed.tali1987@gmail.com
Contact: 0755577832
Address: Bucharest, Romania

Click on any day you want it as appointment day.

Figure 5.33 Appointment Calendar



Patient Noran Albahadli
Age: 25 Years
Email: noranum3011@gmail.com
Contact: 0742509528
Address: Bucharest, Romania

APPOINTMENTS:

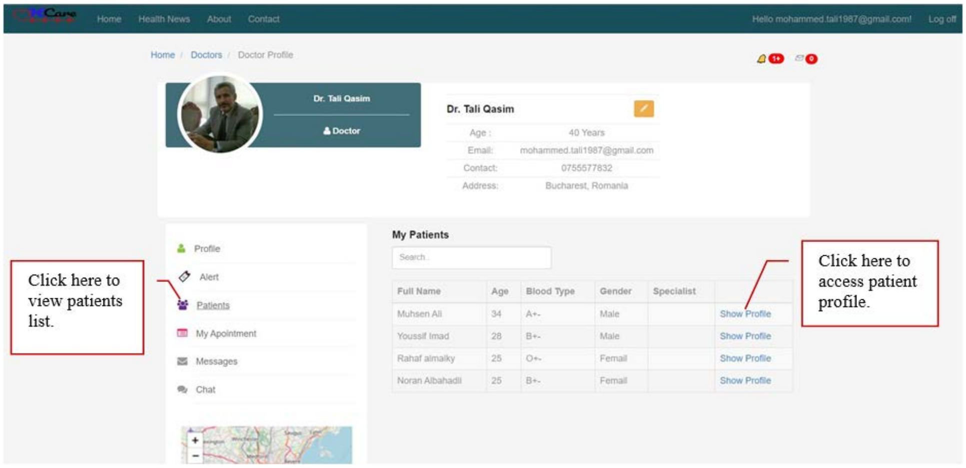
Full Name	Purpose	Time	
DR: Tali Qasim,Pa: Noran Albahadli	I need appointment to check my heart condition.	3/10/2020 (11:00 AM - 12:00 PM)	Confirmed
DR: Nicoleta Oprescu,Pa: Noran Albahadli	I want an appointment.	3/12/2020 (12:00 PM - 1:00 PM)	Confirm

Click Here to view an appointments list.

This is confirmed appointment.

Click **confirm** to allow the doctor accessing patient's health data.

Figure 5.34 Appointments List of Patient



Dr. Tali Qasim
Age : 40 Years
Email: mohammed.tali1987@gmail.com
Contact: 0755577832
Address: Bucharest, Romania

My Patients

Full Name	Age	Blood Type	Gender	Specialist	
Muhsen Ali	34	A+-	Male		Show Profile
Youssif Imad	28	B+-	Male		Show Profile
Rahaf almalky	25	O+-	Femail		Show Profile
Noran Albahadli	25	B+-	Femail		Show Profile

Click here to view patients list.

Click here to access patient profile.

Figure 5.35 Patients List of a Doctor

5.9.2.7 Design of ECG Analysis Section

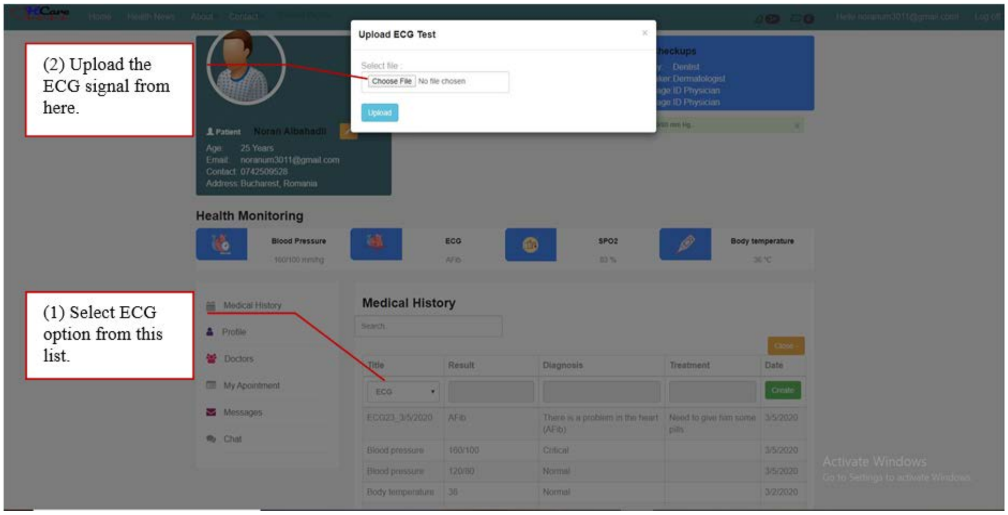
The ECG analysis section designed to support the doctor in diagnosing the electrocardiogram (ECG) of patients for an AFib disease by uploading the signal manually or receive an ECG signal from the patient side through the system. The system provides a doctor with the ability to view the ECG signal and analyze it to predict the result in case it is Normal, AFib, another disease, or very noisy can't be classified even after the filtering processes.

