Cellular Phone Based Online ECG Processing for Ambulatory and Continuous Detection

X Chen, CT Ho, ET Lim, TZ Kyaw

Institute of Infocomm Research, SG, Singapore

Abstract

A cellular phone based online ECG processing system for ambulatory and continuous detection has been developed. It aids cardiovascular disease (CVD) patients to monitor their heart status and detect abnormalities in their normal daily life. This system is a solution to supplement the limitations in conventional clinic examination such as the difficulty in capturing rare events, off-hospital monitoring of patients' heart status and the immediate dissemination of physician's instruction to the patients.

1. Introduction

Holter Systems are available for cardiovascular patients in recording the cardio activities of patients with cardiovascular diseases as demonstrated by Lanza GA *et al* [1]. However, Holter systems do not detect arrhythmias when patients are out of the hospitals. Moreover, Holter Systems are unable to automatically transmit information at the moment when abnormal cardio activity is present.

In 2001 there have been notion of telemedicine using the mobile phone by Negoslav Daja *et al* [2] with power efficient algorithms for Paroxysmal Atrial Fibrillation by G Schreier *et al* [3] being devised concurrently. In 2002, F Gouaux *et al* [4] did propose a smaller and feasible device for telemedicine. However, it was still insufficient due to the lack of processing of the raw ECG signals on their devices.

E Kyriacou *et al* [5] designed a telemedicine framework yet it did not discuss the issue of processing raw ECG signals on the mobile device. Guidelines for designing telemedicine for the future were given by B. Woodard *et al* [6] and P Rubel *et al* [7]. With the proliferation of smaller and more wearable ECG sensors by Santiago Led *et al* [8] and Thaddeus R.F. Fulford-Jone *et al* [9], we can observe the increasing importance and reliability of telemedicine, W Lim *et al* [10] as well as in telemedicine technology, J Rodriguez *et al* [11].

In this paper, we differentiate our proposed framework with the following factors:

- Enabling of online service for ECG signal to be processed on mobile devices in real time and transmission of abnormal data upon its detection.
- Transmission of only abnormal ECG data, thus saving transmission costs and preventing network congestion
- Onboard processing producing immediate results even when there is outage in other parts of the framework
- Fusion of ECG data and intensity of body movement to provide a context aware ECG analysis for ambulatory and continuous monitoring and examination
- Continuous monitoring of patient's cardiac status anytime, anywhere

We will explain the researched framework of continuous monitoring of patients with cardiovascular diseases in section 2. In section 3, we will explain the technology that underlies the Mobicare Cardio Monitoring System. We demonstrate the successful trial usage in a simulated environment and on an individual in section 4. Finally, concluding in section 5 with our foresight in future works.

2. Mobicare cardio monitoring system

The Mobicare Cardio Monitoring System consists of a cellular phone embedded with real time ECG processing algorithms (MobiECG), a wireless ECG sensor [12], a web based server, a patients' database and a user-interface.

Figure 1 Mobicare Cardio Monitoring Framework

The wireless ECG sensor used in this system serves to capture one channel ECG, one 3D accelerometer signal and to transmit those signal data via Bluetooth to cell phones. The key role of MobiECG here is to works as a local processor to process data in real time. It receives ECG and accelerometer data from wireless ECG sensor via Bluetooth, filters the data, detects QRS complex, identifies Q onset and T offset, and calculates intensity of patient's body movement using obtained accelerometer data. A context-aware(patient's activity) ECG processing is carried out by MobiECG and it will send the abnormal ECG data over a cellular network (GPRS/3G) to hospitals or care centers to alarm physician only when it detects abnormal ECG signal.

In order to avoid the continuous transmission of normal ECG data to physicians and to prevent the flooding of the telecommunication channel, no ECG data is sent out by MobiECG when abnormality is not detected. The duration of the ECG data forwarded is from a fixed amount of time before the point of detection followed by a similar fixed amount of time after the point of detection. This is done to provide a more concise overview of the data that surmounted to the detection of the abnormality in question.

The data is especially packed into data packets using a self-designed enhanced communications protocol, Medical Data Transmission Protocol. This scalable protocol is able to cater to periods of time when the data load is large, to prevent starvation of a certain data, or employ minimal bandwidth when the data load is low.

A Web server is set up to receive data from the cellular network and route the data to terminals in hospitals or care centers. The physicians at the hospitals or care centers will examine the ECG data through the user interface and further verify/diagnose whether the patient is at high or low risk, so the hospitals or care centers will act accordingly by sending ambulance immediately or give the patient an instruction through GPRS/3G. A patients' database is developed to record patients' personal particulars, clinical history and all ECG data logs.

3. Mobicare technology

The Mobicare Monitoring System is divided into modular subcomponents. These components are able to function individually in the absence of the other components.

3.1. ECG processing on mobile telephone

The mobile phone in use for this project is currently the Dopod 595 windows mobile enabled phone. It has a Samsung 300 MHz processor and features the ARM5 instruction architecture set. However, our earlier implementation has also proven that the program can also be executed on an O2 XphoneII. The O2 Xphone II has T1 OMAP 730 processor and features the ARM4 instruction set architecture. The difference is 3G and GPRS can be used as the communication medium in the former while only GPRS can be used as the communication medium in the latter.

