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The IoT-based heart disease monitoring system for pervasive healthcare service

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Abstract

In China, most of heart attack results in death before the patients get any treatment. Because the traditional healthcare mode is passive, by which patients call the healthcare service by themselves. Consequently, they usually fail to call the service if they are unconscious when the heart disease attacks. The Internet of Things (IoT) techniques have overwhelming superiority in solving the problem of heart diseases patients care as they can change the service mode into a pervasive way, and trigger the healthcare service based on patients' physical status rather than their feelings. In order to realize the pervasive healthcare service, a remote monitoring system is essential. In this paper, we proposed a pervasive monitoring system that can send patients' physical signs to remote medical applications in real time. The system is mainly composed of two parts: the data acquisition part and the data transmission part. The monitoring scheme (monitoring parameters and frequency for each parameter) is the key point of the data acquisition part, and we designed it based on interviews to medical experts. Multiple physical signs (blood pressure, ECG, SpO2, heart rate, pulse rate, blood fat and blood glucose) as well as an environmental indicator (patients' location) are designed to be sampled at different rates continuously. Four data transmission modes are presented taking patients' risk, medical analysis needs, demands for communication and computing resources into consideration. Finally, a sample prototype is implemented to present an overview of the system.

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Keywords: Pervasive healthcare, Internet of Things, heart diease, monitoring system

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1. Introduction

Nowadays, heart diseases cause more than 1,500,000 deaths in China each year and are now the leading cause of death in the country. Usually, patients with heart diseases live at home and ask for healthcare service when they feel sick. However, usually they won't feel sick until the very late stage of the disease, and it is so late that the damages have already turned irreversible. And most of the patients die before they get any treatment. Therefore, the key to improve heart diseases healthcare performance and reduce the death rate is turning the passive healthcare mode into a pervasive way. That means the physical status of patients should be monitored by physicians, who will decide when to delivery healthcare service based on patients' real-time status. The essential part of this pervasive healthcare mode is the real-time monitoring system.

With the Internet of Things (IoT) technique, it is feasible to monitor vital functions of human no matter where they are and what they are doing. Additionally, the data acquired can be sent to the remote physicians with low cost, which ensures these experts be aware of patients' physical status continuously and in real-time. In this paper, we proposed an IoT-based monitoring system for pervasive heart diseases healthcare. This system monitors the patients' physical signs such as blood pressure, ECG, SpO2, as well as relevant environmental indicators continuously, and provides four different data transmission modes that balance the healthcare need and demands for communication and computing resources. We also implemented a sample prototype to present an overview of the system. This monitoring system fulfills the basic needs of pervasive healthcare for heart diseases, also takes the cost into consideration to ensure the pervasive mode as economical as possible. Furthermore, it can also be combined with real-time analysis algorithms to assess patients' health condition and give warnings to potential attacks in advance, which can make the pervasive healthcare more intelligent. But in this paper, we only focus on the monitoring part.

The remainder of this paper proceeds as follows. Related works will be discussed in Section 2, and Section 3 illustrates the system from three aspects: the system architecture, its data acquisition and transmission parts. In Section 4, we explain the system's four operation modes, while a prototype of the system is presented in Section 5. Section 6 gives the conclusions and discusses the future work.

2. Related Works

As the amount of elderly people and chronic diseases patients grow rapidly, drawbacks of traditional healthcare service are increasingly prominent. The most significant one is that healthcare service is only available in hospitals, so it is inconvenient for elderly or disabled people, and cannot fulfill healthcare demands under emergency conditions[1]. Therefore, a new concept, pervasive healthcare, was proposed to address the challenge and to delivery healthcare service to everyone, everywhere and all the time. A lot of pervasive healthcare applications have been proposed in recent years. Uniyal[1] reviewed existing pervasive healthcare applications which aim at different living conditions like elderly people living alone[2] and disabled healthcare[3], or diseases such as Parkinson[4], heart diseases[5], diabetes[6], etc. The researches about pervasive healthcare can be divided into serval aspects: real-time monitoring, incidence detection algorithms, emergency intervention and patients self-management[7].

