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PLATFORM INDEPENDENT WEB-BASED TELECARDIOLOGY FOR CONNECTED HEART CARE

Kui Lin Kam, Yuan Wen Hau*

IJN-UTM Cardiovascular Engineering Centre, Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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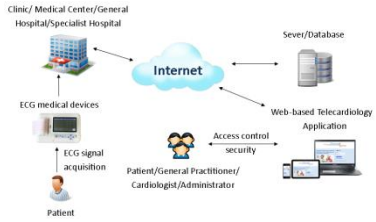
*Corresponding author
hauyuanwen@utm.my

Graphical abstract



Abstract

Most of the commercial telecardiology systems are platform-dependent and operating system (OS)-dependent. This causes inconvenience to medical officer for retrieving data from database and hence reduce the work efficiency. In this paper, a platform-independent and OS-independent web-based telecardiology system, named *VirtualDave System*, is proposed based on client-server model and developed in Hypertext Markup Language 5 (HTML5), Active Server Pages (ASP) scripting and C# languages. This system allows users to log on and access the patient medical data from any technology devices that equipped with web browser and internet access. Besides, it also allows targeted users to communicate and get remote medical consultation without long distance traveling and long-time queuing. Verification result shows that this proposed system could be executed in any platform regardless the OS. This web-based telecardiology could significantly help to improve the health care services especially in rural area.

Keywords: Electrocardiogram (ECG), platform-independent, remote consultation, telecardiology, web-based application

Abstrak

Kebanyakan sistem telekardiologi yang telah dikomersialkan adalah bergantung kepada tapak ataupun sistem operasi. Batasan ini menyusahkan pegawai perubatan untuk mendapatkan data dari pangkalan data serta mengurangkan kecekapan kerja mereka. Dalam kertas kerja ini, sebuah sistem telekardiologi tapak dan OS bebas berasaskan web yang dinamakan *VirtualDave System* telah dicadangkan. Sistem ini dibangunkan berdasarkan model pelanggan-pelayan dengan menggunakan Hypertext Markup Language 5 (HTML5), skrip Active Server Pages (ASP) dan bahasa C#. Sistem ini membenarkan pengguna untuk log masuk dan mengakses data perubatan pesakit dari mana-mana peranti teknologi yang dilengkapi dengan pelayar web dan akses internet. Selain itu, sistem ini juga membolehkan pengguna berkomunikasi dan mendapat nasihat perubatan dari jarak jauh tanpa perjalanan jauh dan masa menunggu yang lama. Hasil pengesahan menunjukkan bahawa sistem ini boleh diakses dengan mana-mana tapak tanpa bergantung kepada OS. Telekardiologi berasaskan web ini dipercayai dapat membantu meningkatkan perkhidmatan penjagaan kesihatan terutama di kawasan luar bandar.

Kata kunci: Aplikasi berasaskan web, elektrokardiogram (ECG), konsultasi jarak jauh, tapak bebas, telekardiologi

1.0 INTRODUCTION

Cardiovascular diseases remain as the leading cause of death throughout the world in this century. According to the World Health Organization (WHO), there are 17.5 millions of people died from cardiovascular diseases in year 2012 [1]. For asymptomatic patient, the treatment of cardiovascular diseases may be delayed until a cardiac event occurs. Therefore, in order to reduce the risk of fatality, a rapid initiation of treatment and continuous monitoring of cardiac activity is required for patients with suspected or actual cardiovascular disease [2].

Electrocardiography is a non-invasive method for measuring and recording of electrical activity of heart through electrodes attached on the surface of skin. It is usually done in clinic or hospital by healthcare professionals. The electrocardiogram (ECG) obtained is then interpreted by physician or cardiologist for heart rhythm diagnosis.

Unluckily, in most of the developing country, there is lack of cardiologists to serve their citizen population. For example, in Indonesia, there were only 630 cardiologists available in year 2013 or ratio of one cardiologist to 600,000 population [3], whereas the recommended density of cardiologists by Royal College of Physicians and British Cardiac Society is one cardiologist per 50,000 populations [4].