The scenario of this section is performed according to the following steps:

- Upload the ECG signal of patient from the sub-page (Medical History) of the patient as shown in figures 5.36 and 5.37.
- The doctor will be notified about this uploaded ECG signal by the system to analyze it through the "ECG Analysis" page. To display the "ECG Analysis" page the doctor must

click on the button (ECG) from the Health Monitoring bar of the patient as presented in figures 5.38 and 5.39.

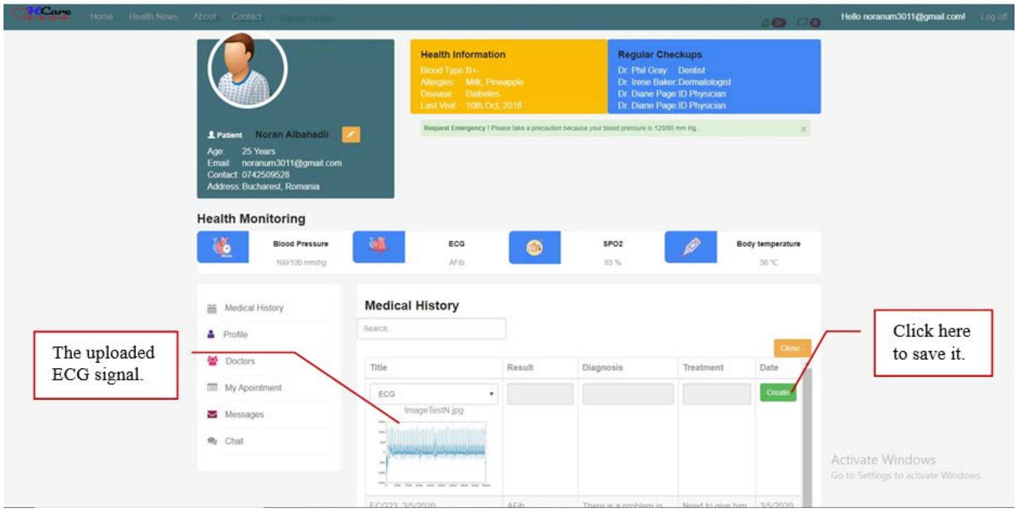
- From ECG Analysis page, select the uploaded ECG signal then click on the "View" button to display it as shown in figure 5.40.
- Then, click on "Analysis" button to start analyzing the ECG signal, once the analyzing process is finished then the result will be given as explained in figure 5.41.
- Finally, doctor can add notes and treatment according to the result then click on the "Save Result" button to record it in the medical history record of patient. Also, the result with diagnosis details and treatment will be displayed on the patient page as shown in the figure 5.42.



(2) Upload the ECG signal from here.

(1) Select ECG option from this list.

