Cardiovascular remote monitoring system with Electronic Health Record

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Cardiovascular disease is the leading cause for death in developed countries. Measuring and Tracking the heart parameters with less cost can benefits the public health directly. This paper proposes a cardiovascular remote monitoring system which collects data from ubiquitous computing device with ECG, Blood Pressure (BP), and Oximeter sensors. The monitoring device has USB connectivity which is widely used with Personal Computer and many other portable devices. It stores the data at local and sends a copy to data processing center for analysis. The communicating message follows HL7 Version 3 standard and can be used to exchange information among different Health Information Systems. Users can manage their own health information by visiting the website hosted at server side. The processing center includes a Decision Support System which analyzes cardiovascular data with related models. It also learns from doctor's decisions for self wellness purpose. The whole system is portable, low cost, and easy to use.

Keywords: ubiquitous computing, Pulse Oximeter, ECG, remote monitoring, HL7

1. INTRODUCTION

In North America, heart disease is the leading cause of death, and almost two thirds of the cardiac deaths occur outside the hospital. Epidemiological data suggests that proper pre-hospital care may reduce the fatality rate of acute myocardial infarction (AMI) than the intensification of treatment in hospital (1). A general coronary cardiovascular risk can be evaluated by computerized calculators or tables. If an individual with high cardiovascular risk factors can be identified, preventive treatment and strategies, such as drug treatment, diet change and exercises, will lead to improvement for risk factor control.

This paper is to develop a remote monitoring system for the acquisition, transfer, demonstration and evaluation of diverse patient vital signs, such as electrocardiogram (ECG), percutaneous blood oxygen saturation (SpO_2), blood pressure etc. With this information, the cardiac risk assessment can be done routinely to evaluate the patient's circulatory situation.

This Home Monitoring System (HMS) can get higher quality data than Office/Clinic System. Without anxiety at clinic, some special effects can be avoided such as White Coat Hypertension. Related BP measurement had been performed for 524 patients with hypertension from a single general practice with 12 month follow up. (2) 89% of the patients completed the trial which shows high user acceptance. As the result, BPs fallen down 5.2/3.2 mmHg and control rates reached 44.8% from original 29%. The system uses short interval successive BP reading to give better prediction. Research shows that 1 minute successive BP readings result in a much closer value to the ambulatory BP. (3) The stroke risk will reduce 40% when BP is controlled within recommended levels.

The HMS is widely applicable to many special fields for cardiac care. It can help physicians to recognize 91% of lead related Implantable Cardioverter-Defibrillator (ICD) complications and perform quick reactions. (4) HMS had been used for heart failure patients in elderly population. It can achieve similar result as specialist care. (5) Real time monitoring can be performed with acceptable latency high fault tolerant. Client side computer can detect cardiac risk with build-in criteria and training data.

The proposed remote monitoring system is designed to be portable. All sensors can be easily add to or remove from the device so that the system can reach the balance of usability and convenience. It also makes the system wildly applicable for different environments other than just home or clinical office. We can collect cardiovascular data under various circumstances. It provides more valuable data which is helpful to better understand user's cardiac condition.

Electronic health record (EHR) keeps patients' medical records in digital format. It facilitates the transmission, reuse and research with those records. Further processing and assessment will be done at control center to take the advantage of large quantity

