Author's response to reviews

Title: A Cloud Computing Based 12-Lead ECG Telemedicine Service

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Author's response to reviews:

To Whom It May Concern:

I greatly appreciate the responses, suggestions, and questions provided by Dr. Pinherio, Dr. Tan, and Dr. Rubel. This draft has been revised based on their comments. The following are the new addition or revisions: Sec 1.2, Sec 1.4, Sec 2.1 (Sec 2.1 is a new addition), Sec 3.2, Sec 3.3, Sec 4.1 (Sec 4.1 is a new addition), and Sec 4.6 (the previous Sec 4.5), and Sec 5. Moreover, Figure 1, Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8 are refined based on the reviewers’ comments.

Sincerely,

Jui-chien Hsieh, Ph.D.

My replies to the reviewers’ questions are as follows:

Dr. Pinherio’s Comments and Questions:

The work submitted if of fine quality, however, answering a few notes would be of interest to improve some elements.

Minor Essential Revisions

1. One essential point in Tele-ECG is interoperability, which the authors mention in the introduction. The discussion/conclusions section should also mention explicitly the ability of this work to integrate with the heterogeneous data formats (either integrating inside, or being integrated in other existing platforms).

My Reply: In this revised draft, the discussion/conclusions section provides more explanation on the abilities of cloud computing and how cloud computing can facilitate ECG interoperability, which integrate the heterogeneous ECG data
formats on our developed platforms outside the hospitals.

Sec 4. Discussion

Sec 4.1 12-Lead ECG Interoperability

This study implemented a cloud computing based telemedicine application, which can upload 12-lead ECG reading to a cloud service from which they can be visualized on a variety of network connected devices, both mobile and fixed. This cloud application supports a variety of clinically used 12-lead ECG devices, such as Philips XML-ECG, HP compatible SCP-ECG, and Mortara DICOM-ECG by first transcoding the data from a vendor-specific format to an XML format in a public cloud computing platform, Azure.

Sec 5. Conclusions

As compared with the traditional ECG tele-consultation, this cloud-based pervasive telemedicine service can realize interoperability across various mobile and fixed devices. It greatly enhances the convenience of ECG interpretation and the efficacy of tele-consultation, as it enables cardiologists to interpret ECG ubiquitously, to access patients’ current and past ECG records across hospitals via centralized cloud database, and to provide pre-hospital diagnosis in time. Apparently, this service advances clinical work and research on 12-lead ECG telemedicine with ECG interoperability, as it establishes an open tele-consultation platform from clinic to person and from hospital to hospital.

Dr. Pinherio’s Comments and Questions:

Minor Essential Revisions

2. Taiwan is cited as an example, so a few more notes on the inherent infrastructure should integrate the paper. Are the hospitals serviced by different O.S.? How fast is the cloud connection in the different settings? Comments on heterogeneity, and also on equipment of rural areas (which were cited) should be provided.

My Reply: Section 2.1, ECG Infrastructure, has been added in this revised draft to provide more explanation of ECG telemedicine connection infrastructure.

Sec 2.1: 12-Lead ECG Infrastructure

In this study, we developed an ECG telemedicine service from clinically used
ECG devices with heterogeneous data formats, such as HP compatible SCP-ECG, Mortara DICOM-ECG and Philips XML-ECG, which are commonly used in both urban and rural areas in Taiwan. Most modern 12-lead ECG devices in clinical practice can directly export ECG reports via wired or wireless based network, such as Philips ECG XML-ECG, or indirectly export ECGs via internet through the transformation from the traditional serial transmission, RS232 or USB, to Ethernet based network, such as HP compatible SCP-ECG device and Mortara DICOM-ECG device. In this study, the Ethernet based network with an average speed ranging from 15 Mbps to 80 Mbps via TCP/IP protocol was used to transmit and receive ECGs between the cloud service and ECG devices either at a metropolitan hospital or at a rural clinic. A 3G mobile telephone network allowing ECG delivery with the speed of 1.5~3.6 Mbps was used between the cloud service and the cardiologist’s mobile phone to realize ubiquitous 12-lead ECG tele-consultation. This cloud ECG service can directly receive various ECG files from ECG devices generating ECGs via TCP/IP based network and allow a clinician to browse ECG reports via Web, which operates independently from the hospital O.S.

Dr. Pinherio’s Comments and Questions:

Minor Essential Revisions

3. Fig. 7 would be seen with more trust if it were photos of an actual device.

My Reply: Fig 7 has been replaced with the photos of an actual mobile phone.