Similarly, Malaysia has only 199 cardiologists or density of 0.07 per 10000 populations available in 2011 [5]. Among these 199 cardiologists, most of them, that are 60 cardiologists, are located at Kuala Lumpur which is the capital city of Malaysia. In contrast, Kelantan and Sabah as states under development which have huge citizen population have only five and seven cardiologists respectively in the states. This shows a very poor cardiologist to population ratio for Kelantan and Sabah, which is 0.03 and 0.02 per 10,000 populations, respectively. Moreover, according to [6], there are only 90 hospitals out of 341 surveyed hospitals provided cardiac service in 2009. Among these 90 hospitals, 16 of them are located at Kuala Lumpur whereas Kelantan and Sabah only have three hospitals provide cardiac service. Due to this uneven distribution of healthcare service and workforce which contribute the poor cardiologist to population ratio, the public in rural area suffering from long queue waiting or long distance traveling, in order to get cardiac service from cardiologist.

In ideal case of heart care service, the public could do the electrocardiography anywhere, and transmit their ECG to cardiologist for interpretation and diagnosis through telecardiology to enable remote consultation and remote monitoring. Telecardiology is the transmission of cardiac data such as ECG, radiographs, ultrasounds and medical records by using information and communications technology (ICT) [7]. With the development of computerized ECG, users can transmit and share the ECG digitally over a network for viewing easily. There are many researches and pilot studies have proven that telecardiology is useful for reducing unnecessary hospitalizations, improving cardiac diseases management, assisting medical officers in decision making and rationalizing health-care costs [3, 8].

Nowadays, there are some ECG manufacturers, for example, Welch Allyn [9] and Schiller [10], aware about the increasing demands on telecardiology and start developing product that supporting this functionality. However, most of them have certain limitations. One of the common problems is that most of the telecardiology applications are still dependent on computing platform and operating system (OS) to access the software or to retrieve data from database. In other words, laptop or desktop with dedicated OS (e.g. Microsoft Windows) and pre-installed telecardiology software must be together with medical officers in order to send or receive data for interpretation. Consequently, it causes inconvenience and hence reduces the work efficiency.

Based on the aforementioned problem, this paper proposes a platform-independent and OS-independent web-based telecardiology system. This system allows users to log on from any computer or mobile communication devices that equipped with internet access and web browser for cardiac data sharing and remote consultation.

2.0 TELEMEDICINE AND TELECARDIOLOGY

Many researches have been done on the topic of telemedicine since 1900s [11]. Telemedicine is the delivery of health care services using ICT for the transmission of medical information and data for diagnosis, treatment and prevention of disease [7]. Telecardiology is the application branches of telemedicine in cardiology that transmits cardiac data such as ECG, radiographs, ultrasounds and medical records from the patient site to cardiologist.

There are three categories of telecardiology applications: pre-hospital, in-hospital and post-hospital [12, 13]. ECG obtained during pre-hospital period is useful for early detection of myocardial infarction and this information is transferred to the receiving emergency physician before the arrival of the patient [14]. In-hospital telecardiology is mainly used for the communication between small hospitals in rural areas and main hospitals in urban city for information exchange [15]. The applications of post-hospital include teleconsultation between physicians and cardiologists [16], home monitoring for chronic cardiac diseases [17], and the diagnosis of arrhythmias [18].

Some research had proposed web-based telecardiology in either mode of real-time or store-and-forward transmission to avoid local software installation due to demand on remote diagnostic and remote consultation. For example, Mahesh *et al*. [15] has developed a web based telecardiology framework for the diagnosis of cardiac patients in

rural areas. The proposed system only requires a computer with web browser and internet access for ECG waveforms display. The patient's post diagnostic information will be stored in server for future reference.

D'Angelo *et al*. [19] has also proposed a web-based system for intelligent home care which enable ECG upload and prioritization. The system interprets and priories the received ECG so that critical ECG will be read by cardiologist first. Besides, the web application also allows patient, doctor and cardiologist to retrieve the data with different access authority.

Based on the review from Hsieh *et al.* [20], mobile teleconsultation and cloud computing are the two main component of modern telecardiology. Also, according to Chu *et al.* [21], the transmission of ECG through Transmission Control Protocol/Internet Protocol (TCP/IP) has higher reliability with less interruption compared to traditional telephone line. With the issues of data confidentiality and interoperability as well as the network latency and accessibility to be overcome, the teleconsultation will be ubiquitous [20]. This statement is also supported by the case study in Brazil [22], where the main difficulty at the beginning of the implementation is to establishing a proper network connection with the necessary quality of service with the server. These literature have proven the significance of web-based telecardiology system and its challenges in design and implementation.

