東 海 大 學 資 訊 工 程 研 究 所

碩士論文

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醫療照護導向的雲端心電圖系統：以臺灣中部某醫學中心為例

Cloud Electrocardiogram System Based on Healthcare：A Medical Center experience in Middle Taiwan

研究生：張修書

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中文摘要

心電圖(Electrocardiogram, ECG)是用來測量和診斷心臟異常節律的最好方法，對於醫師診斷急性心肌梗塞(Acute Myocardial Infarction)病患而言，是不可或缺的重要判斷依據。對於急性心肌梗塞病患處理，臺灣各醫學中心均推行降低「Door to Balloon」(D2B」時間(即急性心肌梗塞病患送入急診室後，至抵達心導管室並將心導管置入心臟病灶之間所花費的時間) ，以提高急性心肌梗塞病患存活率。但急性胸部疼痛病患進入醫院(幾乎均為急診)，並執行心電圖後，該病患影像仍須由心臟科專科醫師會診，以確診為急性心肌梗塞無誤，醫護人員方可將病患送至心導管室，進行氣球擴張術。以往心臟科專科醫師在接獲確認急性心肌梗塞確認要求時，須使用個人電腦，透過網路連上醫院內的網路環境，再使用醫療影像儲傳系統(Picture Archiving and Communication System, PACS)專用瀏覽軟體方可瀏覽該病患心電圖，如此徒然會增加 D2B 的時間。因此，本文提出一個讓心臟科專科醫師收到急診簡訊通知進行確認要求後，可直接使用智慧型手機瀏覽該急性心肌梗塞病患心電圖的雲端心電圖系統(Cloud Electrocardiogram System)，目的在降低 D2B 時間。本系統已於台灣中部某醫學中心上線年餘，成功地降低了 D2B 時間 10 分鐘以上，成效良好。

關鍵字：心電圖, D2B, PACS, 雲端心電圖系統, 智慧型手機, 簡訊

Abstract

Electrocardiogram (ECG) as one of the best methods to measure irregular heartbeats is a dispensable method for doctor to diagnose Acute Myocardial Infarction (AMI) patients. Most medical centers in Taiwan implement the reduction of Door to Ballon (D2B) time, which is defined as the time interval starting when an Acute–Myocardial-Infarction patient arrives at the Emergency Department, and ending when a catheter guide wire crosses the culprit lesion as the acute-myocardial-infarction treatment on the patient in the cardiac catheterization room. Generally, when a patient with acute-chest pain is sent into hospital (always to Emergency Department) and his/her ECG has been collected, the ECG must be evaluated by a cardiologist to ensure that the patient really has Acute Myocardial Infarction. Then the medical workers deliver the patient to the cardiac catheterization room to operate balloon angioplasty. In previous years, the cardiologist must utilize a PC to connect to the Intranet of the hospital and employ a special PACS (Picture Archiving and Communication System) image browser before he/she can check the patient's ECG. But this will prolong the D2B time since the doctor may stay outdoors and he/she needs some time to find a PC and network. Of course, if the PC has not installed the PACS image browser, the doctor has to download and install it. Consequently, the D2B time should be very long, thus may seriously impacting the patient's life. Therefore, in this paper, we introduce a Cloud-based Electrocardiogram System, with which cardiologists can directly utilize their smart phones to browse the patient's ECG so as to shorten the D2B time. This system has been an online production system in a medical center in middle Taiwan for more than one year and the shortened D2B time is longer than 10 minutes, i.e., receiving fine results.

Key Words：ECG, D2B, PACS, Cloud Electrocardiogram System, smart phone, short message service

List of Contents

List of Figures

List of Tables

1. Introduction

Cloud, as an important advanced Information Technology in modern age, can supply multi-faceted applications to improve people's working efficiencies and service quality [1].

Cloud-based Picture Archiving and Communication System (Cloud-based PACS) as a popular cloud implementation is now widely utilized in medical and healthcare industry [2]. In a hospital, a traditional PACS receives different types of images from medical-image instruments. Such instruments map their images to doctor's medical orders. After that, the images and the orders are integrated as a part of the patient's medical record, these images are sent to the PACS. Since different instruments generate different images of different sizes, resolutions, tag values and formats [3], that is why Digital Image and Communications in Medicine (DICOM) [4-5] has been proposed to unify the formats. Otherwise, information among images and their showing package will be incompatible. Nowadays, all images uploaded to the PACS server must follow the DICOM standard, making the images e.g., $image_1$, stored in a PACS, e.g., $PACS_1$, will be compatible with those created for other PACS systems, e.g., $PACS_2$. Consequently, $iamge_1$ ($image_2$) can be accepted by and displayed on $PACS_2$ ($PACS_1$). Without following the standard, the PACS will not accept the images. But due to this special standard, we need to install specific image viewers or particular components in browser which accepts images of DICOM standard before we can browse such kind of medical images.

Basically, when a patient, e.g., Bob, feels that his heart is seriously uncomfortable, he will be sent to a hospital with, e.g., an ambulance. On arriving at the hospital's Emergency Department, Electrocardiogram (ECG) examination will be performed where ECG, as one kind of medical images used to record the electrical activity of hearts over a period of time, is gathered by placing electrodes of an ECG device on the skin of chest near the heart [6]. After the ECG examination, a medical staff (i.e., physician, nurse, medical technician) will upload the ECG graph to the PACS. Following that, if Bob is not in acute-chest pain, the Emergency Department physician will give some medicine orders to reduce the patient’s pain. Otherwise, Emergency Department physician must consult with a cardiologist to make sure whether Bob has Acute Myocardial Infarction. On receiving the notification, the cardiologist then downloads the ECG graph from the PACS server to the viewer installed in the doctor’s personal computer and checks this medical graph. Unfortunately, if cardiologist does not have a computer at hand right now, it is difficult for him/her to access the patient’s ECG. This may prolong the time period from the time point when the ambulance carrying the patient arrives at the hospital to the time when cardiologist starts diagnosing Bob’s ECG. Consequently, the risk to the patient’s health will be dramatically risen.