Dr. Tan’s Comments and Questions:

This paper employs cloud computing and mobile communication technologies to realize a ubiquitous 12-lead ECG telemedicine service. The proposed service supports ubiquitous delivery and interpretation of inter-hospital 12-lead ECG reports via cell phones. It is able to offer tele-consultation for patient anytime and anywhere, and therefore, can significantly improve medical service quality and efficiency and particularly benefit patients in rural areas. This service has been evaluated and demonstrated its effectiveness by cardiologists in Taiwan. The paper is well written and well organized. This paper is recommended to be accepted if the following minor revision can be made.

1. Please change “we have design” to “we have designed” in line 2, page 9.

My Reply: Change has been made.

2. Please change “a detail 12-lead” to “a detailed 12-lead” in line 2 of Section 3.1, page 10.
My Reply: Change has been made.

3. Please change “or emergency tele-consultation is on” to “or emergency tele-consultation that is on” in line 4 of page 11.

My Reply: Change has been made.

4. How do you measure the average time for browsing an ECG report in Section 3.2 (page 11)? What tool do you employ?

My Reply:

To measure the average time to browse an ECG report on a mobile phone, a “trigger” is pre-implemented in a mobile phone. This “trigger” is a procedural SQL code which is automatically invoked by the mobile database, upon the occurrence of a data manipulation event. For example, when a cardiologist issued an ECG report query command, the trigger starts the timing until the requested ECG is successfully delivered to the mobile phone.

5. In Section 3.2, what is the specification of the mobile phone used in the experiment? Is the mobile phone capable of data encryption and decryption in real time? Please explain this in detail.

My Reply:

As shown in Figure 7, an Android based mobile phone, HTC sensation with a CPU speed of 1.2 GHz and the memory capacity of 768 MB, is used to receive ECG reports from Cloud Azure. To offer more efficient diagnosis and treatment for patients with heart diseases, cardiologists must have access to ECG reports as quickly as possible. However, the current mobile phone CPU speed does not allow ECG data encryption, decryption, and verification on the mobile phone in a timely fashion. To enhance the speed of ECG browsing on a mobile phone, ECG file encryption and decryption is carried out in the cloud instead of on the mobile phone. The overall ECG delivery procedures are as followed: (1) First, an encrypted ECG report in the cloud database is decrypted and verified in the cloud before it is sent to a mobile phone. (2) During ECG transmission, the decrypted ECG report is delivered via secured HTTPS. The ECG packet encryption and decryption are performed on the secure sockets layer. (3) Once the mobile phone receives the ECG packets successfully, the ECG file is restored on the mobile phone.
Sec 3.2 has been revised as the following:

3.2 Practice and Evaluation of ECG Tele-Diagnosis via Cell phone

Using online services via cell phones to deliver or retrieve ECG reports can effectively realize ECG telemedicine. Even when a senior cardiologist is not at the hospital, this cardiologist can timely respond to the consultation request to offer ECG interpretation and decision making support via cell phones and this cloud ECG service.

As shown in Figure 7, an Android based mobile phone, HTC sensation with a CPU speed of 1.2 GHz and the memory capacity of 768 MB, is used to receive ECG reports from cloud Azure. The panel A of Figure 7 shows the cell phone with email alert notifications delivered from cloud ECG services to remind the off-site expert cardiologist to respond to an emergency email where patients' ECG reports are attached. As illustrated on the panel B of Figure 7, the off-site expert cardiologist can easily download the attached 12-lead ECG reports, interpret the ECG, and instruct on-site physicians to prepare for the appropriate treatment via his cell phone. As shown on the panel C of Figure 7, the off-site cardiologist can use his cell phone to browse past and present ECG records of the same patient via cloud ECG database connection.

To evaluate the time needed for a clinician to receive ECG files via his mobile phone from the cloud, 100 trials of data transmission from the cloud to the mobile phone are conducted. To measure the average time to brows an ECG report on a mobile phone, a “trigger” is pre-implemented in a mobile phone. This “trigger” is a procedural SQL code which is automatically invoked by the mobile database, upon the occurrence of a data manipulation event. For example, when a cardiologist issued an ECG report query command, the trigger starts the timing until the requested ECG is successfully delivered to the mobile phone. The average time for browsing an ECG report without data verification in the cloud is approximately 5.65± 0.38 secs, but the average time for browsing the file with data verification in the cloud is approximately 6.28± 0.13 secs. While these telemedicine applications ensure data security, the mechanisms of data encryption, decryption and verification in the cloud and in the process of being delivered to the mobile devices slightly delay data visualization and thus have a little toll on the time efficiency of the programs.