Although telecardiology is not a new cutting edge technology, yet the infrastructure is still not well established in most of the developing countries, including Malaysia. A pilot study was initiated by Malaysia Ministry of Health (MoH) to develop a teleconsultation portal for transmitting medical images and video clips [23]. The telecardiology system was targeted for Northern region (Pulau Pinang, Kedah, Perlis, and Perak) and Sabah only [24]. According to the analysis from the MoH, there are total of 409 cases have been sent through telecardiology from 2010 to 2012 [25]. Compare to other disciplines such as neurosurgery and radiology, the usage of telecardiology is still considered underutilized due to immature telecardiology infrastructure.

3.0 PROPOSED WEB-BASED TELECARDIOLOGY

Figure 1 shows the system framework of the proposed web-based telecardiology. There are two medical devices used for ECG signal acquisition and processing, which are Welch Allyn CP 150 Resting ECG [26] and PC-based Resting ECG [27]. By referring to application programming interface (API) of Welch Allyn CardioPerfect Workstation (CPWS) cardiopulmonary data management software as the backbone, a web-based in-hospital and post-hospital telecardiology application, so-called *VirtualDave System*, was developed based on client-server model.

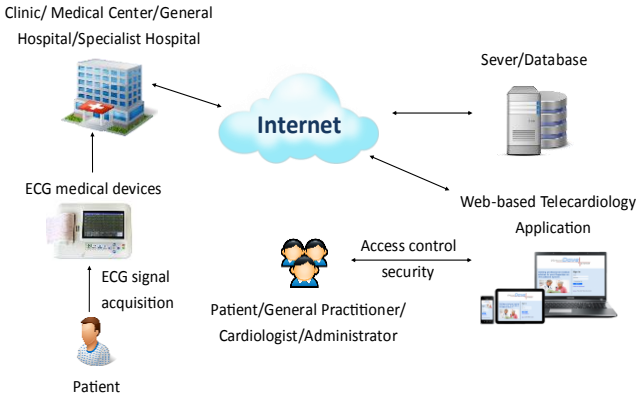


Figure 1 Overview of proposed telecardiology

The proposed telecardiology application allows users to log on from any computer or mobile communication devices (e.g. smart phone, tablet, PDA, etc.) that equipped with web browser and internet access. It transmits ECG using store-and-forward method where all the medical records are stored in a server. Apart from that, it also enables patients to get remote medical consultation from physician or cardiologist through instant messaging without long distance travelling.

There are four targeted users for the *VirtualDave System*: physician, cardiologist, administrator and patient. Different users have different role and authority on the medical data management which is summarized in Table 1.

The application was developed in Hypertext Markup Language 5 (HTML5), Active Server Pages (ASP) scripting and C# language by using Microsoft software development tools. Before the application was developed, the basic underlying components such as server, CPWS and medical devices were installed. Please note that in this proposed system, the CPWS is only required to be installed in the server to host ECG test record, and any computer or workstation that connected with cardiovascular medical device for signal acquisition. For users who access the *VirtualDave System* to retrieve patient data and ECG test record using technology devices, the CPWS is not required to be installed.

Different content pages with different functionality have been developed to work as an interface between the users and the database. The overall functionality of the *VirtualDave System* is modelled as the uses case diagram shown in Figure 2. The application mainly consists of five processes, which are user pre-registration and registration, user login, patient information and ECG medical record retrieval, ECG signal acquisition, and instant messaging. The detail of each process is described in subsections below.

Table 1 User role and authority on medical data management

User	Role/Authority
Cardiologist	• Review and update patient personal information and medical record • Review ECG history • Edit and confirm ECG interpretation • Consult physician and patient
Physician	• Review and update patient personal information and medical record • Review ECG history • Edit ECG interpretation • Consult patient • Request consultation from cardiologist
Administrator	• Review and update patient personal information • Register new patient, physician and cardiologist
Patient	• Review and update own personal information and medical record • Review ECG history • Request consultation from physician or cardiologist