The ACC/AHA (American College of Cardiology and American Heart Association) guidelines [7] recommend that D2B time should not be longer than 90 minutes where D2B time is defined as the time period starting at the time point when the ambulance carrying the heart disease patient, e.g., Bob, arrives at the door of Emergency Department and ending when a catheter guide wire crosses the culprit lesion as the acute myocardial infarction treatment on the patient in the cardiac catheterization room. Otherwise, the delay often results in poor medical operation outcome and higher mortality [8].

Therefore, in this thesis, we introduce a Cloud-based Electrocardiogram System

(C-ECGS for short) which temporary stores ECG graphs with jpg format (besides the ECG graphs of DICOM format uploaded to PACS) so that the concerned cardiologists can download these ECG graphs from C-ECGS in time with their mobile phones and then diagnose these graphs as soon as possible to shorten the D2B time. By using this system, all cardiologists can spend their treasure time to save patients' lives, rather than finding a suitable device to connect to the hospital's Virtual Private Network (VPN) [9] and DICOM viewer to download these ECG graphs.

The contributions of this study are listed below.

1. The C-ECGS helps medical staffs in a hospital to shorten D2B time. This can significantly reduce the mortality.
2. Cardiologists can access the acute-chest pain patient's ECG graph with his/her smart phone. This will relatively easier for them to access the ECG graphs.
3. Even the cardiologist is not in the hospital, he/she still can diagnose the patient remotely.

The rest of this thesis is organized as follows. Section 2 briefly reviews related literatures and challenges. Section 3 describes the system architecture and data workflow of the C-ECGS. A practical case study is given in Section 4. Section 5 concludes this thesis and addresses our future studies.

2. Literature review

Cloud-based Electrocardiogram Systems are developed based on mobile environments and cloud computing. Users can download required data and retrieve information from cloud systems faster and more conveniently than before with a mobile phone. Cloud systems refer to as a technology infrastructure that enables several types of computing tasks to be performed sequentially and simultaneously, and provides organizations with IT capabilities and storage all via networks. They have several features, including client, server, infrastructure as a service (IaaS), software as a service (SaaS), platform as a service (PaaS), and data as a service (DaaS) [10-11]. Generally, a mobile environment comprises mobile terminal devices, network infrastructure and information platform, in which the information platform often supports mobile applications and business models [12-13].

With the evolution of cloud computing and mobile environment, the workflows of many information systems in healthcare industry, like Health Information System (HIS) [14] and PACS, accordingly change to adapt themselves to current trends of application domains. By the support of cloud technology, all medical practitioners vary their work models from hand writing to computer operation. The American Health Information Management Association (AHIMA, called American Medical Records Institute before) defined five steps of medical records evolution [15] : Automated Medical Record, Computerized Medical Record, Provider-based Electronic Medical Record, Electronic Patient Record, and Electronic Health Record, which obviously show the evolution sequence of patient's medical records. Before performing any medical treatment and activities, physicians and nurses have to consult the patient's medical records, like examination data, progress note [16], vital signs [17] and medical images. The purpose is knowing the patient's medical history which may strongly affect the underlying medical treatment and activities. In recent years, with the assistance of related high-tech technology, medical staffs can consult or input the patients' medical records directly through their smart phones, consequently not only providing necessary medical information to medical staffs immediately, but also saving the time before they can start taking care of patients. This thereby significantly enhances the safety of patients, reduces the medical costs and improves the quality of medical services.

According to the report announced by the Ministry of Health and Welfare (MOHW), Taiwan, heart diseases are the top second place causing death in Taiwan [18], and Acute Myocardial Infarction is one of the key reasons resulting in deaths. Although the incidence rate due to Acute Myocardial Infarction was going down from 58.7 to 57.0 per one hundred thousand people in the time period from 2009 to 2013, in the same time period, the rate in middle-aged population from 40 to 49 years old grew up from 76.4 to 99.2 [19] also per one hundred thousand people. If Acute Myocardial Infarction has occurred on someone without appropriate medical treatment, the risk of death is extremely high up to 81% [20].

In order to treat patients with Acute Myocardial Infarction much easier, many specialists provide methods to detect the disease by integrating medical and modern technology. From patient and operation viewpoints, modern technology can further deepen the activities and effects on healthcare, thus pushing medical technology from e-Health [21] to m-Health [22]. For example, medical staffs can monitor the patient's Holter monitor [23], from which to receive the patient's ECG data via the portable medical instrument that he/she carries. Another example is the corresponding acute–chest-pain patient who is now in an ambulance bound for a hospital. If there is an ECG device with 3G/4G Internet in the ambulance and well integrated with the PACS in a target hospital, the ambulance can transmit the ECG to the hospital after ECG examination in the vehicle. Both the two examples are the trends of current research on healthcare information systems for improving the quality of medical treatment to Acute-Myocardial-Infarction patients.

Due to the fast development of Internet of Things (IoT) [24], patients can put on wearable ECG devices with which to monitor their vital signs and upload their ECG information to remote site through Wi-Fi or 3G/4G Internet. Currently, the remote site may be a hospital, doctor's clinic or nursing station depending on the characteristics and scale of the institute/organization taking care of the patients. Of course, in such a remote monitor environment, if the patient with heart disease can be supported by Internet Service Provider (ISP) and wearable devices, the corresponding medical effects can be well collected and demonstrated. This medical and high-tech integration can also set up patient's health-status alarm. That is if the patient's ECG wave forms sent by wearable devices are some level away from their normal situation, the remote site will warm the healthcare-givers immediately so as to efficiently prolong the golden window of cure [25-27].

In the second example of current research trends mentioned above, when receiving the patient's ECG from an ambulance on the way to the hospital H, through 3G/4G wireless network, Emergency Department instantly activates the standard operation process (SOP) to speed up the following process on the arrival of the patient [28-29].

According to the reports announced by the well-known Framingham Heart Study [30-31] and another research on the rate of sudden death [32], if this is the first time patients without heart disease history are ill, the rates that they got Acute Myocardial Infarction, even sudden death, are about 62% for male and 46% for female. Over 26 years, the number of sudden-death cases on male in the United States is 146, among which 69 cases have no heart-disease history. Of course, the remaining 77 cases are with such history. The number of sudden death cases on female is 50, among which 34 cases have no such history and the other 16 are with the history.