6. As stated in Section 3.3 (page 12), Fig. 8 is a categorized ECG. Please describe what categorization method has been considered with cited papers.

My Reply:
In Sec 3.3, the ECG categorization for e-learning in this study is based on the recommendation provided by the American College of Physicians (please see reference [31]).


7. Quality of some figures is not good enough, please refine them.

My Reply:

Figure 1, Figure 6, and Figure 8 are refined with the increased pixel resolution.

Dr. Rubel’s Comments and Questions:

This is an interesting paper showing how cloud computing could improve remote, standard 12-Lead ECG interpretation services by facilitating inter-hospital 12-Lead ECG consultation and overcome the limitations of vendor-specific solutions while reducing the overall hardware and software possession costs. The paper is comprehensive, scientifically and technically sound and well written, and there are only a few issues that we would ask the authors to take into consideration to improve the overall quality of the paper.

Minor Essential Revisions

1. There are a few typing errors in figure 4 (Blob, not Blog; ECG Decoding, not ECG Decording; Data encryption, Data verification, not Deta) and in figure 5 (SQL command, not commond; Data encryption, Data verification, Data Decryption, not Deta).

My Reply: The typos in Figure 4 and Figure 5 are fixed.

2. There are also a few typing errors all over the manuscript, for example page 4: “cannot provide”, not provides; page 9: “we have designed”, not design; page 10: “a detailed 12-lead ECG report”, not detail; page 11: “can easily and quickly or rapidly browse”, not rapid; page 11: “clinically-used”, not clinically-use; page 13 section 4.3: “we designed”, not design; page 13 section 4.3: “telecommunication services do”, not “telecommunication service does”; page 17 reference 24:
“Windows”, not Wndows.

My Reply: Changes have been made.

Discretionary revisions

3. The paper would benefit from amending or completing some statements about SCP-ECG and from citing or discussing some reference papers in the field of serial ECG analysis and advanced, easy to use ECG based pervasive telemedicine architectures.

My Reply:

An important European ECG project, EPI-MEDICS, is mentioned in Sec 1.4 to describe the transition from the traditional hospital-based cardiac care services to the newly developed pervasive ECG telecare services, as well as EPI-MEDICS system architecture and the advantages of using serial SCP-ECGs.

Sec 1.4 12-lead ECG Telemedicine and Pervasive Health

A pioneer ECG telemedicine project, “Enhanced Personal, Intelligent, and Mobile system for Early Detection and Interpretation of Cardiac Syndromes (EPI-MEDICS)”, was created to change the traditional hospital-based cardiac care services to the personalized and non-hospital-based cardiac telecare services [13-14]. In this European project, a self-developed ECG device, Personal Electrocardiogram Monitor (PEM), has the following functions: (a) synthesizing 12-lead ECG from the measured 3-lead ECG, (b) storing serial ECGs in the standard SCP-ECG format, (c) storing personal health record (PHR) in the XML format, (d) containing artificial intelligence based ECG interpretation, and (e) transmitting ECGs with PHR to remote care providers via Global System for Mobile Communication (GSM). This device greatly helped enhance the quality of cardiac telecare services because remote cardiologists can therefore offer timely diagnosis and treatment order for patients with heart diseases. Additionally, the integration of serial SCP-ECGs allows the cardiologists to access patients’ past and current ECG records, as well as PHR, which greatly facilitate the process of performing diagnosis and treatment with more comprehensive references to patients’ medical records [15-16].


