Development of Platform-Independent Web-Based Telecardiology Application for Pilot Case Study

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***Abstract*— Telecardiology is one of the branches from telemedicine that transmits cardiac data such as electrocardiogram (ECG) and medical records from the patient site to cardiologist for the purpose of diagnosis by using telecommunication and information technologies. Most of the current commercialized telecardiology applications are cost expensive, vendor-specific, and dependent on computing platform and operating system (OS). There are plenty of research have been done on web-based telecardiology application either in real-time transmission or store-and-forward. In this paper, a platform-independent and OS-independent web-based telecardiology application, named *VirtualDave System*, is developed. The proposed system allow users to log on and access from any computer or mobile communication devices such as smart phone as long as they have internet access and web browser. The developed application allows users in categories of patient, administrator, medical officer and cardiologist, to communicate and get medical consultation without long distance traveling. With the improvement to the system dependency and functionality enhancement such as instant messaging, this web-based telecardiology could significantly help to improve the health care services especially in rural area.**

I. Introduction

According to the World Health Organization (WHO), among the top ten causes of death of the world in year 2012 [1], ischaemic heart disease is the leading cause of mortality in worldwide with total of 7.4 million of deaths per year. Similarly in Malaysia, the main cause of death is the disease of circulatory system (also called the cardiovascular system) with total of 25.1% in 2012 based on the statistic from Ministry of Health (MoH) [2]. Due to its long asymptomatic period, the risk management of cardiovascular diseases always been neglected until a cardiac event occurs [3]. Hence, in order to reduce the risk of fatality, a rapid initiation of treatment and continuous monitoring on the electrocardiogram (ECG) is required for patients with suspected or actual cardiovascular disease [4].

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Unluckily, there is lack of cardiologist and specialist hospital in rural area. According to the annual report of the Percutaneous Coronary Intervention (PCI) Registry 2007-2009 from National Cardiovascular Disease Database (NCVD) [5], there are 90 hospitals out of 341 surveyed hospitals provided cardiac service. Among these 90 hospitals, 16 of them are located at Kuala Lumpur whereas the states under development such as Kelantan and Sabah only have 3 hospitals provide cardiac service. Similar trend is also applied to number and density of cardiologist in Malaysia, which most of the cardiologists, that is 51 out of 175, are located at Kuala Lumpur. Both Kelantan and Sabah which has huge citizen population have only 6 cardiologists in both states. This shows a very poor cardiologist to population ratio for Kelantan and Sabah, which is 0.04 and 0.02 per 10,000 populations, respectively. Instead of long distance traveling, development of telecardiology infrastructure enables provision of health care service to these rural areas. Research and a lot of pilot studies have proven that telecardiology is a useful tool to reduce unnecessary hospitalizations, to improve management of cardiac diseases, able to support decision making of medical officers and rationalizes health-care costs [4, 6].

Although telecardiology able to improve the quality of clinical health care in rural area by enabling remote supervision and home monitoring, it still having some limitations. One of the main issues is that most of the telecardiology application still dependent on computing platform and operating system (OS) to access the software or to retrieve patient medical record from database. In other words, laptop or desktop with dedicated OS (e.g. Microsoft Windows) with pre-installed telecardiology software must always be together with medical officers in order to send or receive data for interpretation. This causes inconvenience to them and hence reduce their work efficiency.

Another concern about the telecardiology is the implementation and maintenance cost. The installation cost of telecardiology infrastructure is usually very cost expensive which could cost more than a million. According to the study from Andrade *et al.* [7], the total cost of the Minas Telecardio (MTC) project from June 2006 to December 2008 is R$ 2,133,941.18, including the implementation cost, maintenance cost and assessment cost.

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

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The paper is organized as below. Section 1 presents the current issues of existing commercial telecardiology software while Section 2 reviews the related work of telecardiology. Sections 3 and 4 describe the proposed web-based telecardiology as well as results and discussions, respectively. Section 5 concludes this project with some recommendations.