Now we can know that many Acute-Myocardial-Infarction patients' incidents are the first time without any advanced symptoms. Right now, many patients who already know that they had heart-disease history are using wearable ECG devices. Usually people without any heart-disease history will not carry Holter Monitor on their body all the time. Even many potential Acute-Myocardial-Infarction patients do not know that they have such disease, all the phenomenon above often cause accidents directly or indirectly.

As we known, Acute Myocardial Infarction will cause myocardial necrosis, which means the cells of an area of the heart muscle, as a result of oxygen deprivation caused by obstruction of the blood supply, will die [33-34]. As the D2B time is longer, more Acute-Myocardial-Infarction patient's heart muscle will keep dying, thus increasing the risk of his/her death. Of course, decreasing the D2B time will lower the myocardial necrosis crisis of the patient.

Although medical technicians in an ambulance can send the ECG of the patient (e.g., Bob) now in this vehicle to the target hospital to speed up following medical SOP, it also has some technical challenges to be conquered, like the ECG signals transmitted through 3G/4G may be unstable, the contents of Bob's medical records in other hospitals may be different from those kept in the target hospital, and the ECG generated by ECG device in vehicle, as a part of Bob's medical images, may not be integrated with those images gathered for Bob in the PACS system of the target hospital. The latter is often due to the fact that only a part of hospitals use patient's social security numbers (or personal ID in Taiwan) as their own medical record IDs. Even through Bob's medical images actually exist in the hospital's PACS, they can not be integrated with the newly generated medical record.

In fact, to avoid the occurrence of these cases, the integration between the ambulance ECG device and the PACSs in each of the possible target hospitals must be fully tested beforehand. If the problem can be effectively solved in the future, it will significantly improve the positive effect brought to C-ECGSby the ECG in vehicle.

On the other hand, only a part of acute-chest-pain patients has Acute Myocardial Infarctions and needs Percutaneous Transluminal Coronary Angioplasty (PTCA) [35]. When ECG graph of a patient is available, no matter whether the examination is performed in an ambulance or in the Emergency Derpartment, Emergency Department physician has to consult with the cardiologist. If the cardiologist on duty confirms that the patient has Acute Myocardial Infarction, the PTCA work flow will be activated. How to shorten the time period from the time point when the cardiologist receives the checking notice from medical staffs to the time point when he/she finds a suitable device and starts checking the ECG will be described below.

3. System Architecture

Figure 1 shows the architecture of the mentioned Cloud-based Electrocardiogram System, which consists of six subsystems, including Medical Operation, Main System, ECG Management System, Short Message Service Server, Cloud-based Electrocardiogram System Server, and a smart phone.

3.1 Medical Operation

Functions of this subsystem, i.e., Medical Operation, are two-fold, ECG examination and patients' ECG report finished by cardiologists. Each patient with acute-chest pain must be performed an ECG examination when he/she is sent to a hospital. After the examination, the medical staff transmits the ECG graph, in XML format with binary waveforms data, to the ECG server which is in ECG Management System, via ECG devices. After the cardiologist downloads the ECG graph from the ECG Server through the ECG Gateway and diagnoses the graph, he/she types the patient's medical ECG report by using the ECG report system. The functions of ECG Server and ECG Gateway will be described as follows.

3.2 Main System

This Main System consists of HIS and PACS. The HIS stores patients' basic information, like his/her name, medical record ID, gender, shift table of cardiologists, etc. through the ECG Gateway. When a patient's ECG graph is available, medical technician then uploads the graph to the C-ECGS. After that, Emergency Department physician will trigger a short message sent to the cardiologist on duty with the help of the Short Message Server. Of course, patients' registered records, diagnoses results by doctors, nursing healthcare records, results of specimens, etc. are also stored in HIS database. HIS brings huge benefits in many fields, like Medical researching, clinical teaching and medical treatment strategy. Researchers can analyze those data which they desire, e.g., exploreing the possible indicators of some specific diseases and accordingly develop new drugs. Clinical cases may be taken as medical teaching templates and materials for education. One most important thing is how to treat patients when they are ill. Actually, HIS plays an important role in these fields. The