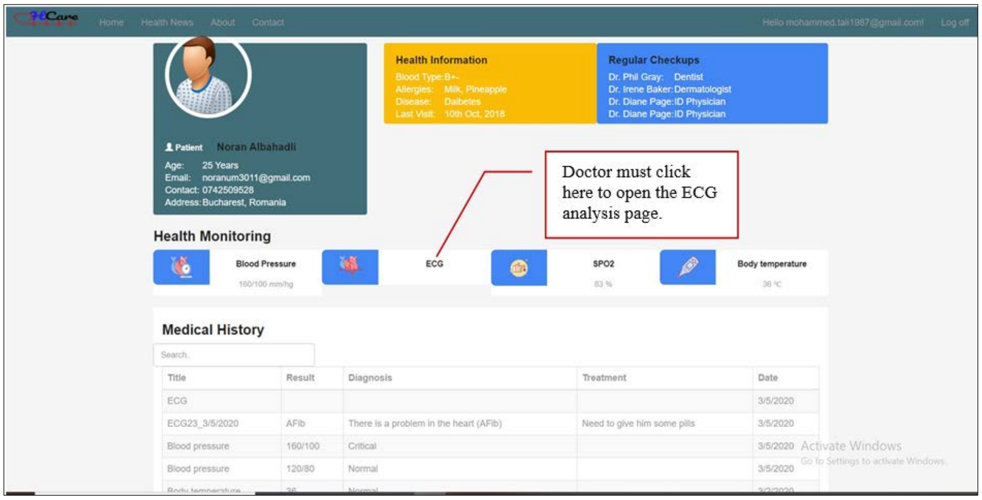
Figure 5.36 Upload ECG Signal of the Patient



The uploaded ECG signal.

Click here to save it.

Figure 5.37 Save ECG Signal



Health Information
Blood Type: B+-
Allergies: Milk, Pineapple
Disease: Dalbetes
Last Visit: 10th Oct, 2018

Regular Checkups
Dr. Phil Gray: Dentist
Dr. Irene Baker: Dermatologist
Dr. Diane Page: ID Physician
Dr. Diane Page: ID Physician

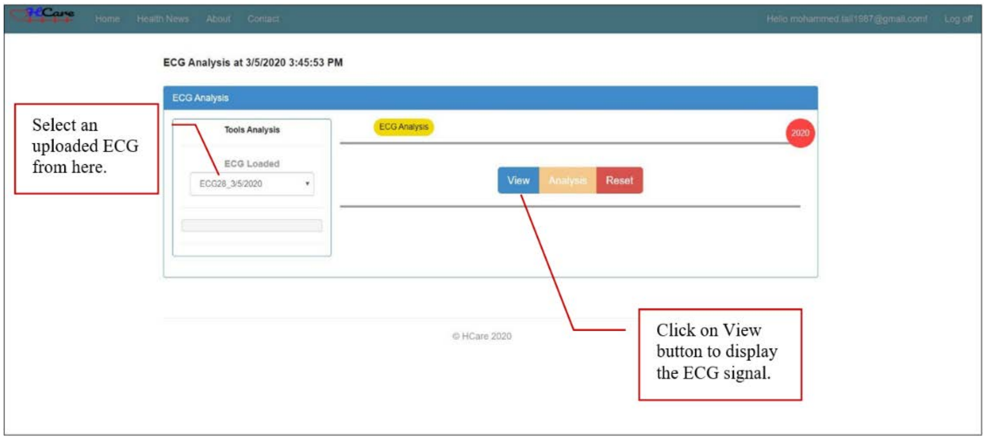
Patient Noran Albahadli
Age: 25 Years
Email: noranum3011@gmail.com
Contact: 0742509528
Address: Bucharest, Romania

Blood Pressure 160/100 mm/hg
SPO2 83 %
Body temperature 36 °C

Title	Result	Diagnosis	Treatment	Date
ECG				3/5/2020
ECG23_3/5/2020	AFib	There is a problem in the heart (AFib)	Need to give him some pills	3/5/2020
Blood pressure	160/100	Critical		3/5/2020
Blood pressure	120/80	Normal		3/5/2020

Doctor must click here to open the ECG analysis page.