Figure 2: Mobicare Cardio Monitoring Hand phone

The data received from the ECG Sensor is processed by MobiECG to decode the ECG and accelerometer data. The processing is done as and when the data is received.

There are various reasons that contributed to the abnormality detection and processing of the raw data at this stage and not the later stages when the data is at the server or client terminal. One of the most important reasons is that in the event of a network outage that will disrupt communications between the mobile phone and server or client terminal, the detection processing cannot be done if it is on the server or client terminal. It is this self-sufficient online detection processing on the mobile phone that ensures the patient gets informed of the latest happenings of his own heart activities anytime, anywhere.

The other reason would be to reduce the amount of data transmitted to the server. By transmitting data that are suspected of being abnormal, the mobile telephone is not taxed by the constant transmission. Consequently, the transmission of suspected the data do not flood the GPRS/3G channels and internet with unnecessary packets of data. Flooding the internet invokes the quality-of-service mechanism to deter internet hogging and this would disrupt the real-time transmission of suspected data when it is a genuine case of abnormality.

3.2. Mobicare phone monitoring GUI

The processed data from MobiECG is visualized as a graphical display on the mobile phone. Currently, the ECG data and accelerometer data are displayed as graphs in real-time. In addition, the heart rate and QT interval are displayed as readable measured values and marked on the ECG data graph as red and green lines respectively. The GUI also displays the detected conditions of Atrial Fibrillation (AF) and Maximum Heart rate (MH). And the body movement intensity can be seen on the accelerometer running graph.

On the same panel of the visualized waveform, there is a communication portal. This portal allows either the program to inform the user of any abnormalities detected by the detection algorithm or instructions as disseminated by the clinicians. This portal is important as it informs the user of the latest information with regards to the health of his heart.

3.3. Medical data transmission protocol

The mobile phone is required to transmit the suspected abnormal data to the clinician. A special packet structure for the deliver of such information is formulated to package the information for delivery. This special structure is scalable as more information is required by the clinician in the future and the transmission protocol will be revised to ensure that the maximal amount of required information is delivered without compromising the freshness of the data.

3.4. Mobicare server

The Mobicare Server functions as a centralized information exchange. The data transmitted via GPRS/3G from the mobile phone arrives at the server and becomes a streaming feed that clients of the Mobicare Server can subscribe to. Multiplexing of the feeds is handled by the server. Clients need only indicated their preference of the feeds and those feeds will be streamed to them accordingly.

The Mobicare Server also facilitates the communication between the patient and clinicians, allowing immediate follow-up procedures if required.

3.5. Mobicare terminal monitoring GUI

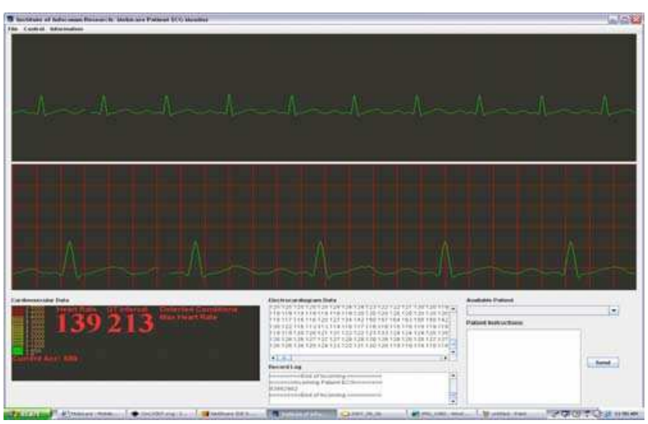

Figure 3: Mobicare Cardio Monitoring GUI

The monitoring graphical interface enables clinician to visualize the feeds that they are subscribing to. This monitoring interface is web-based and lightweight. Hence, making is convenient for clinicians to access it from any of their hospital computer terminals. The top window displays the overall ECG wave pattern that is being received at that moment. The bottom window with the grid lines is a modified of ECG graph paper that facilitates the clinician to verified and calculate the RR internal of the ECG wave pattern. The auxiliary window on the bottom left features additional information tied to the current ECG wave pattern. Currently, it has a body movement intensity reading, the condition as detected by the mobile phone, the heart rate and QT interval measurements from the current ECG signal.

4. Experiments

4.1. Experiments setup

Experiments were set up to validate the framework that we have proposed and implemented. There were 2 separate experiments. The purpose of the first experiment was to validate the correct usage and reliability of the framework under controlled simulated conditions. The purpose of the second experiments was to validate the feasibility usage on an average person going about his/her daily activities.

In the first experiment, we are using a MPS450 multiparameter simulator from FLUKE Biomedical [13] to generate the raw ECG signals. The MPS450 is able to generate raw ECG signals that simulate a patient with various heart conditions. The raw signal is transmitted via 2 electrodes to the Alive Technologies ECG sensor before being transmitted to our Mobicare Systems for processing and evaluation.