PACS server keeps all medical images, including the ECG graphs and all other

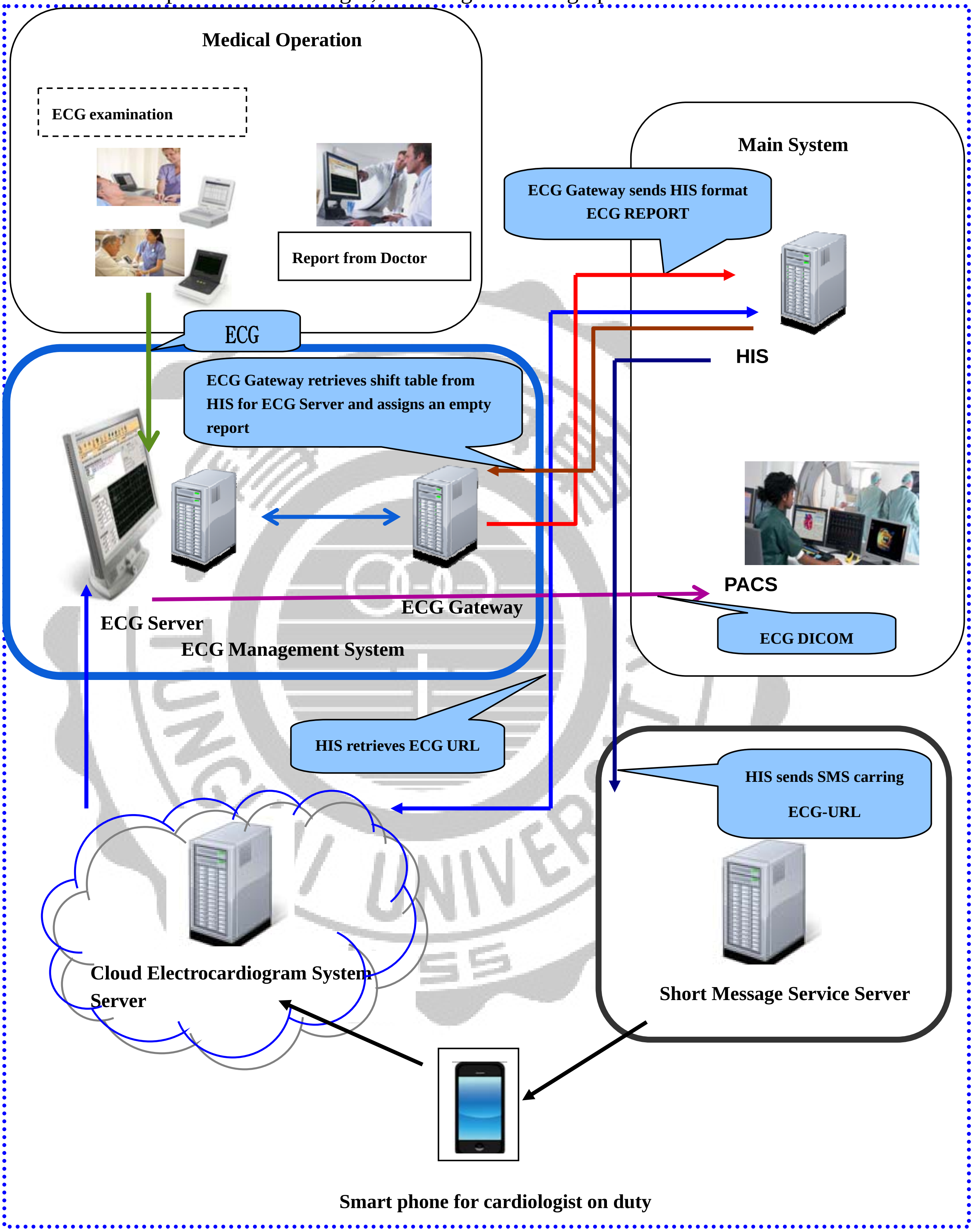

Figure 1：The framework and workflow of the mentioned Cloud-based Electrocardiogram System.

medical images produced in the hospital. Generally, a medical technologist executes the radiography after signing up the order submitted to the HIS by doctors. Then he/she sends the images to PACS with the instrument that follows the DICOM standard. The format of a DICOM image consists of two parts: pixel data which are addressable pixels comprising the image, and attributes which are metadata of DICOM information. Figure 2 illustrates an example. Pixel data constitute the foot x-ray image. The attributes are the data in the window, e.g., Tag ID (0008,0060) means the modality of this image is CR (Computed Radiography). The DICOM tag's description can be seen in [3].

Because this standard is globally accepted in medical image domains, and almost all the medical image instruments follow this standard, patients can bring their own medical images from one hospital to another without extra radiography as long as both hospitals' PACS architectures follow the DICOM standard. This greatly enhances the efficiency of medical treatment, and also reduces medical resources consumption.

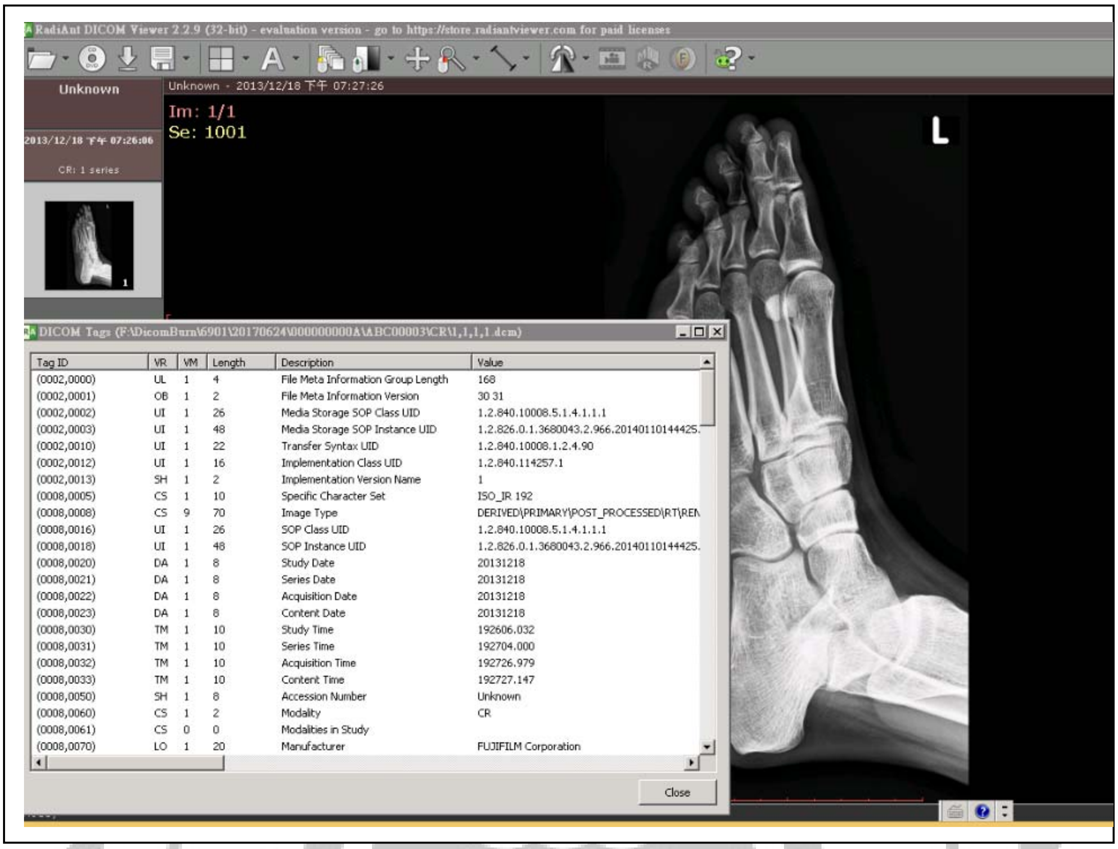

Figure 2: An example of DICOM image : pixel data and attributes. Pixel data constirute the foot x-ray image. The attributes are the data in the window, e.g., Tag ID (0008,0060) means the modality of this image is CR (Computed Radiography). The description can be seen in [3].