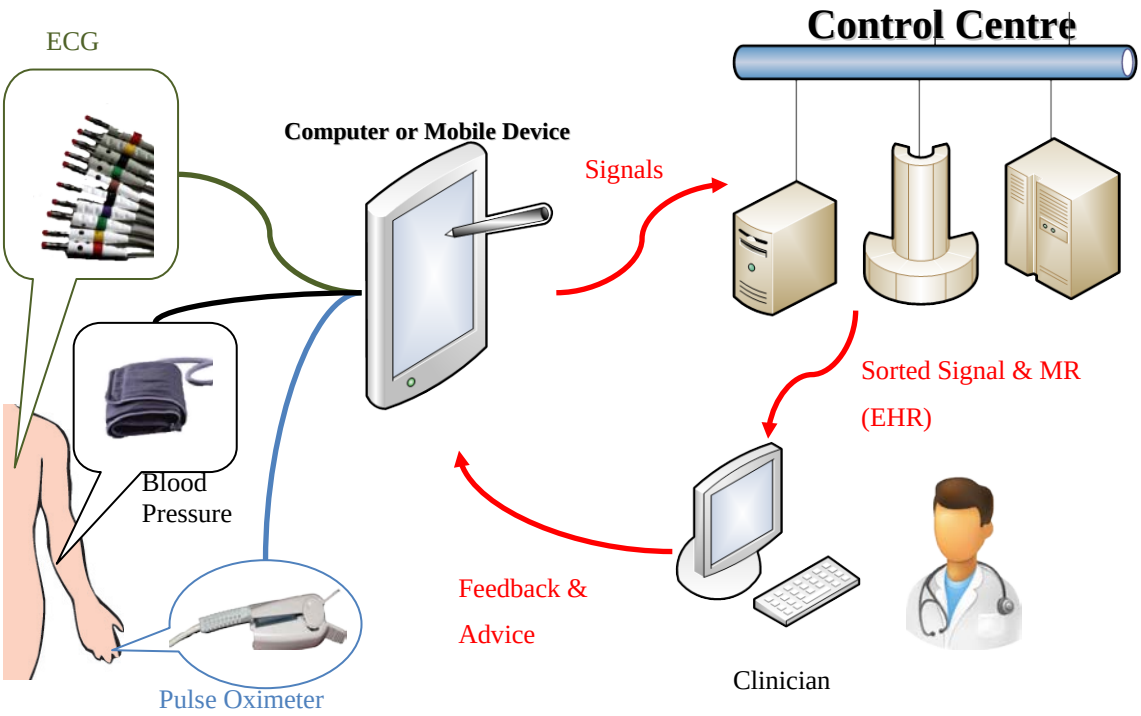

Figure 1 Overview of the Home Monitoring System for cardiovascular vital signal collection and transfer

of EHRs. The automated assessments improve the detection of high risk patients and lower the cost. (6)

With the popular use of EHR, an automatic calculation for cardiovascular risk will free the manually calculation from clinicians. Therefore, cardiac risk appraisal can be done for all patients. With some patients missing risk factor information in their EHR and some patients with high cardiac risk factors, a Remote Monitoring System for collection transmission of major cardiac vital signs will be beneficial for cardiac risk monitoring and earlier stage Cardiovascular Disease diagnosis.

The system provides USB connectivity which can easily works with personal computers and may portable devices. This design reduces the cost for building a whole system and makes it much cheaper than traditional medical devices.

2. System Design

The system includes four modules to handle the data acquisition, transfer and local storage. The four modules are (Figure 1): Electrocardiogram Sensor, Pulse Oximeter Sensor, Non Invasive Blood Pressure Sensor, a computer or mobile device collecting vital signs and transmitted to Control Center.

This computer collects and transmits vital signs. The requirements for this system: fit to the small free space; a compact construction tolerant both to the bad mechanical and electromagnetic conditions; easy connection to the patient's body for vital sign collection; communication over the wireless connection, secure data transmission.

The system can collect the following vital signs: Up to 3-lead ECG, Percutaneous Blood Oxygen Saturation (SpO_2), Heart Rate (HR), Non-Invasive Blood Pressure, Stroke Index, Cardio output, Arterial Stiffness Index.

Since patients have variable risk at different time periods, whole day model will be established during the training period. Usually some measurements are significantly lower at night time such as systolic blood pressure, diastolic blood pressure, pulse rate etc. (7) The system will create different criteria for risk detection based on training data.

The system applies Health Level 7 (HL7) standard to information. It organize information for instances according to Reference Information Model (RIM) which is the cornerstone of HL7 Version 3. The control center provides web service interface to external Hospital Information System (HIS) so that doctors and health care personnel can easily retrieve information right after being authorized by the patient. Connections are verified with hand-

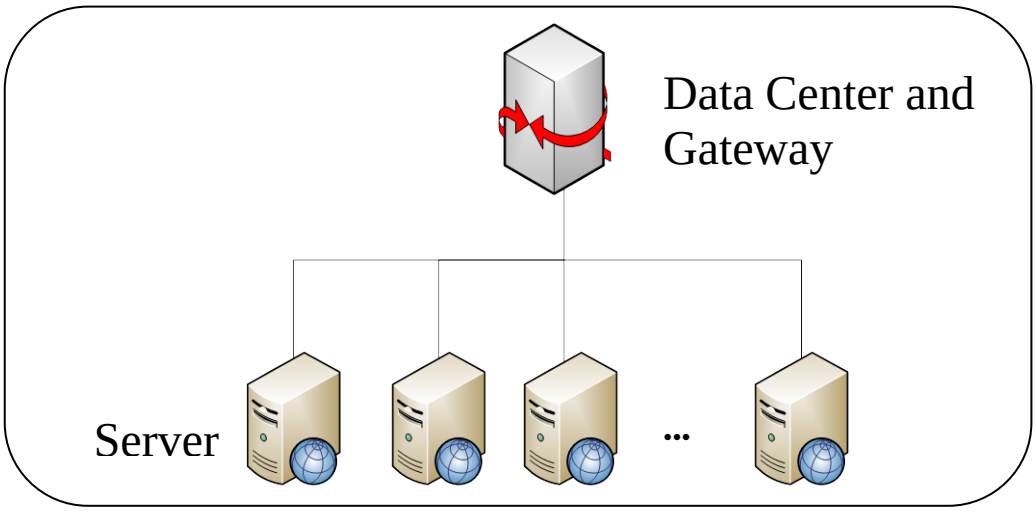

Figure 2: Distributed Structure of Control Center.

shake mechanism before starting a communication. The information is in XML format which follows the V3 Clinical Document Architecture (CDA). Medical Record is stored in predefined data structures and concepts such as Message, Segment, Fields, Table, etc. This information can be migrated into different HIS systems. It also can be interpreted by web application which is system independent. Doctor's advices and feedbacks are given with different priorities. In this model, patient's information can be used by different Health Care Institutes with less cost.