Among these aspects, monitoring systems definitely represent a very hot research topic. Many research projects and prototypes have been developed with different aims, dealing with various diseases, users, or different geographical scopes. For example, the monitoring projects proposed by Rofouei[8] and Bsoul[9] only focus on the sleeping issues. Lin et al. developed a system aiming at monitoring people's brain bioelectrical activities[10]. And some systems are designed especially for elderly people, which can monitor their postures[11,12] or detect falls[13]. Besides, researchers considered not only systems used in wide areas[14], but also ones used in a controlled area like a hospital[15]. Because of their different aims, their architectures and monitoring modes are diverse. As a leading cause of death, heart diseases also attract a lot of research interests[16]. Although they deal with the same illness, theses research is various from several aspects. First, the physical signs to be monitored are more or less different. Some only pay attention to one certain sign, such as heart rate, ECG[17], or blood pressure. While others monitor multiple parameters which may not be limited to only physiological ones. These non-physiological parameters are considered as they can provide context information of patients which may assist the remote analysis or facilitate context-based services. Compared with the single-parameter monitoring systems, multiple ones can give more accurate and rich information to remote experts. For these systems with multiple parameters, different physical signs should be sampled at different frequencies to satisfy the medical requirements, while transmit them separately at their own sample frequencies will lead to huge amount of data and a great burden to the remote server. Therefore, most systems first resample all sensor data at a tradeoff frequency and transmit the resampled data all together.

In summary, the monitoring system is an essential part of pervasive healthcare service. And multi-parameter monitoring systems are more helpful than those only monitor one sign. However, data transmission for multiple parameter is an important problem. Although the current resampling methods can lighten the remote server's burden, they also loss the data accuracy. In health applications, data accuracy is crucial to the overall performance and may even affect patients' life. Therefore, we propose a multi-parameter monitoring system which keeps all sensor data, but uses a flexible transmission scheme to reduce communication and computing cost. Patients' risk level is used as the key of transmission control. Patients with higher level will send data more frequently, while ones with lower risk level only send data during important periods. Therefore, burden of the remote server can be lightened without losing data accuracy.

3. The Iot-based heart disease monitoring system for pervasive healthcare service

3.1. System architecture

The general architecture of IoT applications can be divided into three layers: the sensing layer, the transport layer and the application layer. This kind of architecture is clear and flexible enough for our monitoring system, thus we design the system architecture based on that general model. Figure 1 shows the architecture of the IoT-based monitoring system for heart diseases patients.

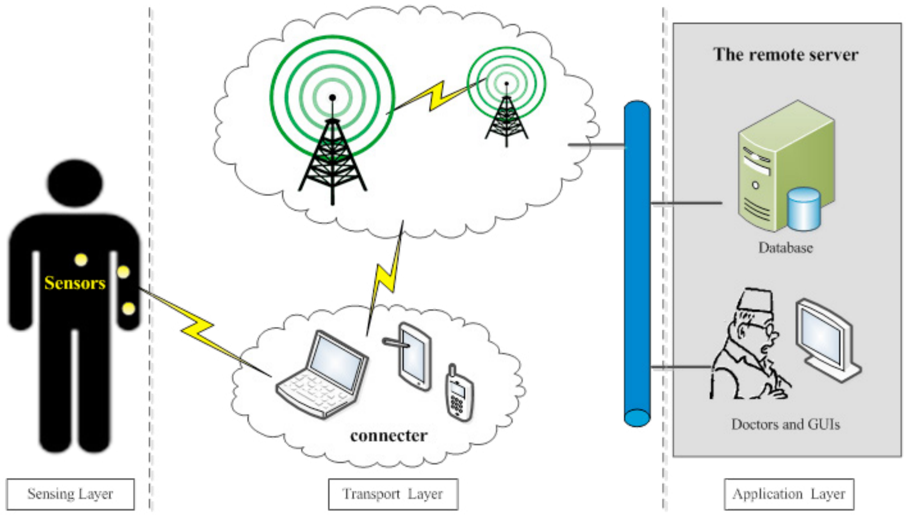


Fig.1. architecture of the monitoring system.

3.2. The data acquisition part

Data acquisition part is primarily composed of sensors wear or carried by patients, as shown in Fig. 1. And the selection of sensing devices should be based on two issues: which parameters to be monitored, and what is the sampling frequency for each parameter.