II. Telemedicine and Telecardiology

Telemedicine is the delivery of health care services using telecommunication and information technologies for the transmission of medical information and data for diagnosis, treatment and prevention of disease [8]. There are three basic components in a telemedicine network which are computers, clinical data and telecommunications between the sending and the receiving site [9]. Depends on the mode of transmission, the data can be transmitted either in real-time or by store-and-forward through a network such as Integrated Services for Digital Network (ISDN), internet, private network or Public Switched Telephone Network (PSTN).

Telecardiology is one of the application branches of telemedicine 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. 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. In-hospital telecardiology is mainly used for the communication between small hospitals in small towns and main hospitals in urban city. The applications of post-hospital include teleconsultation between physicians and cardiologists, home monitoring for chronic cardiac diseases, and the diagnosis of arrhythmias [10, 11].

There are a lot of researches have been done on the topic of telemedicine since 1900s [12]. Many researches have 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.* [13] has developed a web based telecardiology framework for the diagnosis of cardiac patients in rural areas. The proposed system only requires a computer with a web browser and internet network connection to enable the ECG waveforms display for easier diagnosis. Besides, the system also allows patients' post diagnostic information to be stored in the server for future reference. D'Angelo *et al.* [14] has also proposed a web-based system for intelligent home care which enable ECG upload and prioritization with a simple user interface of only three buttons. It able to records and uploads an ECG data using a wireless ECG recorder. It also provides ECG interpretation using Hannover ECG System (HES) algorithm and automated ECG prioritization so that critical ECG will be overread by cardiologist first. In addition, the web application also allows patients, doctors and cardiologists retrieve the data with different access authority.

A telecardiology system that based on ubiquitous email services was also developed by Costa *et al.* [15] to support remote diagnosis and reports of ECG and echocardiography in Portugal and Angola. The proposed system utilizes internet service which having an advantage over server-based infrastructure in which it does not require the installation of telemedicine centre. A security model was also developed in the system to ensure data privacy and confidentiality.

Furthermore, there is some researches focus on the phone-based telecardiology which is useful for home monitoring. For example, Scherr *et al.* [16] has reported testing results of the reliability, acceptability and feasibility of a home monitoring system for cardiac patients. In the research, patients are asked to measure and transfer the data including their blood pressure, pulse and body weight together with the dosage of medication to the telemonitoring server using wireless internet technology in the mobile phone every day. The results show that the system was reliable and easy to handle for both patients and health care professionals.

Although telecardiology is not a new cutting edge technology, yet the infrastructure is still not well established in Malaysia. Instead of starting from scratch, this proposed telecardiology application, named *VirtualDave System*, utilizes Welch Allyn existing cardiopulmonary medical devices and their CPWS Application Programming Interface (API) in the first deployment. It is developed for future pilot case study in Universiti Teknologi Malaysia.

III. Proposed Web-Based Telecardiology, *VirtualDave System*

Figure 1 shows the overview of the proposed web-based telecardiology application, *VirtualDave System*. In this proposed system, two medical devices from Welch Allyn, CP 150 Resting ECG and PC-based Resting ECG are used as ECG acquisition and signal processing devices. By referring to the CPWS and its API, a web-based in-hospital and post-hospital telecardiology application was developed using client-server model. This application allows users to log on from any computer or mobile communication devices (e.g. smart phone) as long as it equipped with web browser and availability of internet access. It transmits ECG signal using store-and-forward method where all the medical records are hosting at the server to enable remote professional medical consultation. Apart from that, this application also enables patients to get an immediate medical consultation from physician or cardiologist through instant messaging without long distance travelling.