In the second experiments, we asked an average healthy person to wear the ECG sensor and carry the mobile phone with our embedded program in his daily activities. His daily ECG signal was captured and transmitted to the processing and evaluation program on the Mobicare System via the 2 electrodes ECG sensor.

4.2. Experimentations

In the first experiment, we used the MPS450 multiparameter simulator to generate 3 signals, a normal sinus rhythm of 80 beats per minute – heart rate of a normal person but not at rest, a normal sinus rhythm of 140 beats minutes – heart rate of a normal person doing strenuous exercise and a supra-ventricular rhythm – a person with the cardio-vascular condition of Atrial Fibrillation. And the conditions for alarm for both experiments are a normal sinus rhythm of 140 beats – indicating a very fast heart beat and hence might have cause for concern, and the Atrial Fibrillation condition.

In the first experiment, we successfully demonstrated that the signals are only shown on the Mobicare

Monitoring GUI when the latter two conditions were simulated with signals generated by the MPS450 multiparameter simulator. This demonstrated that the ECG Signal Processing has correctly identified the relevant abnormal conditions and proceeded to forward the detected conditions to the Mobicare Monitoring GUI - assuming that the GUI will be on a monitoring in the relevant medical authorities.

In the second experiment, we have attached the ECG sensor onto a person as a test subject. The test subject was then asked to go through a series of non-strenuous activities like moderate jogging and stair climbing shown in Figure 4. The ECG signal though received, processed and recorded on the mobile phone was not sent to the Mobicare Monitoring GUI as none of the two alarm conditions was fulfill.

Figure 4: MobiECG Processing ECG Signal in Real Time

There were cases when ECG data was forwarded, however these were due test subject's heart rate crossing the threshold of 140 beats per minute signaling that his heart beat is too fast. These are pre-cautionary in nature. However, over all the Signal Processing Program was able to identify correctly under normal circumstances, the ECG signal should not be forwarded.

5. Conclusion and future works

This system provides a good solution for ambulatory and continuous monitoring when CVD patients are out of hospital and going about their daily life. It enables hospitals to respond immediately when something happens to patients when they are at home, at work or on travel. Currently the ECG processing algorithms embedded in MobiECG is able to detect in real time irregular heart rhythm, measure QT interval and identify atrial fibrillation. More function modules can be added on to detect other heart problems. Moreover, from the point of early detection, MobiECG is useful for normal people but with potential heart problem, it helps them to detect abnormality early when no symptoms are present and prompt them for a medical check-up so that they can arrange for therapy as early as possible.

We are progressing towards the stages of conducting clinical trials. We are validating our feasibility studies as well as the reliability and robustness of our framework. We are planning to work with clinicians to gather feedback on our framework as well as to identify other key data that will be helpful in improving the feasibility of Mobicare Monitoring Systems to provide better telemedicine monitoring.

References

[1] Usefulness of the addition of heart rate variability to Holter monitoring in predicting in-hospital cardiac events in patients with unstable angina pectoris, America Journal of Cardiology 1997, Lanza GA et al

[2] Telemonitoring in Cardiology - ECG Transmission by Mobile Phone, Annals of the Academy of Studenica 4/2001, Negoslav DAJA et al

[3] An Automatic ECG Processing Algorithm to Identify Patients Prone to Paroxysmal Atrial Fibrillation, Computer in Cardiology 2001, G Schreier et al

[4] Ambient Intelligence and Pervasive Systems for the Monitoring of Citizens at Cardiac Risk: New Solutions from the The EPI-MEDICS Project, Computers in Cardiology 2002, F Gouaux et al

[5] Multi-purpose HealthCare Telemedicine Systems with mobile communication link support, BioMedical Engineering Online March 2003, E Kyriacou et al

[6] Wireless Telemedicine: The Next Step, Proc of the 4th IEEE Conference on Information Technology Applications in Biomedicine UK 2003, B. Woodward et al

[7] Beyond EPI-Medics, 2nd OpenECG Workshop 2004, Berlin, Germany, P Rubel et al

[8] Design of a Wearable Device for ECG Continuous Monitoring Using Wireless Technology, 26th Annual International Conference of the IEEE EMBS 2004, Santiago Led et al

[9] A Portable, Low-Power, Wireless Two-Lead EKG System, 26th Annual International Conference of the IEEE EMBS 2004, Thaddeus R.F Fulford-Jones et al

[10] The Reliability of Electrocardiogram Interpretation in Critically Ill Patients, 25th International Symposium on Intensive Care and Emergency Medicine 2005, W Lim et al

[11] Real-Time Classification of ECGs on a PDA, IEEE Transactions on Information Technology in Biomedicine, Vol 9, No.1 March 2005, J Rodriguez *et al*

[12] Alive Heart Monitor http://www.alivetec.com

[13] Fluke Biomedical MPS450 Multiparameter Simulator http://global.flukebiomedical.com/busen/products/MPS450.htm?catalog_name=FlukeUnitedStates&Category=FB-MPPS(Fluke Products)

Address for correspondence:

Xiang, Chen
21, Heng Mui Keng Terrace Singapore 119613
xchen@i2r.a-star.edu.sg