3.3 ECG Management System Server

This subsystem, i.e., the ECG Management System, which consists of ECG Server and ECG Gateway, is responsible for receiving ECG data generated by all ECG devices in the hospital, transforming them into DICOM graphs, sending the ECG DICOM graphs to main PACS, and providing system interfaces for cardiologists to type in ECG reports. When an ECG graph is uploaded to the ECG Server, ECG Server will refer to the shift table of cardiologists stored in HIS and assign the ECG empty report to the cardiologist on duty. On receiving the finished report from the cardiologist, ECG Server integrates the patient’s ECG graph with this report, and calls for the ECG Gateway services to retrieve the patient’s basic information, like his/her name, medical record ID and gender. After that, ECG Server transforms the ECG graph into DICOM images and sends it to PACS server directly. It also transforms the

ECG report into HIS format and sends it to HIS via ECG Gateway. All authorized cardiologists are allowed to access the integrated ECG reports, i.e., ECG graph and ECG report, for the patient's follow-up medical treatment. Furthermore, all authorized medical staffs in the hospital are able to access the ECG report stored in HIS for medical or teaching purpose.

3.4 Short Message Service Server

This subsystem, i.e., the short message service server, provides short message services with which HIS can issue different emergency calls to notify cardiologists and other medical staffs. The concerned hospital has signed a contract with a telecommunication operator to provide these communication services. On receiving these calls, cardiologists can retrieve the corresponding ECG graph through the ECG URL carried in the short message sent to them.

3.5 Cloud-based Electrocardiogram System

This subsystem, i.e., the Cloud-based Electrocardiogram System (C-ECGS), transforms the qualified ECG graphs, i.e., dcm files, into jpg files through the self-developed service for suiting mobile communication and storing the transformed files in its database (See Figure 3). In this figure, there are 7 dcm files which belong to 7 patients who had finished their ECG examination in the Emergency Department, and all of the dcm files are transformed into jpg files, ready for the cardiologists to check on their smart phones. After a cardiologist retrieves the ECG graph to his/her smart phone and diagnoses the patient's illness, this ECG graph stored in this subsystem is no longer needed and is then deleted. In other words, the ECG graph stored in the C-ECGS server is only for cardiologist to fastly and remotely diagnose the Acute-Myocardial-Infarction patients. Medical staffs still can retrieve this ECG graph from the main PACS afterward when necessary. Further, considering the security of medical records and the storage efficiency, if the time consumed for transforming an image file from dcm (i.e., DICOM file) to jpg format is longer than one hour, the file will be deleted by the scheduled job which as a system function of the C-ECGS executed once per hour is designed for deleting files and database records that are too long.

```
[root@ecg ecgtif]# ls /usr/local/apache-tomcat-7.0.40/webapps/ROOT/work
1decfd80-6151-11e7-4823-15b247aa0029.jpg
44a72780-60b0-11e7-4823-016e01e10029.jpg
5091f880-6147-11e7-4823-000219cb0029.jpg
592ff380-60a1-11e7-4823-010c45590029.jpg
65718a80-614d-11e7-4823-1599e6680029.jpg
95158980-609e-11e7-4823-00fa26b30029.jpg
9643c680-6131-11e7-4823-14e3bf370029.jpg
[root@ecg ecgtif]# ls
07041749_PhXm_95158980-609e-11e7-4823-00fa26b30029_xml_1499161679.dcm_affb.dcm
07041810_PhXm_592ff380-60a1-11e7-4823-010c45590029_xml_1499162880.dcm_22ed.dcm
07041922_PhXm_9643c680-6131-11e7-4823-14e3bf370029_xml_1499167208.dcm_d542.dcm
07041958_PhXm_44a72780-60b0-11e7-4823-016e01e10029_xml_1499169266.dcm_b28b.dcm
07042158_PhXm_5091f880-6147-11e7-4823-000219cb0029_xml_1499176526.dcm_738b.dcm
07042243_PhXm_65718a80-614d-11e7-4823-1599e6680029_xml_1499179187.dcm_108b.dcm
07042307_PhXm_1decfd80-6151-11e7-4823-15b247aa0029_xml_1499180728.dcm_19c2.dcm
[root@ecg ecgtif]#
```

Figure 3: The message is sent to HIS after ECG an graph with unique ECG ID in C-ECGS is transformed into jpg file.

On the other hand, every Short Message Server has its own limits, especially the number of delivered characters. In Taiwan, the upper limit is 70 characters. But the number of characters of an ECG URL is always longer than this limit. In this way, the message will be divided into two individual messages. But this will result in the fact that the cardiologist will click an incomplete URL. Of course, the ECG graph will not be shown on his/her smart phone. To solve this problem, in this study, we invoke the Google-URL-Shortener service which is given the developer's API key. The service returns a shortened URL.

3.6 Smart Phone

When the cardiologist receives the short message, he/she can retrieve the patient's ECG graph from the CECGS server and diagnose the graphs with his/her smart phone immediately. We do not limit the types of smart phones used by cardiologists. Any one which can show jpg files and text is fine.

Our conclusion of this section is that all medical records and images are stored in HIS or PACS depending on their characteristics. Normally, there are 3 steps before the ECG can be stored in the main PACS. An ECG graph is first sent to the ECG Server. Next, the ECG Server transforms the graph into DICOM image. Finally the transformed image is delivered to the main PACS.

To shorten the time in which the cardiologist can start accessing the ECG, our system, i.e., the C-ECGS, bypasses these three mentioned steps. On the contrary, it retrieves the ECG graph from ECG server, transforms the ECG data, the size of which is about 200 KB, into DICOM image and provides the ECG graph, which is integrated with HIS data, to cardiologists. The data mentioned above is encrypted by the vendor of ECG devices and the server offered by original equipment manufacturer is workstation, which takes 7 seconds to transform an ECG record. For improving the transformation efficiency, we substitute the ECG workstation with a powerful machine, i.e., ECG Server, which consumes 0.1 second to transform each record of ECG data. The purpose is to accelerate the availability of the ECG graph. Besides, the Google API is used to shorten the uniform resource locator (URL) which is employed to show correct position of the patient's ECG. By the integrating the Google API, we can solve the problem of 70-characters limit of a short message in Taiwan.

Figure 1 also illustrates the detailed work flow of C-ECGS which consists of 5 steps:

Step 1：After finishing the ECG examination, medical technicians upload the examination results to ECG server.

Step 2：After receiving the ECG, ECG Server stores the data in its temporary repository. Then the C-ECGS checks to see whether the data stored in the ECG server is qualified or not. If yes, it transforms the qualified data into jpg and stores them in its database. At this moment, the ECG graph is available to the cardiologists. Meanwhile, ECG server follows its normal procedure to transform the qualified data to DICOM image and sends the result to the Main PACS through the ECG gateway after the ECG Server integrates the DICOM images with the patient's HIS records.