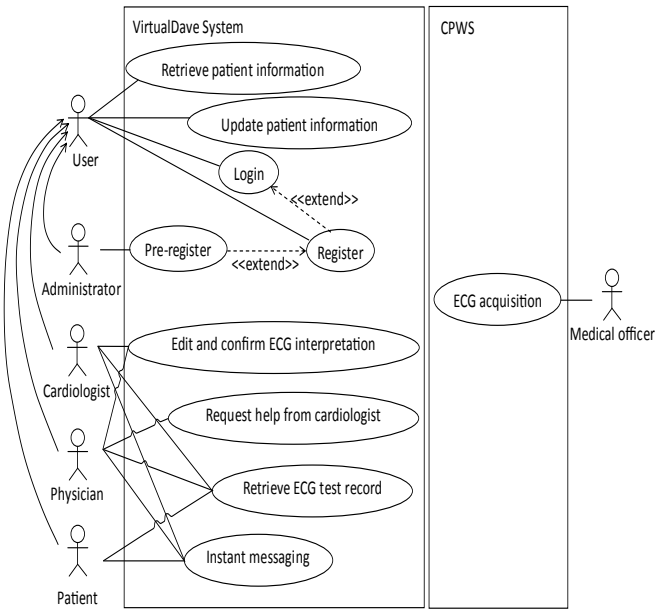


Figure 2 User case diagram of *VirtualDave System*

3.1 User Pre-Registration and Registration

The registration of administrator for each involved hospital is done at the centre hub. Figure 3 shows the sequence diagram of user pre-registration as patient and professional clinician, respectively, by registered administrator. During pre-registration, some general and contact information such as name, role and email address must be provided by user to generate the user identifier (UID). The server will then check for the existing of patient or professional clinician in database with respective role (*Check_Patient( )*, *Check_Member( )*) before the new user entry is created (*Add_Patient( )*, *Add_Member( )*). To provide security access control in protecting privacy and confidentiality of medical database, user registration is restricted to those who having the unique server-generated UID that sent to them after pre-registration (*Send_Email(email,UID)*).

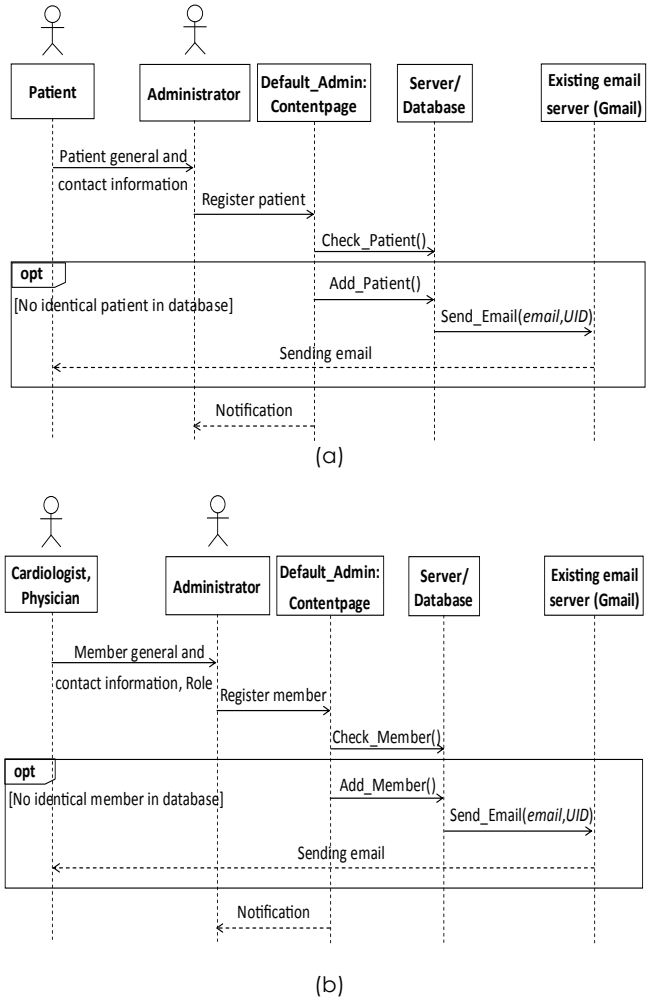


Figure 3 Sequence diagram - User Pre-registration for:(a) patient, (b) cardiologist and physician

During registration process as shown in Figure 4, users have to log on to the sign up page (*Sign_Up:Contentpage*), select their role and fill in all the required information including the UID provided. All the user inputs will postback to the server for verification (*Check_UID( )*). The registration is successful if the UID provided is correct and match with the role selected as well as there is no identical user in database (*User_Registration( )*).