[14] Atoui H, Télisson D, Fyn J, Rubel P: Ambient Intelligence and Pervasive Architecture Designed within the EPI-MEDICS Personal ECG Monitor, Int J of


4. Indeed, as stated in section 3.1, one of the “most important references for clinicians to determine whether the patient is at an immediate risk of dying” is to grant a timely access, anytime and anywhere, to both the patients’ “past and current ECG records”. This statement is strongly supported by Luepker RV (“Delay in acute myocardial infarction: why don't they come to the hospital more quickly and what can we do to reduce delay?”, Am Heart J 2005;150(3):368–70) and by the ACC/AHA/ACP-ASIM Task Force (Kadish et al, ACC/AHA clinical competence statement on electrocardiography and ambulatory electrocardiography: a report of the ACC/AHA/ACP-ASIM Task Force on Clinical Competence (ACC/AHA Committee to Develop a Clinical Competence Statement on Electrocardiography and Ambulatory Electrocardiography), Circulation 2001;104:3169–78), that highly recommends, to electrocardiogram readers, to compare the current ECG with previous recordings to enhance the accuracy of some diagnoses, in particular of acute myocardial ischemia. Performing serial ECG analysis is however only possible if we are able, thanks to services as the ones proposed in this paper, to timely retrieve almost one previous ECG, if any, and if the record has been stored in a format that is compatible with the serial analysis software and/or with the provided ECG viewer. SCP-ECG could be as suggested by the authors one of these interchange formats.

My Reply:

I am very grateful for Dr. Rubel’s suggestions of the useful references. These references are now cited in the Sec 3.1 [29-30] . The discussion of SCP-ECG as one of the suggested interchange format for ECG diagnosis has been added in Section 4.6 (please see my reply to Question 6).

5. However, in section 1.2, the authors state that most ECG manufacturers having implemented SCP-ECG “change a portion of the format using
vendor-specific rules, especially the ECG waveform data encoding rules”. This is not exactly true, as the waveform data encoding rules are an essential part of the SCP-ECG standard and thus must be strictly followed to be compliant with the standard. Only section 9 can be manufacturer specific, for example to store computed measurements that are not yet standardised. Some manufacturers abusively use this facility to store their textual interpretation report and sometimes omit to store the standard lead by lead measurements in section 10 and the textual interpretive statements in section 8. It is the customer’s role to demand the manufacturers to provide solutions that are fully compliant with the SCP-ECG protocol, and to select only those products that are really compliant with the standard. To my knowledge, almost all well known manufacturers have fully implemented SCP-ECG, but sometimes omit to tell that they can provide a product that is fully compliant with SCP-ECG because “customers are not requesting it”.

My Reply:

In Taiwan, Philips trim series (vendor-specific XML format) and HP pagewriter (SCP-ECG compatible; which adopts basic SCP-ECG data structures but changes several important sections, such as the byte-length of section 1 and Huffman encoding rule in section 128) are commonly used ECG devices in clinical practice. In fact, ECG dealers in Taiwan do not provide hospitals with ECG waveform data extraction services unless hospitals purchase vendor-specific ECG viewers. Although vendor-specific ECG viewers can export ECG waveform data, it is O.S. dependent and ECG waveform encoding rules are unknown. As a result, these vendor-specific ECG formats impede the advance of ECG applications.

Based on the suggestions of Dr. Rubel, Section 1.2 is modified as the following:

Sec 1.2

In 2002, Open-ECG, an international academic organization, promoted the development of computerized 12-lead ECG by providing researchers with technical references of 12-lead ECG data formats, including International Organization for Standardization (ISO) approved Standard Communication Protocol–ECG (SCP-ECG), Food and Drug Administration (FDA) proposed Extensible Markup Language based ECG (XML-ECG), and National Electrical Manufactures Association (NEMA) recommended Digital Imaging and Communications in Medicine based ECG (DICOM-ECG) [1-4]. However, several ECG manufactures do not completely adopt the open protocol standards. Instead, they develop vendor-specific ECG data formats and ECG waveform encoding rules. Consequently, 12-lead ECG data formats are heterogeneous and vendor-dependent in clinical practice. With the help of OPEN-ECG, hospitals can develop 12-lead ECG e-diagnosis instead of paper-ECG by extracting the
waveform data from several ECG instruments [5-6].