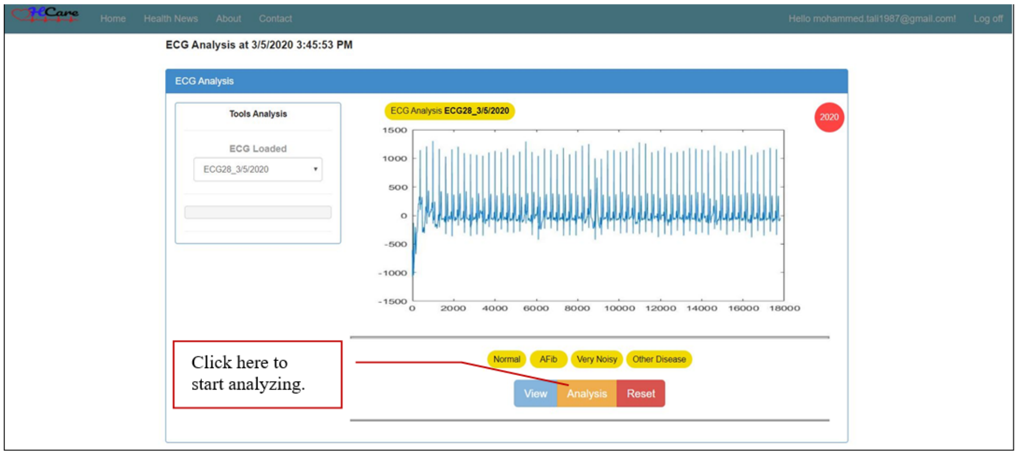
Figure 5.38 Patient Page from the Doctor Side



Select an uploaded ECG from here.

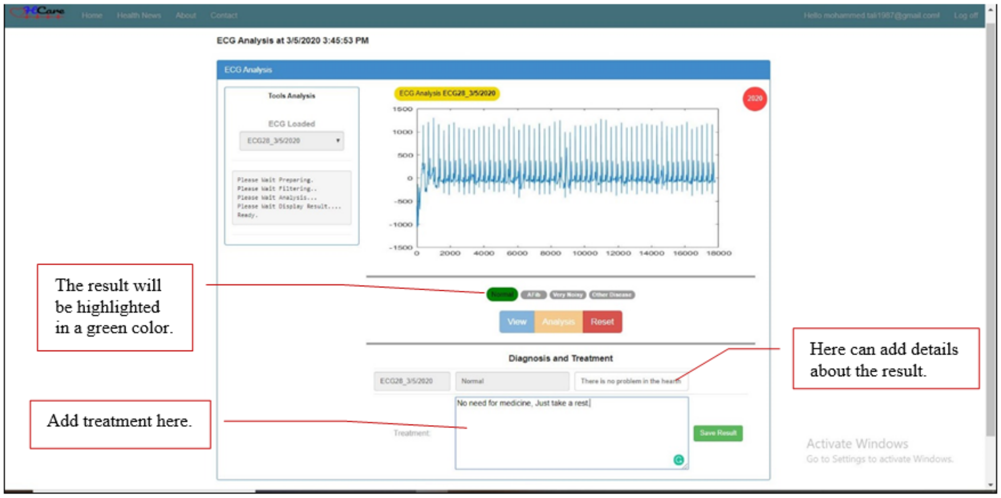
Click on View button to display the ECG signal.

Figure 5.39 ECG Analysis Page



Click here to start analyzing.

Figure 5.40 View ECG Signal by the ECG Analysis Page



ECG Analysis at 3/5/2020 3:45:53 PM

```
Please Wait Preparing.
Please Wait Filtering..
Please Wait Analysis...
Please Wait Display Result....
Ready.
```