Step 3：The Google-URL-Shortener is employed. Developers must apply to obtain the API key, which will be used in their code and the returned result is in XML (See Figure 4), from Google inc.. The C-ECGS creates this service, named “Acute Myocardial Infarction Groupcall” (See Figure 5), which is used by physicians in Emergency Department to call for the C-ECGS service and shorten the mobile ECG URL. Meanwhile, this HIS service enquires both the ECG Server’s and the C-ECGS’s databases, and accordingly checks to see whether the ECG of jpg format truly belongs to the concerned patient.

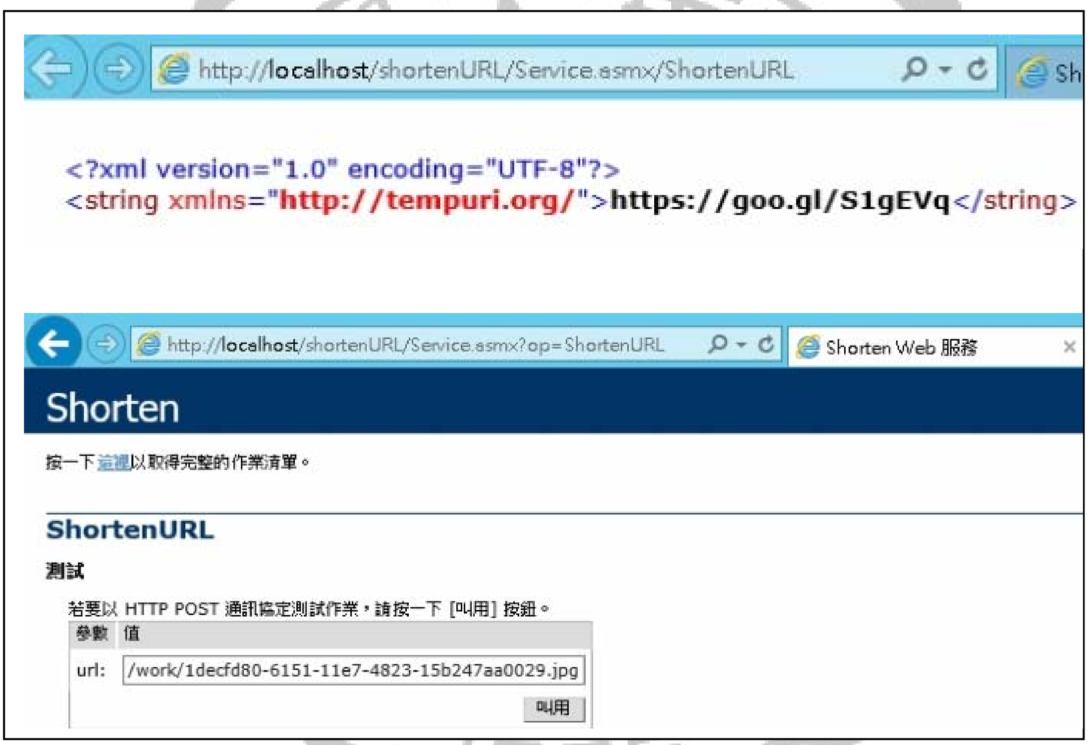

Figure 4: The self-developed Google-URL-Shortener Service. The full URL is http://ecgtif.vghtc.gov.tw/work/1decfd80-6151-11e7-4823-15b247aa0029.jpg (Only the right portion is shown due to long string). The returned result is in xml and the shortened URL is https://goo.gl/S1gEVq (See the right string on the top rectangle).

Step 4：HIS sends the mobile ECG URL and the patient’s data stored in its database to cardiologist’s smart phone through the SMS server. After the cardiologist clicks this URL, the ECG graph will be shown without requiring any other APP installed in his/her smart phone.

Step 5：The C-ECGS deletes the patient's whole data from its storage one hour after ECG is shown to cardiologist to ensure the patient's privacy and security and save ECG's management cost of this system.

Figure 5: HIS service function, used to call cardiologist for acute-chest pain patient, is only for Chief Resident and higher. ("急性冠心症群呼(限總醫師以上)" means Acute Myocardial Infarction Groupcall (only for Chief Resident and higher); "醫師功能 > 測試人 急診 00000000 > 急性冠心症群呼(限總醫師以上)" stands for Doctor Function > Virtual Patient Name Emergency Department Emergency Serial Number > Acute Myocardial Infarction Groupcall (only for Chief Resident or higher)).

4. A Practical Case Study

The concerned hospital includes its Main Hospital, and its Puli, Chiayi, and Wenqiao Branches. The ECG Management System stores the data it has ever received, such as the ECG graph, the patient's information and the sequence number in each inspection sheet. After diagnosing the ECG graph, the cardiologists can type in the corresponding ECG report, and then the ECG graph will be sent to the Main Hospital's or one of its branches' PACS, depending on where the data is produced for patients, the Main Hospital or its branches. Because the ECG Management System was successfully developed and it is actually running now, ECG workflows inside the Main Hospital, inside its branches, and between each pair of them are paperless, i.e., all are electronic records, thus prolonging the life of images for storage, and also bringing huge convenience to users, i.e., cardiologists, medical staffs, and patients since the medical staffs do not have to print the ECG results.. The project of expanding the mentioned ECG functions of the ECG management system (which is other than the project of developing the C-ECGS) was started at early 2013 and ended at the end of 2013. After that, medical staffs can access images, and cardiologists can write ECG reports anywhere in the Main Hospital and its branches. This has greatly enhanced image diagnostic quality and reduced the production of Carbon. In fact, the similar project can be applied to other fields, like medical, teaching, research and others. In terms of medical, the electronic ECG graph can keep much longer than printing results can. Of course, it is much helpful in curing patients, and worth for discussion in cardiology conference. From big-data-analysis viewpoint, analyzing the ECG examination results is particularly useful for future medical treatment since researchers may discover hidden illness factors from them.