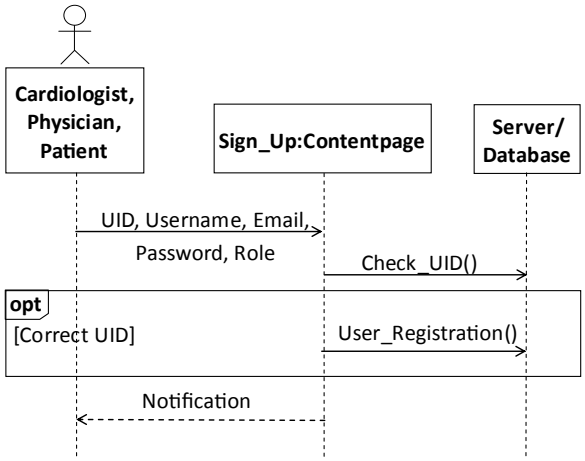


Figure 4 Sequence diagram - User Registration

3.2 User Login

Figure 5 shows the sequence diagram of user login process. To login, the users can log on to the sign in page (*Sign_In:Homepage*) and provide their registered email address and password for authentication and verification (*Check_Input( )*). After the users are authenticated, the user information such as UID, name and role will be added to table *LoggedInUsers* in database (*Sign_In( )*). Next, the server will login to the CPWS which running in the background for ECG test record retrieval process (*Login_CPWS( )*). After that, the authenticated users will be redirected to their respectively content page according to their role.

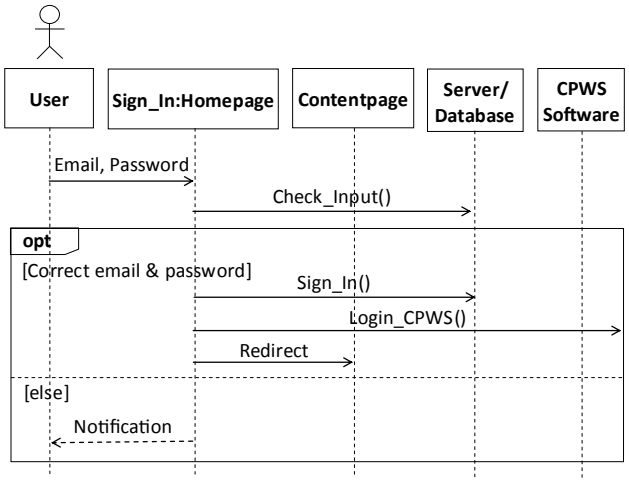


Figure 5 Sequence diagram - User Login

3.3 Patient Information and ECG Data Record Retrieval

The sequence diagram of the patient information retrieval process is shown in Figure 6. For users in categories of administrator, physician and cardiologist, they can search a patient by using patient name or number (*Check_Patient( )*). If the patient exists, the patient information (*Get_Patient( )*) and list of ECG test history (*Get_TestHistory( )*) will then be retrieved from database. For patient group, they can only view and check their own information and medical records but cannot make any amendment except basic information such as phone number.