Diagnosis and Treatment

ECG28_3/5/2020

Normal

There is no problem in the hearth

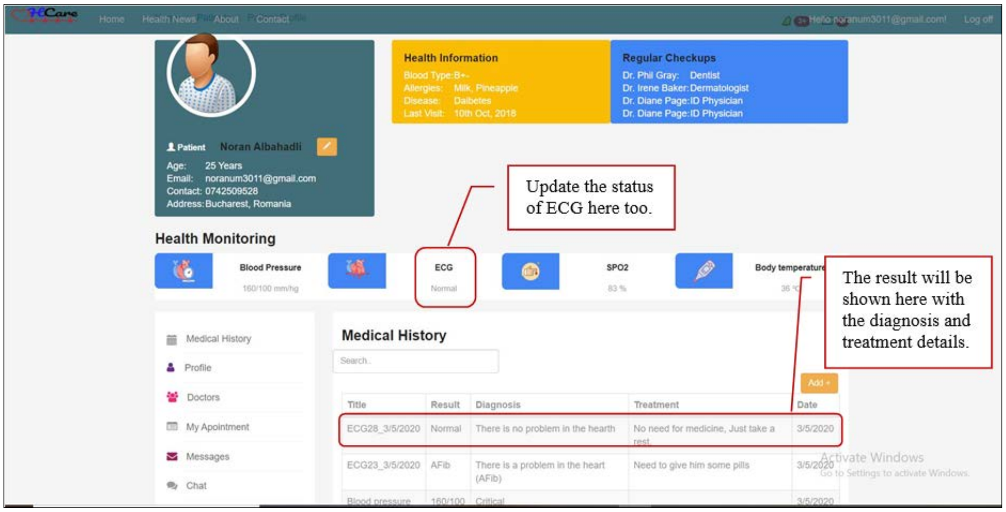
No need for medicine, Just take a rest

The result will be highlighted in a green color.

Here can add details about the result.

Add treatment here.

Figure 5.41 Stages of ECG Analysis Process



Patient Noran Albahadli
Age: 25 Years
Email: noranum3011@gmail.com
Contact: 0742509528
Address: Bucharest, Romania

Health Information
Blood Type: B+-
Allergies: Milk, Pineapple
Disease: Daibetes
Last Visit: 10th Oct, 2018

Regular Checkups
Dr. Phil Gray: Dentist
Dr. Irene Baker: Dermatologist
Dr. Diane Page: ID Physician
Dr. Diane Page: ID Physician

Medical History

Title	Result	Diagnosis	Treatment	Date
ECG28_3/5/2020	Normal	There is no problem in the hearth	No need for medicine, Just take a rest	3/5/2020
ECG23_3/5/2020	AFib	There is a problem in the heart (AFib)	Need to give him some pills	3/5/2020
Blood pressure	160/100	Critical		3/5/2020

Update the status of ECG here too.

The result will be shown here with the diagnosis and treatment details.

Figure 5.42 View the Results in the Patient's Page

5.9.3 Test Implementation

The proposed Hcare Web Application was intensively tested from several aspects with the use of various browsers such as Google Chrome, Brave, and Internet Explorer and in different devices like laptops, smartphones, and tablets. Hcare was tested by numerous doctors and patients, and they were satisfied with the use of Hcare and its services. The functionalities of proposed system were tested as illustrated in table 5.10:

TABLE 5.10 HCARE TESTING TABLE

Test No.	Test Description	Expected outcome
1	Registration and Login	User was registered and login successfully.
2	Profile	User could add, delete, and edit the personal information.
3	Medical history and records.	Able to access the medical history of the patient and add records.
4	Appointments	The scenario of appointment between the patient and doctor was designed and it worked successfully as was proposed.
5	Health Monitoring	The health activities of patient (SPO2, blood pressure, body temperature, and ECG) were monitored and the doctor was able to make electronic diagnoses and treatment through Hcare and per the values that he received it from the patient.
6	ECG Analysis	The doctor has loaded the ECG signal, view it, analyzes it through the system, and the system predicted the result successfully. Also, the doctor has added the notes and treatment according to the obtained result and saved the result in the medical history of the patient as a record.
7	Alert processes	The users were receiving alerts successfully as was proposed in this work.
8	Administrator	The functionalities of administrator were tested, and they were functioning properly.
9	Emergency center	The emergency staff received alerts of the critical conditions of patients, could view a patient profile and his medical history, and send an SMS for the medic of the ambulance. All these functionalities were tested, and it worked successfully.
10	Message	Sending and receiving messages was tested and it worked successfully.
11	Chat	The chat between users was tested and it is working properly.
12	Health news	Users could view and read health news successfully.

5.10 Conclusion

This work presents a design and implementation of Hcare web application framework for ehealth monitoring based on various vital signs like blood pressure, SPO2, body temperature, and electrocardiogram ECG. The design was based on different requirements that are determined based on a previous survey. This project includes a cloud computing, the mechanisms of security and confidentiality, and the use of the Responsive Web Design (RWD) pattern. The main tools that used to design and develop the Hcare are C#, ASP.net MVC, Jave Script (JQuery), Entity Framework, Bootstrap, and SQL Server technologies due to good operability and compatibility. This system supports patients by providing them with medical assistance and saves time and mobility. The system provides several services for the patients and medical professionals such as monitoring the medical activities of the patients by the patients themselves and their doctors, and they will receive warning alarms as system notifications or SMS according to the severity of the medical condition of the patient.