After expanding the ECG Management System, the system can accommodate more ECG devices and offer a fast access to ECG graph. On the other hand, the authorized users can also access ECG graphs by using a computer (rather than smart phones) which installed special PACS image browser, In other words, the system does not affect the working process that should be done by medical staffs. But it truly saves the time a cardiologist spends to access ECG graphs. Another project which establishes the CECGS aiming to reduce D2B time started at the middle of 2014. The C-ECGS was successfully installed in the Main Hospital at the end of 2014. The detailed procedure and the corresponding implementations are as follows.

First, Emergency Department physician orders ECG examination right after acute-chest-pain patient is sent into the Main Hospital. (Note that all its branches will have the same functions in the near future, and the functions will be the same as those developed for the Main Hospital). When the ECG graph is uploaded to ECG server, Emergency Department physician uses the HIS function (i.e., Acute Myocardial Infarction Groupcall (see Figure 5) to call the cardiologist immediately without having to wait for the finish of the upload. But this HIS function is only for Chief Resident and higher (The doctor rank from low to high is Intern, Resident, Chief Resident, Visiting Staff, and Chief Physician) because the Resident needs more clinical experience before he/she can accurately judge whether a patient case should be announced to a cardiologist or not. In his/her current stage, it is not suitable to access the ECG graph. This HIS function sends patient's electronic medical records (EMR) [36] and the ECG graph URL (see Figure 3) to cardiologist's smart phone at the same time via SMS (see Figure 6).

Figure 6: ECG SMS on cardiologist's smart phone. (Short message subject: Taichung Veterans General Hospital Short Message (i.e., 台中榮總簡訊傳呼). Message Body: Patient's ID (i.e., 123865B), ECG, ECG graph link (i.e., https://goo.gl/EIJ81v), Extension Number in Main Hospital (i.e., 3695); Regular text (i.e., 台中榮總關心您(meaning: Taichung Veteran General Hospital is care of you)). Other texts: 訊息: Messages; 詳細資訊: Details; 中華電信: ChungHwa Telecom.)

After receiving the SMS and the ECG-graph URL, the cardiologist clicks the URL and then starts diagnosing the patient. This ECG graph is completely the same as that shown on a computer. Figure 7 illustrates an ECG example. All the values, wave forms, and an automatic simple diagnosis are shown on this graph. The most important information is the wave forms. A cardiologist must check the amplitude and the shapes of the wave forms and compare them with the normal sinus rhythm. In Figure 7, there are 74 vertical and 130 horizontal lattices. For each small lattice, the vertical scale is 0.1 mV voltage and the horizontal scale is 0.04 second. The ECG graph can be zoomed in or zoomed out without conducting distortion so that cardiologists can judge this graph correctly on their smart phones, like that when they stay in front of a computer.

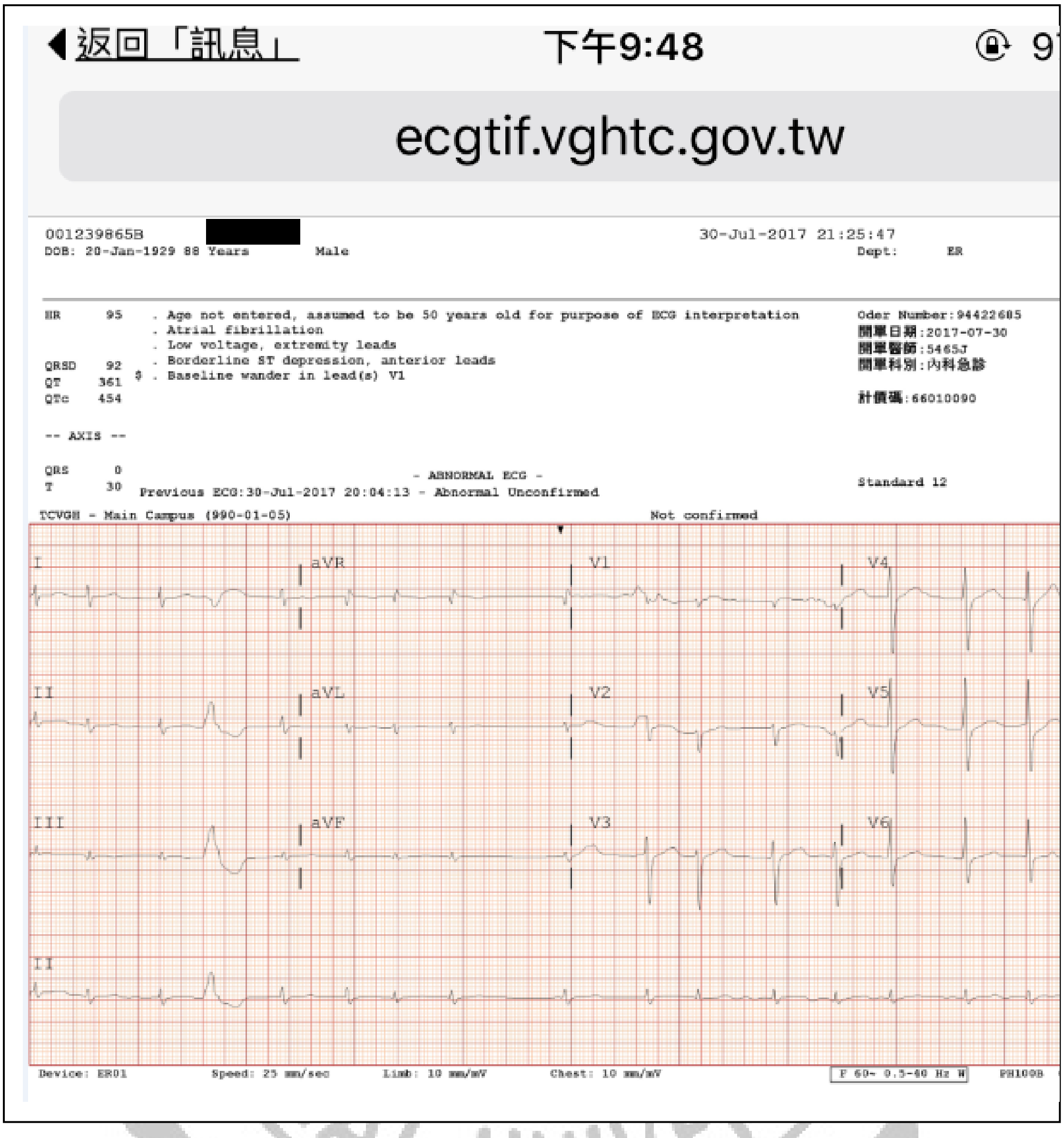

Figure 7: A patient's ECG shown on cardiologist's smart phone (On the left-top, 返回訊息 is "Back to Messages"; on the right top, 開單日期 is the ECG order date; 開單醫師 is the Emergency Physician's ID in TCVGH; 開單科別 is the Emergency Physician's division; 急診內科 is Emergency Medicine Division; 計價碼 is the cost code of the ECG examination in TCVGH.).