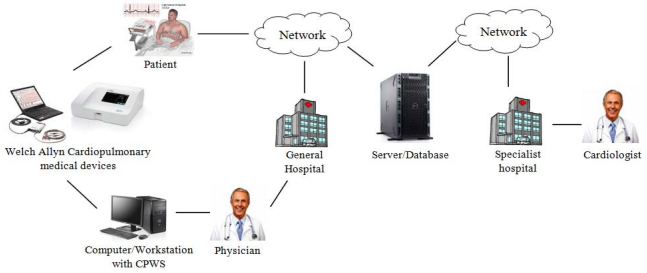

Figure 1. Overview of proposed *VirtualDave System*

In order to develop the *VirtualDave System*, firstly, the basic underlying components such as server, CPWS, cardiovascular medical devices (PC-based Resting ECG and

CP 150 Resting ECG), as well as the Connex CSK were installed. The network setting and access permission is then configured. Please note that in this proposed system, the CPWS is only required to install in server for medical record database, and any computer or workstation that connected with cardiovascular medical device for signal acquisition. To users who access the *VirtualDave System* and retrieved medical data using mobile devices, the CPWS is not need to be installed.

The programming languages used in this *VirtualDave System* development include Hypertext Markup Language 5 (HTML5), Active Server Pages (ASP) scripting and C# language. It consists of five main processes, which are user registration, user log in, patient info and ECG medical record retrieval, ECG signal acquisition, and instant messaging. The detail of each process is described in subsections below.

A. User Registration

Figure 2 and Figure 3 show the sequence diagram of user pre-registration and registration. To provide security access control in protecting privacy and confidentiality of medical database, user registration is restricted to those who have given a unique server-generated Unicode user identification (UID) that sent to user email address after he or she is added to the system by system administrator. To generate the Unicode ID, some basic information such as name, role and email address must be provided by user so that the generated Unicode ID is specific to every single user.

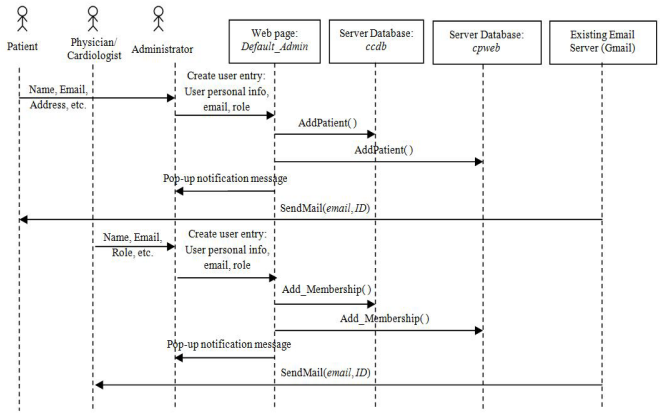

Figure 2. Sequence diagram - User Pre-registration

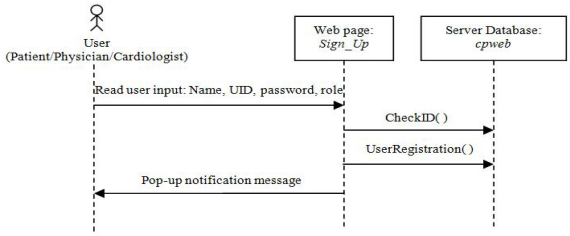

Figure 3. Sequence diagram - User Rregistration

During registration process, users have to select their role and fill in all the required information including the Unicode ID provided. After that, the user input will postback to server for verification. If the Unicode ID is correct and match with the role selected as well as there is no identical user in database, the registration will be successful.

B. User Log In

During log in process as shown in Figure 4, users have to provide their email address and password for authentication. Same as registration process, the user input will postback to server for verification. Apart from that, the server will check if the "*Remember Me*" check box is checked. If the check box is checked, cookies such as "*Email*" and "*PWD*" (password) are created and will be used for the next page loading if it is not postback. After logged in, users will be directed to different main page according to their role and authority. In terms of security, only the authenticated users can access the main pages as the session of "username" is required during page loading.