As the aim of our monitoring system is to assist remote practitioners to be aware about patients' health status and to diagnose or forecast dangerous conditions, satisfying the requirement of medical diagnose of heart diseases and obeying guidelines in medical practice are essential for parameters selection and sampling frequencies. Therefore, we conducted a series of interviews with several professors at Dalian Medical University and practitioners in the affiliated hospital. Besides, the selection of parameters is also subjected to the requirement of moving conditions and usability for ordinary people. With the consideration of both medical and practical demands, the monitoring scheme in our system is listed in Table 1. The sampling frequency of ECG signals is set to be 128 Hz which is typically used for the ECG signals of Holter devices. And the heart rate can be computed from ECG signals. In terms of the blood fat and blood glucose, as the test of these indicators needs intervention from patients (picking a spot of blood from fingers and put the test paper with blood into the sensing device), the monitoring of blood fat and glucose is not continuous. Instead, these parameters are suggested to be tested before and after a meal. The patient location information is selected considering that it is needed if the patient is in danger and resume services should be provided to that patient. Thus, the patient location is sampled on demand, rather than continuously.

Table 1. The monitoring scheme.

Indicator	Sampling frequency (period)
ECG	128Hz
Heart rate	-
Blood pressure	2seconds
SpO2	2seconds
Pulse rate	2 seconds
Blood fat	-
Blood glucose	-
The patient Location	-

3.3. The data acquisition part

Due to the high cost of long distance wireless communication technologies, it is unfeasible to send acquired data to the remote side from sensors directly. Therefore, we divide the data transmission process into two sub-processes. The first sub-process takes responsibility of sending data from sensors to a connecter in short distance. Meanwhile, the connecter should also be able to send data to the remote side at an acceptable cost. As the smart phones, Personal Digital Assistant (PDA) or laptops which are capable of wireless communication in both short and long distances and have computing abilities are extremely popular and widely used nowadays, they are the most suitable devices to be taken as a connecter. After the data is received by the connecter, it will be sent to the remote side through another communication technology that is economical for long distance communication.

Obviously, communication technologies to be used will tightly depend on the specific requirements of each sub-process. For the former one, the technology should offer reasonably high bandwidth, and low cost of being integrated into sensing devices. Additionally, it would be better if the certain technology is widely implemented in smart phones, PDA and laptops which are the candidates of the connecter. For the later one, coverage range of the technology is the factor to be considered principally. Besides, the bandwidth and the communication quality are other important elements. Comparing these requirements and the characters of various communication technologies, we chose Bluetooth technology to be used in the first sub-process, and decided to use cellular technologies (e.g., GSM, and GPRS) as well as broadband wired technologies (e.g., ADSL) in the second sub-process.

4. Four operation modes for the monitoring system

In our monitoring system, we designed four modes for the data transmission operation:

- Mode-*I*： real-time continuous transmission for all data.

In this mode, all data sampled by sensors will be transmitted to the remote service center and be displayed to the practitioners in real time. This mode is the highest monitoring level. It is designed for the situation when the cardiologists need to keep up with the health status changes of special patients, or perform on-line forecast and diagnosis. Generally, the monitoring of patients who are in really high risk of heart diseases' relapses is suggested to be set as this mode to ensure rapid response. It is obvious that with this mode the amount of data to be transmitted and stored at the server side is rather large. In addition, it needs great human resources at the server side to analyze the mass monitored data from patients, and puts forward a higher demand for the network quality, especially the bandwidth. Therefore, although this mode stands for the highest level of monitoring service and can provide experts' guidance for patients in real time, the number of patients with this mode is limited by the system and human resources at the server side, as well as the quality of communication network. That is why we present the other modes as well.

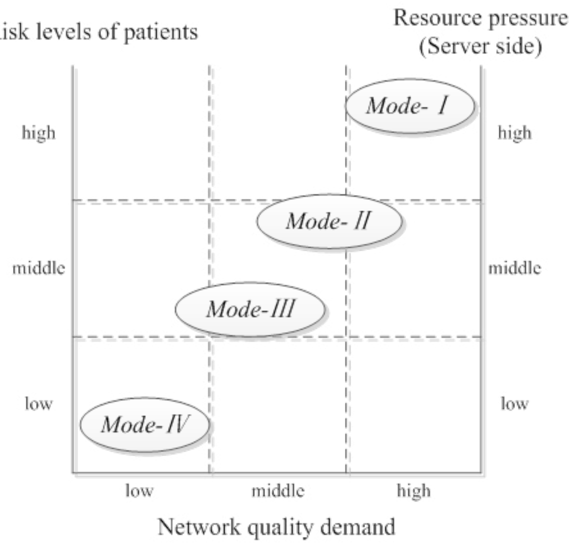


Fig. 2. The relationship among operation modes, patients' risk level, network demand and resource pressure.

- Mode-*II*: continuous transmission in special periods.