The chief objective of this system is to provide the doctor with the ability to analyze the ECG signal of a patient to determine the AFib disease or if there is any other disease, also he can add electronic diagnosis notes and treatment for the patient and save the results in the record of medical history of the patient. In addition, the system provides the patients with the ability to manage the appointments with the doctor and confirm\cancel the appointment by themselves. Also, the system offers various means of communication between the patients and the medical professionals via chats, emails, or phone numbers. Other functionalities are provided by the system to the patients such as a search for doctors based on the medical centers and the specialties of the doctors. The users can read the latest health news and articles to gain the latest information of health.

Through system testing, it proved that all the system functionalities were working properly and successfully as was proposed. Finally, the outcomes of the system will assist doctors or emergency staff to observe patients in order to provide medical support in a timely manner.

CHAPTER 6. CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

The thesis brings contributions on developing an e-health monitoring system based on advanced and innovative techniques. The system was designed to observes various vital signs coming from wearable devices such as blood pressure, SPO2, body temperature, and electrocardiogram ECG. Beside the critical analyze of different technologies, hardware and software components, filtering methods or deep convolutional neural network solutions, this research brings innovative ideas for developing automatic diagnose modules for atrial fibrillation and generates a complex application that reunites all the mechanisms discussed along each chapter of the thesis. The final application includes cloud computing, security and confidentiality mechanisms, and the use of the Responsive Web Design (RWD) pattern. The system was implemented based on different requirements that are determined based on a previous survey.

Therefore, to fulfill this, chapter 2 presented a critical analysis that reviewed state-of-the-art in the research and the development of wearable sensors based on healthcare monitoring systems. Different solutions were carefully analyzed because one of the most challenging features of a WHMS should be related to the new services for detection of unusual situation in the huge heterogeneous streams, these services should support the definition, detection and management of unusual situations that can appear in a medical and healthcare environment. For this reason, the chapter discusses different solutions of architectures dedicated to Wearable Health Monitoring Systems (WHMS) based on microcontrollers and FPGAs. Comparison based on these approaches was also introduced. The literature review revealed the fact that in healthcare domain, the FPGA architecture and Arduino architecture (as a type of Microcontroller) have gain important roles, many eHealth systems being created based on them. This kind of WHMS offers solutions for bringing improvements in healthcare field by offering a many feature that bring comfort, care and safety to a patient. Such a system should be lightweight, robust and portable, maintain the privacy of the patient and collecting important medical information that will provide a better treatment by a real-time monitoring. To achieve all these requirements, the research focused on studying and analyzing many aspects to resolve most of the challenges. A solution for the wireless communication modules of WHAS was presented and discussed.

Chapter 3 focuses on filtering the ECG signals to remove the noises based on a hybrid filtering model. Different windowing techniques have been studied and analyses according to their magnitude responses, the examination of filters responses have suggested that the FIR Chebyshev filter algorithm offer the best result for Low-pass filter from frequencies between 0.05 Hz through 100 Hz respectively, and it could remove the electromyogram (EMG) noise perfectly. The dataset of ECG signal used in this work contains a baseline shift which does not represent the real amplitude of the signal. Therefore, we must detrend the signal before to apply any filtration on the signal, we fitted a low order polynomial to the signal and used the polynomial to detrend it. Thresholding the peaks of QRS-complex is very important where it corresponds to the depolarization of the right and left ventricles of the human heart. Locating the Q-waves by thresholding the peaks result in detection of undesirable peaks where the Q-waves and the noise are overlapping with each other, so smoothing the signal first is required thence find the peaks. Savitzky-Golay filter is applied to eliminate the baseline wander and motion artifacts noise in the signal. Filtering the ECG signal using SG filter was efficient although in some cases it reduced the R-waves voltage to a certain extent. Mean square error (MSE) is used to estimate a signal goodness.