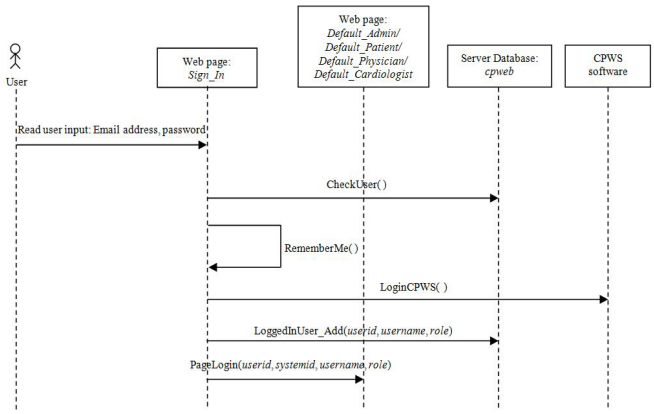

Figure 4. Sequence diagram - User Log In

C. Patient Info and ECG Medical Record Retrieval

The general sequence diagram of the info retrieval process is shown in Figure 5. For user in categories of administrator, physician and cardiologist, the property "*PatNumber*" is required in order to retrieve patient information from database. The user can search patient by entering patient name or number where the most likely result/s will be displayed in a list box. The *PatNumber* of the selected patient will then be used for retrieving patient information from database. On the other hand, for patient group, the patient information is retrieved using property *PatID* where it will be added to session *systemid* during the log in process. In other words, patient can only view and check their own information and medical records but cannot make any amendment.

Figure 6 shows the specific sequence diagram of ECG record retrieval process. To view ECG test record, the property *TstID* is required in order to retrieve the respective test comment, ECG analysis and interpretation. The ECG record is exported in portable document format (PDF) and the results of ECG signal analysis provided include the heart rate, *P*, *PR*, *QRS*, *QT*, *QTc* and *QTd* intervals as well as *P*, *QRS* and *T* axes. Physician or cardiologist can add and confirm an interpretation of ECG test where the changes done will be updated and store in database. For physicians,

there is an additional feature for them to request help from cardiologist when they are unconfirmed with a test where an auto-generated email will be sent to the selected cardiologist for notification.

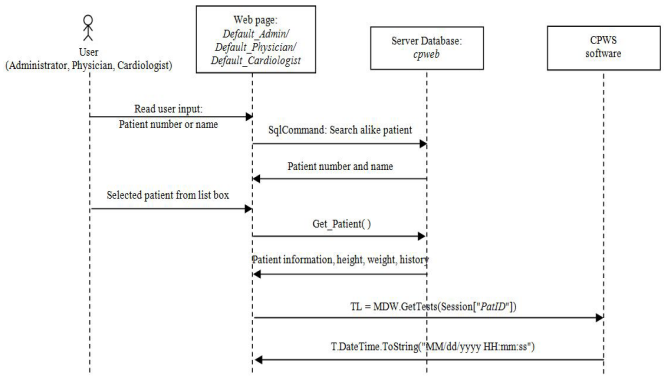

Figure 5. Sequence diagram - retrieving patient information

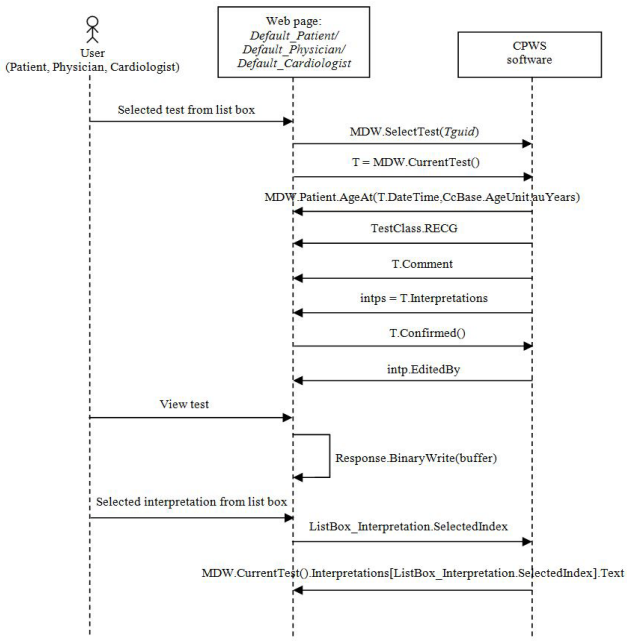

Figure 6. Sequence diagram - retrieving ECG record

D. 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 store in the server and export from CPWS into PDF format for displaying in the developed web application using the functionality provided in the CPWS called FileLink. For technical detail information of ECG acquisition using Welch Allyn CPWS and cardiopulmonary medical devices, please refer to [17].