According to the cases of heart diseases' relapses and cardiologists' experience, heart attacks often take place in several special periods, like 1 or 2 hours after waking up, and 3 to 4 clock at afternoon. Thus, this mode sends continuous sampled data in these periods which are determined by doctors. Beside these dangerous periods, the connecter is configured to select other periods randomly to send continuous monitored data as well in order to increase the chance to detect the potential attacks.

- Mode-*IIII*: event triggered transmission.

In this mode, the sampled data is stored in the connecter first. And the connecter (e.g., smart phones) will conduct an easy data handing process after data arrival. The data handing process compares the sampled data of each parameter with the corresponding range of normal value which is predetermined by practitioners. An event indicates that the sampled data of a parameter is beyond its normal range. When an event happens, the transmission from the connecter to the remote server will be activated, and a sequence of monitored vital signals (the pre- and the post five-minute signals of the event) will be sent. As this mode reduces the amount of data sent to the practitioners, it lightens the system and human resource pressure at the server side. Though doctors at the remote side cannot receive patients' physical indicators value continuously in this mode, they still can keep up with important changes in patients' statuses. This mode suits patients in middle risk of disease relapses.

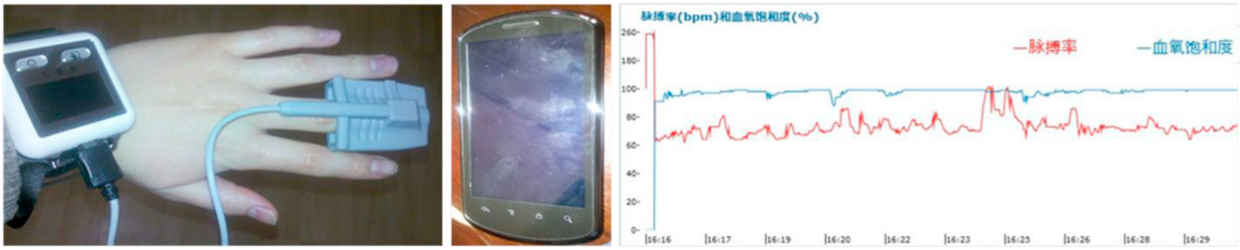
- Mode-*IV*: transmission on patients' demand.

In this mode, the monitored data is mainly stored at the patient side, in smart phones or computers. Only if the patient feels uncomfortable and requests diagnosis from doctors, a sequence of monitored data (the pre- and the post- five minute signals of the request) will be sent to the server. It is the lowest-level of monitoring, and is fit for patients with low risk of heart attacks. However, an apparent shortcoming of this mode is that patients may send requests now and then if the patients are too anxiety.

As illustrated above, the four modes are different from each other in the amount of data sent to the remote server, the requirement for network quality and resource at the server side, and the applicability for different types of patients. Fig. 2 compares these modes from these aspects.

5. Prototype implementation

There are various mature commercial wireless sensors for the parameters to be monitored in this system. Therefore, we chose appropriate devices to make up the sensing layer of the monitoring system. The connecter plays an important role in the data transmission of the system. We used an Android smart phone as the connecter due to the popularity of smart phones and the openness of Android platform. An application on smart phone was implemented in Java. This application is responsible for receiving and storing monitored data from the sensing devices through Bluetooth, and transmitting necessary data according to different operation modes. At the remote server side, a web-based application was realized for the doctors to query monitored data.



(a) (b) (c)

Fig. 3. (a) the SpO2 sensor device; (b) the mobile phone; (c) SpO2 monitoring data.

The above figures present some devices used in the system and an example of monitoring GUI at the doctor side. Fig. 3(a) is a picture of the sensing device for SpO2 and pulse rate. Fig. 3(b) show the connecter in our system, an Android smart phone. And Fig. 3(c) shows the monitoring GUI of patients' SpO2 and pulse rate for remote practitioners.

6. Conclusions

In this paper, we proposed an IoT-based heart disease monitoring system for pervasive healthcare service. This system monitors the patients' physical signs such as blood pressure, ECG, SpO2, as well as relevant environmental indicators continuously, and provides four different data transmission modes that balance the healthcare need and demand for communication and computing resources. We also implemented a prototype to present an overview of the system.

In near future, we plan to integrate the Data Stream Management System (DSMS) technologies into the system to enrich its functions, such as continuous query, windowing, aggregation and so on. Afterwards, data stream mining and context awareness technologies are also considered to provide more powerful pervasive healthcare services like early warning and real-time knowledge support to patients.

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