Chapter 4 proposed to explore the Transfer Learning approach in the Deep Learning field utilizing pre-trained CNN to improve the accuracy of Atrial Fibrillation classification based on the Short-term recorded ECG datasets. The pre-trained AlexNet model has been used in our experiments due to different reasons as illustrated in section 4.3.4 where the network was fully supervised, and the parameters of the model were optimized utilizing the function cross-entropy loss in the classification layer that used stochastic gradient descent with momentum (SGDM). Moreover, Mini-Batch Gradient Descent (MBGD) was utilized in the model with 10 observations at each iteration to train the network faster. Multiclass SVM classifier was used to extract features by knowledge transfer from the pre-trained CNN model in which the features are used to connect the ECG signals to their classifications (AFib, Normal, Other, and Noisy). This study was based on three experiments: feature extraction, transfer learning with data augmentation, transfer learning without data augmentation where transfer learning without data augmentation obtained the top result with 99.21% of accuracy as explained in section 4.5. Thus, the proposed method for automatic prediction has proved to provide robust results.

Finally, chapter 4 presents a design and implementation of Hcare web application framework for eHealth monitoring based on various vital signs like blood pressure, SPO2, body temperature, and electrocardiogram ECG. The design was based on the studies of the previous chapters. This project includes a cloud computing, the mechanisms of security and confidentiality, and the use of the Responsive Web Design (RWD) pattern. The main tools that used to design and develop the Hcare are C#, ASP.net MVC, Jave Script (JQuery), Entity Framework, Bootstrap, and SQL Server technologies due to good operability and compatibility. This system supports patients by providing them with medical assistance and saves time and mobility. The system provides several services for the patients and medical professionals such as monitoring the medical activities of the patients by the patients themselves and their doctors, and they will receive warning alarms as system notifications or SMS according to the severity of the medical condition of the patient.

The chief objective of this system is to provide the doctor with the ability to analyze the ECG signal of a patient to determine the AFib disease or if there is any other disease, also he can add electronic diagnosis notes and treatment for the patient and save the results in the record of medical history of the patient. The automatic diagnose model for atrial fibrillation has been discussed and presented in Chapter 4. Hcare app is connected to this model. The hybrid filtering model proposed and presented in Chapter 3 has also been implemented and connected to Hcare web-app to denoise the noises from the signal before diagnosing. In addition, the system provides the patients with the ability to manage the appointments with the doctor and confirm\cancel the appointment by themselves. Moreover, the system offers various means of communication between the patients and the medical professionals via chats, emails, or phone numbers. Other functionalities are provided by the system to the patients such as a search for doctors based on the medical centers and the specialties of the doctors. The users can read the latest health news and articles to gain the latest information of health.

Through system testing, it proved that all the system functionalities were working properly and successfully as was proposed. Finally, the outcomes of the system will assist doctors or emergency staff to observe patients in order to provide medical support in a timely manner.

6.2 Contributions of the thesis

Several contributions were provided by this thesis in the healthcare monitoring systems field based on Hcare web application framework. The major contributions are listed as follows:

- A critical analysis is presented emphasizing different technological aspects in order to develop healthcare monitoring systems and to discover that places in which some contributions can be done to this field. For this purpose, there were identified the major techniques and communication protocols used in the wearable sensor networks, highlighting their advantages and disadvantages.
- A number of research papers have been reviewed as a current state-of-the-art for each technique. A large diversity of components of the wearable health monitoring system (WHMS) were illustrated such as biosensors, control units, wireless communication modules, processing units, medical shields, links, power supplies, wearable materials, software, and also the advanced algorithms that use for decision making and data extracting. An architecture emphasizing the wireless communication modules for WHMS is also proposed. Results were published in [139].
- A robust comparison of different solutions of architectures dedicated to Wearable Health Monitoring Systems (WHMS) based on microcontrollers and FPGAs are presented and analyzed. Moreover, we proposed a new architecture that uses all the advantages of its components. Results were published in [140].
- A hybrid filtering model is proposed and experimentally tested. This model consists of FIR Chebyshev filter algorithm and Savitzky-Golay filter algorithm. The proposed of

this model was based on an examination of different filters to denoise the ECG signals. Results were published in [5].