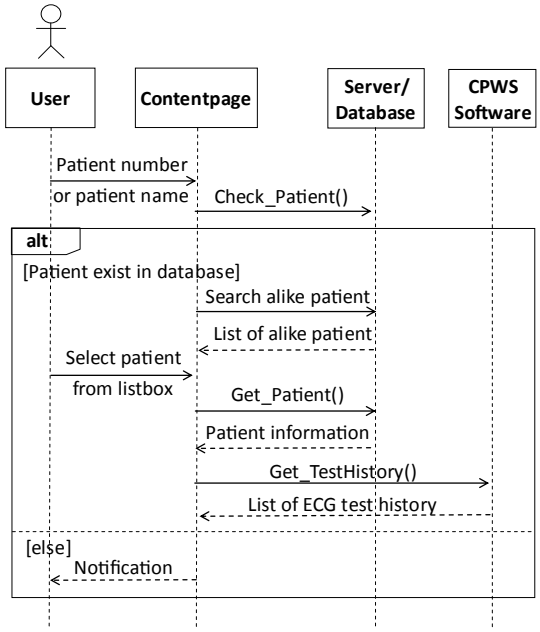


Figure 6 Sequence diagram - retrieving patient information

Figure 7 shows the sequence diagram of ECG test record retrieval process. This process is done by interfacing the CPWS using API (*Get_ECG( ), Get_Interpretation( )*). The ECG graph is viewed in portable document format (PDF) and the result of ECG measurement provided includes the heart rate, *P*, *PR*, *QRS*, *QT*, *QTc* and *QTd* intervals as well as *P*, *QRS* and *T* axes. Physician and cardiologist are allowed to edit (*Edit_Interpretation( )*) and confirm (*Confirm_Interpretation( )*) an ECG interpretation where the changes done will be updated and store in database, as shown in Figure 8. For physicians, there is an additional feature for them to request help from cardiologist when they are unconfirmed with a test (*Request_Help( )*) where an auto-generated email will be sent to the selected cardiologist for notification (*Send_Email(email address, patient number, patient name, test datetime)*), as shown as the sequence diagram in Figure 9.

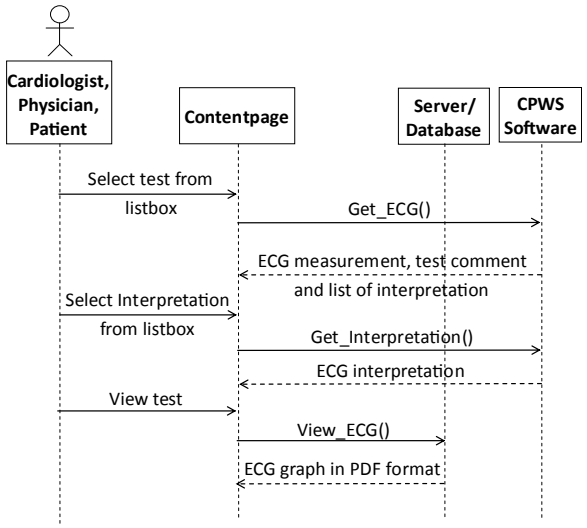


Figure 7 Sequence diagram - retrieving ECG record

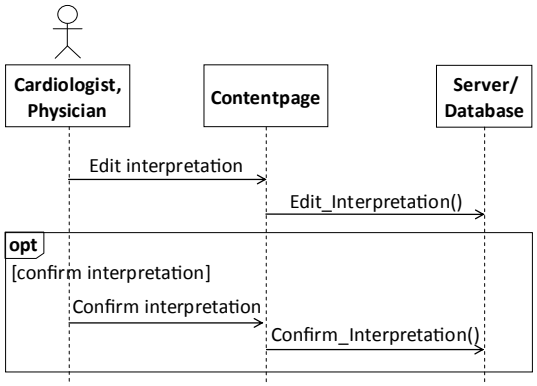


Figure 8 Sequence diagram – editing and confirming ECG interpretation

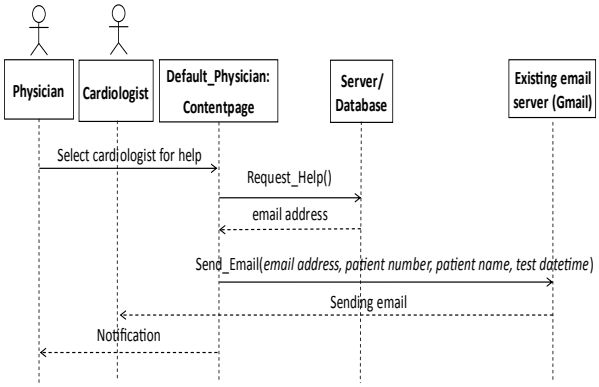


Figure 9 Sequence diagram – request help from physician to cardiologist

3.4 ECG Acquisition

For ECG acquisition, the medical officer has to install the CPWS in a client computer and configure the connection setup so that the database is located at the server. In addition, a data catcher, Connex CSK has to be installed in order to retrieve ECG data from CP 150 Resting ECG into CPWS. After ECG recording, the ECG data will be stored in the server and exported from CPWS into PDF format, using the functionality provided in the CPWS called FileLink, for viewing. For more technical information of ECG acquisition using Welch Allyn CPWS and cardiopulmonary medical devices, please refer to [9].