6. In section 4.5, the authors soundly state that “we need an open and unified ECG data format, which resembles the open and unified medical image format DICOM”. But this was exactly the reason for developing SCP-ECG at the end of the eighties, concurrently with DICOM, to overcome the “inconvenient monopoly situations” of the manufacturer specific solutions (Willems et al “A standard communications protocol for computerized electrocardiography”, J Electrocardiol.1992;24 Suppl:173-8). SCP-ECG was designed from the beginning both to encode and store any type of diagnostic ECG signal and every technical or clinical information cardiologists might need to interpret the ECG, an approach that has also been adopted later on by DICOM. Around eighty percent of the manufacturers of that time participated in the effort, and a first SCP-ECG standard was set up as a European pre-Norm in 1993 (prENV 1064: 1993) and extensively tested within the Open European Data Interchange and Processing for Electrocardiography (OEDIPE) project (Rubel et al “New trends in serial ECG analysis”, J Electrocardiol.1993;26 Suppl:122-8). The wireless transmission of high quality 12-lead SCP-ECG records from the ambulance was demonstrated during the G7 conference on the Information Society in Brussels in 1995 using GSM based mobile phones and the same year for the follow up of the heart diseased French minister Jean-François Deniau during his solo transatlantic race, using INMARSAT C. The main reason, in my opinion, for SCP-ECG not having taken over as largely as DICOM has, is the difficulty of implementing and maintaining secure and cost effective ECG repositories, hospitals being usually reluctant to facilitate remote access to their HISs (for images they usually only provide a CD-ROM). The cloud computing solution proposed in the present paper should help overcoming this gap and provide additional means to easily implement SCP-ECG and converters between different ECG standards and even manufacturer specific solutions (Jumaa et al “XML based mediation for automating the storage of SCP-ECG data into relational databases”, IEEE Comput. Cardiol., vol. 35, pp. 445–8, 2008). Another open solution, which is based on a very similar architecture than the one presented in this paper, is the pHealth approach that has been proposed by the EPI-MEDICS project, where the patient’s previous ECG records and the clinical history are stored on the patients’ or the GPs’ smart media card and the newly recorded ECG together with the previous and/or the reference ECGs are either automatically or on demand transmitted to an alarm server which itself notifies the attending cardiologist or a mobile expert to review the ECG(s) and the health care record by remotely accessing the alarm Web server and by providing means to forward his/her recommendations to the requestor (Fayn et al, “Towards a Personal Health Society in Cardiology”, IEEE Trans Inf Technol Biomed. 2010;14(2):401-9, Atoui et al, “Ambient Intelligence and Pervasive Architecture Designed within the EPI-MEDICS Personal ECG Monitor”, Int J of Healthcare Information Systems and Informatics. 2008;3(4):69-80).
My Reply:

I am grateful for Dr. Rubel's suggestions. Open ECG format standards, such as SCP-ECG, DICOM-ECG, and XML-ECG, are all essential for ECG interoperability and telemedicine. The advantages and disadvantages of these ECG formats for cloud application are discussed in Sec 4.6 as follows.

Sec. 4.6

Despite the progress of mobile computing and the benefit of applying m-health onto cloud computing, the development of 12-lead ECG telemedicine is impeded by heterogeneous vendor-specific ECG data formats where ECG waveform encoding rules are unknown. If the open ECG standards with open ECG waveform encoding rules, such as SCP-ECG, DICOM-ECG, and XML-ECG, can be adopted by most ECG manufactures, ECG interoperability and telemedicine applications can be better realized.

The advantage of SCP-ECG is the size of 15 KB~30KB with compressed ECG waveforms. Therefore, SCP-ECG can be used to deliver ECG without being limited by the bandwidth of mobile phone network, and it can also save the storage charges in the cloud database. Moreover, SCP-ECG is capable of storing serial ECGs, which is useful for clinical ECG diagnosis. The major disadvantage of SCP-ECG is its binary structure, which cannot be easily integrated with text based PHR. On the other hand, DICOM-ECG with the file size of 250 KB and with uncompressed waveforms can be integrated with numerous medical images stored in PACS at the hospitals to enhance the efficiency of medical data management. However, the cloud application on data retrieval from PACS has not been fully realized because most hospitals usually do not allow remote clinicians to retrieve data stored in PACS, and the huge image database in PACS is expensive for cloud applications. As compared with SCP-ECG, XML-ECG with the size of 500KB and with uncompressed waveforms might not be suitable for ECG delivery via mobile telephone network and for ECG storage in the cloud database. Nevertheless, text based XML format is human readable and can be easily integrated with patients' PHR. Additionally, as compared with the binary based ECG formats, the cross-platform XML ECG document can be visualized and easily edited via web browsers and cloud application without the limitations of computer O.S. In conclusion, each of the above three open-standard ECG formats has pros and cons when it is used in ECG telemedicine. It is clear that open-standard ECG formats are superior to vender-specific ECG formats. To advance the clinical research of tele-cardiology, we need open ECG data formats, such as binary based SCP-ECG, DICOM-ECG, and text based XML-ECG. In this way, ECG interoperability can be better realized through the conversions among these open data formats.