- We proposed a robust deep learning approach for ECG automatic diagnose. For this purpose, the Deep Convolution Neural Network (D-CNN) algorithm and a multiclass model for SVM classifier will automate the detection process of ECG images specific to atrial fibrillation cases. The proposed technique improved the accuracy of Atrial Fibrillation classification. Results were published in [6].
- A web application based e-health monitoring system, called Hcare, was designed and implemented using advanced techniques and innovative modules. Due to that, it considered the best compared to its counterparts from the systems. Results were published in [141]. This application is connected to the automatic diagnose model for atrial fibrillation that has been discussed and presented in Chapter 4. Hcare app is also connected to the hybrid filtering model proposed and presented in Chapter 3 to remove the noises from the signal before diagnosing.
- A comparative performance analysis based on call function durations and security aspect has been made of both implementation approaches (with MS Azure and without it) that emphasized the advantages of cloud SaaS technology.

6.3 Future Work

The eHealth research domain is vast, and its exploration is unlimited. There are many approaches and ways that I have in mind to improve this work as:

- Development of a mobile application for E-health monitoring system along with the web application.
- Increase the number of vital signs of the patient for better medical observation. Furthermore, advanced decision-making algorithms can be used to link these vital signs to make advanced diagnose according to their values.
- Improve the security of healthcare monitoring system with use of fuzzy techniques or neural network techniques.
- Fuzzy logic techniques can be used to classify some diseases based on the correlation of different parameters coming from different wearable sensors.

List of Publications

Papers Published in International Conferences:

1. Mohammed Tali Qasim Almalchy, Nirvana Popescu and ALGayar Sarmad M. S. (2018) ''A Critical Analyze on Healthcare Monitoring Systems Requirements', *International Conference on Computational Science and Engineering (CSE),* Bucharest, Romania, vol.1, pp. 123-128. WOS:000458738400020. **(Conference paper, ISI Proceedings)**

2. Mohammed Tali Qasim Almalchy, Nirvana Popescu and ALGayar Sarmad M. S. (2018) 'Solutions for Healthcare Monitoring Systems Architectures', *International Conference on Embedded and Ubiquitous Computing (EUC),* Bucharest, Romania, pp. 123-128. WOS:000458739600018. **(Conference paper, ISI Proceedings)**

3. Mohammed Tali Qasim Almalchy, Vlad Ciobanu and Nirvana Popescu (2019) 'Noise Removal from ECG Signal Based on Filtering Techniques', *Conference on Control Systems and Computer Science (CSCS),* Bucharest, Romania, pp. 176-181, WOS:000491270300030. **(Conference paper, ISI Proceedings)**

4. Mohammed Tali Qasim Almalchy, Nirvana Popescu and ALGayar Sarmad M. S. (2020) 'Atrial Fibrillation Automatic Diagnosis Based on ECG Signal Using Pretrained Deep Convolution Neural Network and Multiclass Model for SVM ', *IEEE International Conference on Communications (COMM),* Bucharest, Romania. (**Conference paper, ISI Proceedings)**

5. ALGayar Sarmad M. S., Goga N., Mohammed Tali Qasim Almalchy and Popa Ramona-Cristina (2018) 'A quantitative research for determining the user requirements for the Medical Social Media System targeted for the Iraqi Environment', *International Scientific Conference eLearning and Software for Education (ICSDE)*, vol.1, pp. 462-471. **(Conference paper, ISI Proceedings)**

6. ALGayar Sarmad M. S., Goga N., Hassoon I. A. and Mohammed Tali Qasim Almalchy (2019) "Medical Social Media Systems – Implementation of the Android Application", *International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*. **(Conference paper, ISI Proceedings)**

7. ALGayar Sarmad M. S., Iuliana Marin, Mohammed Tali Qasim Almalchy, Nicolae Goga, Naseer Abdulkarim Jaber Al-Habeeb and Cristian Taslitschi (2020) "Implementation of (MediCare) social media system", *International Conference on*

Electronics, Computers and Artificial Intelligence (ECAI). Bucharest, Romania **(Conference paper, ISI Proceedings)**

Papers Published in Journals:

1. Mohammed Tali Qasim Almalchy, ALGayar Sarmad M. S., Ahmed Y. F. Alsahlani and Nirvana Popescu (2020) 'Design Hcare Web Application for E-health Monitoring System', *UPB Scientific Bulletin*, *Series C, Electrical Engineering and Computer Science.* **(Accepted article, ISI journal).**

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