3.5 Instant Messaging

The instant messaging functionality is only provided for cardiologist, physician and patient for immediate remote consultation. Figure 10 shows the sequence diagram of instant messaging process. By selecting the online user, the latest 20 messages history will be loaded (*Get_Message( )*) and users can send instant messages to one another within the room assigned by the server (*Send_Message( )*). All the history of messages will be stored in the database. The list box for online user and the message box will refresh every 10 seconds and 10 milliseconds, respectively, for updating information from database.

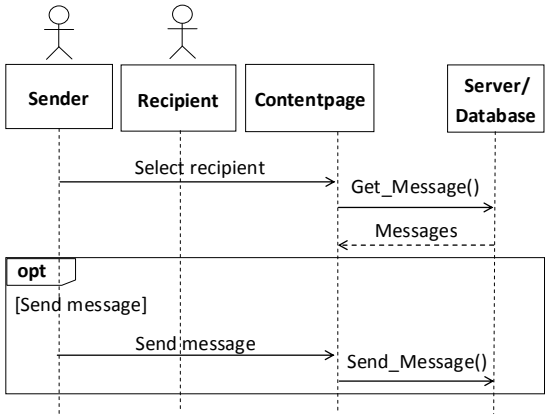


Figure 10 Sequence diagram - instant messaging process

4.0 RESULTS AND DISCUSSION

The developed *VirtualDave System* is benchmarked with original CPWS for functionality verification. Figure 11 shows the several screenshots of the user interface of *VirtualDave System*.

By using the CPWS API, 80% of the features and functionality of original CPWS data management system for resting ECG have successfully duplicated in web-based *VirtualDave System* with additional enhanced features. This includes assigning different user's roles, adding and updating patient information, reviewing of ECG test record, and displaying, editing and confirming the interpretation. For the ECG record, it is viewed in PDF format.

One of the feature enhancements of the *VirtualDave System* compared to original CPWS is on enabling instant messaging. This feature allows user such as patient and physician to get an immediate professional consultation from cardiologist. This feature will definitely be very useful to improve heart care services in rural area.