Control Center accepts two types of data: real time monitoring data and offline monitoring data. Real time monitoring aims at detecting serious heart condition in a timely manner. Real time data are bytes (value ranged from 0 – 255) transferred in binary format in order to reduce bandwidth consuming. The standard sampling rate is 200 points per second and can be reduced to 100 or 50 points per second based on the performance of the computer or portable device. Once the connection is initialized, device will send data every second which means up to 200 bytes per channel. The maximum capacity of real time data package contains 3-lead ECG and 1 pulse wave data. A modern server can easily handle more than one hundred connections with high quality service at the same time.

Control Center has Distributed Structure to improve the Quality of Service. The Gateway is responsible for load balance and server management. It accepts connection requests and forwards them to different servers. Local server will receive high priority for the connections which means servers are likely to serve local users first. Those servers which can work individually, will process the messages in detail. We can easily maintain servers in the system and problem with one server will not affect the system in this way. Servers will select typical and abnormal monitoring data with the statistic logs (monitoring time, maximum, minimum, average of monitoring values, etc) and upload back to data center for future references. Data center has ability to trace the usage of specific user based on the routing records.

The abnormal ECG or Pulse Wave forms will be detected at server side. Actions might be taken after the data is reviewed by medical professionals. Control center will contact the relatives or emergency department in some predefined situations.

Offline data will be generated at client side regarding to the usage. It also includes the typical and abnormal monitoring data with the statistic logs. The system provides a web based application for user to manage monitoring records. Users can easily find out their health condition among specific time period with the help of system assessment. Doctors' advice may add to the system when review is done.

3. Discussion

A simplified system was designed to test HMS. Qualified people were randomly invited to our project. The involved user must have medical record from hospital and internet access at home. We compare the cardiac risk from HMS and medical record to verify the accuracy. Network performance is tested by transmission over internet. 46 patients (age from 23 to 64, Mean 46.479, SD 12.952)

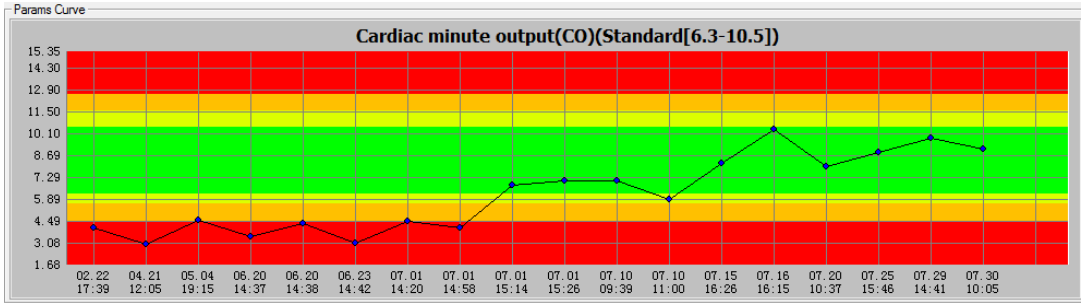

Figure 3. Health Curve that shows the improvement of Cardiac Output

sent back 383 sets of data. All of them were accepted by the control center successfully. 379 records can be recognized and assessed successfully. Most users gave positive feedback for the system and willing to take long term monitoring for next phase of testing.

Continue Monitoring makes more sense to end user for their health condition. With the tracking of cardiac risk or other parameters derived from pulse wave or ECG, user can easily figure out the effect of medicine they are taking or exercises they are doing. Doctors have the ability to give more accurate advices in time. Figure 3 shows the improvement for Cardio Output achieved by user after several months' exercises. Two standards have been applied on HMS result evaluation: record based standard (based on single record) and personal based standard (based on records of a person). 44 records from 17 users are evaluated as low risk. 256 records from 39 users are sorted as middle risk. 78 records from 22 users are assessed as high risk. Personal based evaluation shows that 5 users are in low risk, 29 users are in middle risk, 12 users are in high risk.

HMS records had been reviewed by doctors. The result shows highly correlation between HMS records and medical records. Over 60% HMS records have very similar cardiac risk level as medical records.

ECG and Pulse Wave data are stored and transmitted in binary format to facilitate network communication. A record of 10 minutes Monitoring data (single pulse wave and 3-lead ECG with collecting rate 200 points per second) will transfer about 500 KB data over the network which can be finished within 1 minutes by a normal broadband connection (cable or DSL).

4. Conclusion

We designed a Home Monitoring System to evaluate the cardiac risk automatically. The system store and transfer data in Electronic Health Record format to improve data usability. The system is widely applicable to different user groups and establishes close connections between users and doctors. User acceptance for the system is higher than the traditional devices due to the lower price, portable size and convenient communication.

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