According to the analyzed results from statistic data collected in HIS, the C-ECGS was officially online at the end of 2014. It is really helpful in decreasing the D2B time. Table 1 shows the results, in which the D2B time from 2014 to 2017 is significantly reduced, meaning the developed system has achieved its expected goal. In Table 2, the percentage of the cases in which D2B time > 90 minutes from 2014 to 2017/01 follows the trend. Note that the D2B mean time of 2013 (i.e., 66) was less than that of 2014 (i.e., 76). This is due to the fact that the number of referral patients is higher than that in 2014 (See Table 3). The detailed reason is described below. Before a patient is transferred from a referral hospital, e.g., H, to a return hospital, e.g., TCVGH, the medical staffs of H would make a consultation call to Emergency-Department medical staffs of the return hospital. The purpose is describing the patient's illness. An acute-chest-pain patient must have an ECG before he/she is transferred to the return hospital. The medical treatment team of the return hospital, i.e., its cardiologists, will remotely diagnose the patient and discuss the medical treatment strategy with the cardiologists of H in the consultation call to make sure whether the return hospital can perform medical treatment to this patient or not. If yes, the cardiologists of the return hospital will activate PTCA process immediately. This is one of the main reasons why the D2B time of 2013 is lower than 2014. But if not, meaning the return hospital lacks medical resources, the cardiologists of H will contact other return hospital. This situation of patient transfer usually happens when H is a Regional Hospital and the patient is often sent to a Medical Center (e.g., TCVGH), the level of which is higher than those of a Regional Hospital.

In referral cases, cardiologists of the return hospital activate PTCA immediately after the consultation call. In a non-referral case, the activities of sending a short message to the cardiologist on duty and accessing and diagnosing the ECG graph of the patient by the cardiologist can be omitted. In other words, after the acute-chest pain patient is sent into Emergency Department, the return hospital will start treating the patient, following the PTCA SOP. This is the reason why the D2B time of 2013 was shorter than 2014. More referral cases will shorten the total D2B time. Generally, ECG examination will be performed again in the return hospital to make sure the disease symptoms. The purpose is is to avoid any mistake and misunderstanding during the consultation call.

Table 1: Average D2B time between 2011 and 2017/01 in TCVGH.

Year / min	2011	2012	2013	2014	2015	2016	2017/01
D2B mean time (mins)	101.16	81.94	65.26	75.65	55.90	47.16	43.48

Table 2: The statistics of D2B cases in TCVGH from 2011 to 2017/01.

Year / Of persons	2011	2012	2013	2014	2015	2016	2017/01
Need PTCA (A)	80	114	97	91	92	95	16
No Need PTCA(B)	49	278	204	83	36	37	3
D2B Time >90 mins (C)	17	21	15	13	9	8	1
Total(A+B)	129	392	301	174	128	132	19
D2B Time > 90 mins = (C/A) %	21.25	18.43	15.47	14.29	9.79	8.43	6.25

Table 3: Numbers of Referral Patients Needing PTCA in TCVGH.

Year / Of Persons	2011	2012	2013	2014	2015	2016	2017/01
Referral Patients (A)	53	74	84	64	68	68	12
Total Patients (B)	94	149	122	109	120	121	19
Referral Rate (A/B) %	53.68	49.66	68.85	58.72	56.67	56.20	63.16

Table 4 shows the mortality rate during the time period from 2011 to 2017/01. The C-ECGS brings huge benefit of decreasing the D2B time to TCVGH. As shown, the mortality rates from 2014 to 2017/01 are gradually lowered and almost zero. This saves many more acute-chest-pain patients from their illness.

Table 4: Mortality rates of Acute Myocardial Infarction(AMI) patients in TCVGH.

Year / Persons	2011	2012	2013	2014	2015	2016	2017/01
Death (A)	6	8	5	4	0	1	0
Need PTCA (B)	80	114	97	91	92	95	16
Mortality Rate = (A/B) %	7.50	7.01	5.15	4.40	0	1.05	0

5. Conclusions and Future Work

In this study, we introduce the C-ECGS which has been established in a hospital, and the hospital has demonstrated that the system effectively improves the efficiency in diagnosing patients with acute-chest pain because it significantly reduces the time in retrieving patient's ECG graph by cardiologists, especially when they are out of their offices or wards. Saving the time that cardiologists consume before they can access a patient's ECG graph is the pivotal reason in shortening D2B time. All cardiologists can spend a longer time to discuss and think the patient's medical treatment strategy, rather than spending time to find computers with DICOM browser and connect the computer to the hospital's Virtual Private Network. This hugely benefits patients and health professionals, not only increasing the quality of the medical services, but also reducing the mortality rate.

Our future work is developing the system for all branches of TCVGH and integrating the workflow with ECG devices in an ambulance. Currently, only the Main Hospital has established the C-ECGS. On the other hand, the Electrocardiogram system and ECG devices used in the Main Hospital and the branches are developed by the same instrument vendor. But the HISs of these branches are offered by the vendors other than that of the Main Hospital. However, if all the branches can modify their function codes for their HISs and change their HIS workflows so as to be able to integrate their own PACSs with that of the main hospital, the Main Hospital can then modify the online C-ECGS and handle demands issued by the branches. The branches do not have to cost extra for developing their own IT infrastructures. Only the Main Hospital requires to extend its infrastructure and store ECG data. What the branches should do is purchasing smart phones. Integrating the work flow with the ECG device in an ambulance can also shorten the D2B time since the cardiologists may have finished the ECG diagnosis before the ambulance carrying the patient arrives at the Emergency Department of the hospital. No ECG examination is required in the hospital. These constitute our future work.

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