E. Instant Messaging

The detail sequence diagram for instant messaging process is shown in Figure 7. When log in to the web application, the instance "*UserId*" for the logged in user will be inserted into the table "*LoggedInUsers*" in database. By selecting the online user, user can send instant messages to one another within the room assigned by the server and 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.

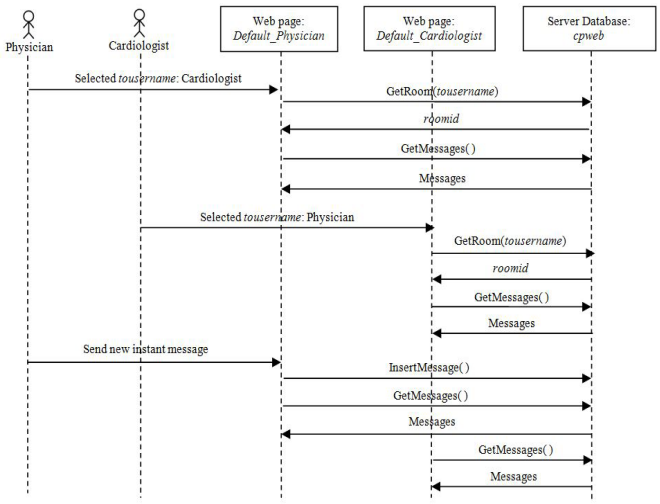

Figure 7. Sequence diagram - instant messaging process

IV. Results and Discussion

The developed *VirtualDave System* web-based telecardiology application is benchmarked with original CPWS for functionality verification. Figure 8 shows the first Sign In menu of the *VirtualDave System*.

By using the CPWS API, some of the features and functionality in CPWS have successfully developed in the web-based application, *VirtualDave System*. This includes assigning of different roles to users, adding and updating patient information, reviewing of test result, and displaying, editing and confirming the interpretation. Figure 9 shows the content of the developed web application which able to display the patient and test information. For the ECG record, it is displayed in PDF format as shown in Figure 10.

Figure 8. Login page

An additional feature of the *VirtualDave System* application compared to CPWS which is the instant messaging. This feature allows user such as patient and physician to get an immediate professional advice and recommendation from cardiologist as shown in Figure 11.

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, the web application 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 developed web-based telecardiology application, *VirtualDave System* with the other related work as shown in TABLE I. Result shows that all the CPWS features have been included in the *VirtualDave System*. However, compared to the other related work, the current *VirtualDave System* still depend on vendor-specific medical devices and ECG data management system. For enhancement and improvement from other works, it has included the instant messages functionality for more effective communication between each user.