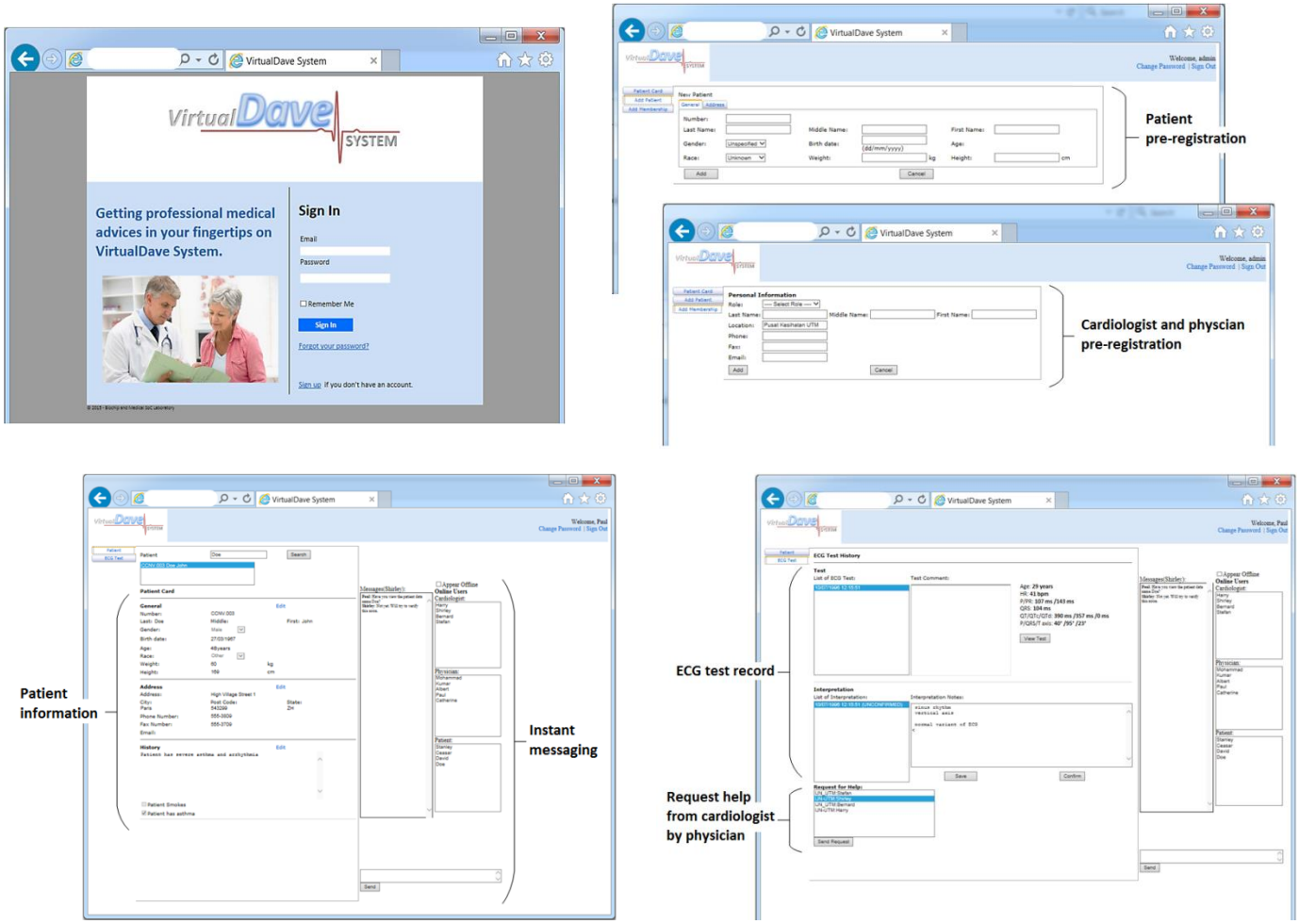


Figure 11 Several screenshots of the user interface for *VirtualDave System*

Table 2 Benchmarking of developed web application with original CPWS and other related research works

Feature/Functionality	*VirtualDave System*	CPWS	V Mahesh *et al.* (2009) [15]	L T D'Angelo *et al.* (2010) [19]	S Kohila *et al.* (2011) [18]	C Costa *et al.* (2012) [28]	M A Kumar *et al.* (2013) [29]
Vendor-independent			√			√	
Platform-independent	√		√	√	√	√	√
OS-independent	√		√	√	√	√	√
Different user roles	√	√	√	√			
Adding and updating patient	√	√	√	√			
Reviewing of ECG test	√	√	√	√		√	√
Displaying, editing and confirming of interpretation	√	√	√			√	√
ECG recording and uploading	√	√		√	√		√
Export ECG data into different data format		√					
Instant messaging	√						
Self interpretation	√	√		√			
Priorisation				√			
Abnormality detection					√		
Real-time transmission					√		
Auto alarm					√		
Sending reminder to cardiologist	√						√

Apart from that, a reminder will also be sent to cardiologist through email if there is any help request from physician.

In original CPWS, the telemedicine is done by sharing database in a network and sending test result through email provided that every involved user or party must have CPWS installed in their computer. Besides, the CPWS is only limited for Windows users. In contrast, *VirtualDave System* is platform-independent and OS-independent in which user can retrieve ECG data with any communication devices without installing any software provided that there is an internet access and web browser.

Besides functionality verification by using original CPWS as the benchmark, the author has also compared the features of *VirtualDave System* with other related work as shown in Table 2. The result shows that the current *VirtualDave System* is still vendor-dependent and a lot of improvements can be done compared to other related works, such as prioritization, real-time transmission and auto alarm.

5.0 CONCLUSION

The proposed web-based telecardiology, so-called *VirtualDave System*, is a platform-independent and OS-independent telecardiology application which aims to overcome the limitations of most commercial products. It enables users to transmit ECG data and obtain professional consultation, as long as they possess any information technology equipment with internet access and web browser. Besides, it can also be used for remote screening by transferring and sharing data that stored at database between different parties over a network through internet. By such a way, it helps to filter out healthy individual and hence reduce unnecessary hospitalization in specialist hospital. By developing the proposed web-based telecardiology system, it is hope the heart care quality of developing country can be improved.

For future enhancement, the system interoperability will be improved. A standard interface based on standard will be developed for integration of various medical devices from different vendors which support standard ECG data format in order to solve the issues of vendor-dependent. Besides, a secured info structure will also be developed in order to protect medical data both at rest and in transmission. After system enhancement and improvement, the application will be implemented for real life application.

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