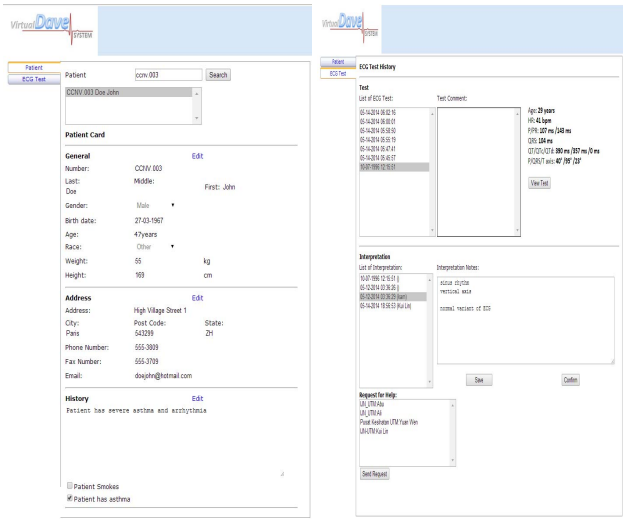

Figure 9. Patient card and ECG test history

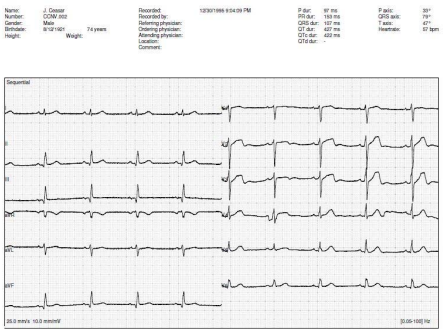

Figure 10. Example of ECG record in PDF format

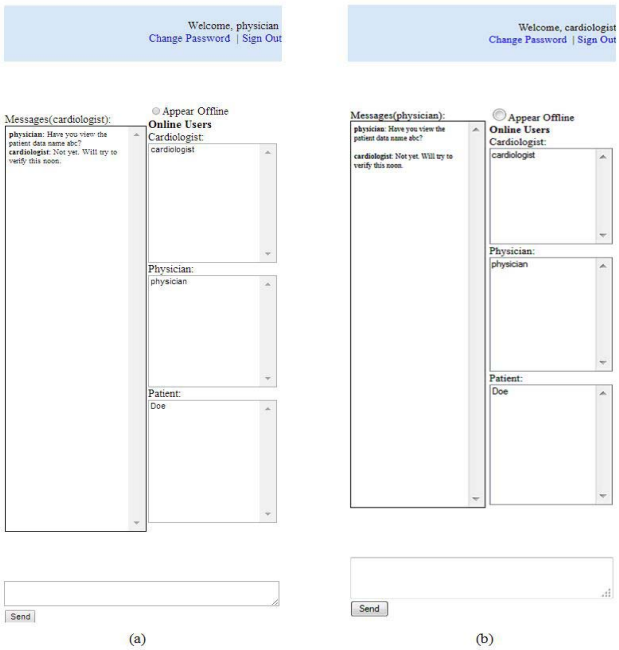

Figure 11. Instant message between (a) physician and (b) cardiologist

V. CONCLUSION

By installing the web-based telecardiology infrastructure, clinical health care is able to be delivered to the rural area and the management of cardiac diseases can be improved by applying home monitoring application and remote professional consultation. Due to the web-based telecardiology is platform-independent and OS-independent, it enables users to transmit ECG data and obtain remote professional supervision, as long as they possess any information technology equipment with internet access and web browser.

The proposed telecardiology application can be used for remote screening by transferring and sharing data that stored at database between different parties (patient, doctor and cardiologist) over a network wirelessly through internet without requiring human-to-human interaction. Besides, it also helps to improve Malaysia citizen heart care quality by enabling frequent cardiac condition monitoring without long distance travelling and long time queuing at specialist hospital.

As improvement for this project, the feature of ECG recording will be added to the application by developing a universal interface based on standard for integration among various medical devices and the web application in order to solve the problem of vendor-dependent. Besides, a secured infostructure will also be developed in order to protect medical data at rest and data in transmission. After the completed and improved application has been developed, the application will be implemented for real life application.

TABLE I. BENCHMARKING OF DEVELOPED WEB APPLICATION WITH ORIGNAL CPWS AND OTHER RELATED RESEARCH WORKS

Feature/ Functionality	Developed Web-based Telecardiology	CPWS	V Mahesh *et al.* (2009) [13]	L T D'Angelo *et al.* (2010) [14]	S Kohila *et al.* (2011) [18]	C Costa *et al.* (2012) [15]	JC Hsieh *et al.* (2012) [19]
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	√	√		√	√		
Instant messaging	√						
Self interpretation	√	√		√			
Priorisation				√			
Abnormality detection					√		
Real-time transmission					√		
Auto alarm					√		

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