

# THE IOT-BASED MOBILE MONITORING SYSTEM FOR PATIENTS WITH HEART DISEASES

## Abstract

*Heart diseases are one typical kind of chronic illnesses with rather high recurrence rate. What's worse, in most cases heart attacks occur suddenly without obvious omens. However, these patients usually live at home rather than stay in hospitals, which makes them far away from medical resources when emergencies happen, as well as leads to a great difficulty for physicians to know the patients' status in time. Consequently, heart diseases have become one of the leading cause of death in China. Mobile and Internet of Things (IoT) technologies have overwhelming superiority in solving the problem of heart diseases patients care as they can expand the availability of medical resources greatly. With wireless sensors and mobile devices, the real-time physical status of patients can be known by the remote physicians no matter where they are or what they are doing. By doing so, not only can the precious rescue time be saved, but also will an opportunity of giving early warnings to heart attacks be provided. Therefore, mobile monitoring systems really do good to life saving of heart diseases patients. In this paper, we propose a mobile monitoring system based on the IoT technology that can send patients' physical signs to remote medical applications in real time. The system is mainly composed of two parts: data acquisition part and data transmission part. The monitoring scheme (monitoring parameters and frequency for each parameter) is the key point of the data acquisition part, we design it based on interviews to medical experts. Multiple physical signs (blood pressure, ECG, SpO<sub>2</sub>, 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, and demands for communication and computing resources into consideration. We implement a sample prototype at the end.*

*Keywords: Mobile healthcare, Internet of Things, Monitoring system, data transmission, Heart diseases.*

## 1. Introduction

Nowadays, the heart diseases have become one of the most difficult problems faced by Chinese society. The number of patients with heart diseases grows rapidly but never reduces a bit. What's more, this kind of diseases causes more than 1,500,000 deaths in China each year and is now the leading cause of death in China. There are three factors contribute to this situation. First, heart diseases have high recurrence rates, and heart attacks usually occur all of a sudden without noticeable omens superficially. Second, the best rescue time for patients who has a heart attack is rather short, only several minutes after the attack happens. However, thirdly most patients live at home, rather than stay in hospitals. Therefore, they are far away from medical resources and staffs when emergencies happen, and remote physicians are unable to know their physical status well. Besides, many patients are elderly people living alone, which makes the situation even worse. These factors together make it rather difficult to give in-time treatments to patients after attacks.

Mobile and IoT technologies have overwhelming superiority in solving the problem of heart diseases patients care as they can expand the availability of medical resources greatly. With them, it is feasible to monitor the 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 the patients' physical status continuously and in real-time. In this paper, we proposed an IoT-based mobile monitoring system for patients with heart diseases. This system monitors the patients' physical signs such as blood pressure, ECG, SpO<sub>2</sub>, 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 sample prototype to present an overview of the system. This kind of monitoring system can also be combined with realtime analysis algorithms to assess patients' health condition or even give warnings to potential attacks in advance. In addition, with mobile devices' computing ability, context-based patients self-management can also be proposed. 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, the data acquisition part, data transmission part, while a prototype of the system is presented in Section 4. Section 5 gives the conclusions and discusses the future work.

## 2. Related Works

Since telemedicine was proposed, research about long-distance healthcare service has been of great concern. And soon after that, the growing ubiquity and penetration of mobile phones has helped fuel the initiation of mobile health (mHealth) (Soninsky and Mechael, 2008). Researches about phone-based interventions focus on providing medical and healthcare education, facilitating the clinical practice (Lindquist, etc. 2008), improving patients' adherence to antiretroviral treatment (Pop-Eleches, etc.

2011), and so on. As the most widely supported and used technology is it, SMS has been taken as one broad adopted way to delivery health interventions of an kind. Because of its push feature, SMS is largely used for sending reminders, education materials, and medical advices to patients(Fairhurst K., Sheikh A. 2008; Armstrong, Watson, et al. 2009). However, these messages can only facilitate patients' self-management, and cannot make the doctors clear about patients' status remotely. As current smartphones all provide ways to connect with external devices, such as wireless sensors, a new trend is to combine mobile phones with some sensors aiming at enabling remote doctors to gain the sight of patients' physical conditions continuously (Klasnja & Pratt, 2012).

Health monitoring systems definitely represent a very hot research topic these days. Many research projects and prototypes have been developed with different aims, dealing with various diseases or users, and used in different geographical scopes. For example, the monitoring projects proposed by Rofouei et al. (2011) and Oliver et al. (2006) only focus on the sleeping issues. Chen et al. (2009) developed a system aiming at monitoring people's brain bioelectrical activities. And some systems are designed especially for elderly people, which can monitor the posture (Kim et al. 2011, Zhang et al. 2011) or detect falls of these people (O'Donovan et al. 2009). Besides, researchers considered not only the monitoring systems used in wide area (Mitra et al., 2012), but also some used in a controlled area like hospitals (Pandian et al., 2007). Because of their different aims, the architectures and monitoring modes of these systems are diverse so as to meet distinct demands. A leading cause of death as is it, heart diseases also attract a lot of research interests (Shengh et al. 2011). Although they deal with the same illness, theses researches are various from several aspects. First, the physical signs to be monitored have more or less differences. Some only pay attention to one certain sign, such as heart rate, ECG (Jin et al., 2009), or blood pressure. While others monitor multi-parameters. These may not be limited to only physiological ones. These non-physiological parameters are considered as they can provide context information of the 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 at the same frequency all together.

In summary, multiple parameter monitoring systems are more helpful than those only monitor one sign. However, data transmission for multiple parameter monitoring systems 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 even may affect patients' life. Therefore, we propose a multi-parameter monitoring system with a flexible transmission scheme. Patients' risk level is used as the key of transmission control that patients with higher level will send data more frequently, while ones with lower risk level only send important partial data. Therefore, the burden at the remote server can be lightened without losing data accuracy.

### 3. The Iot-Based Monitoring System

#### 3.1. The architecture of the monitoring system

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.

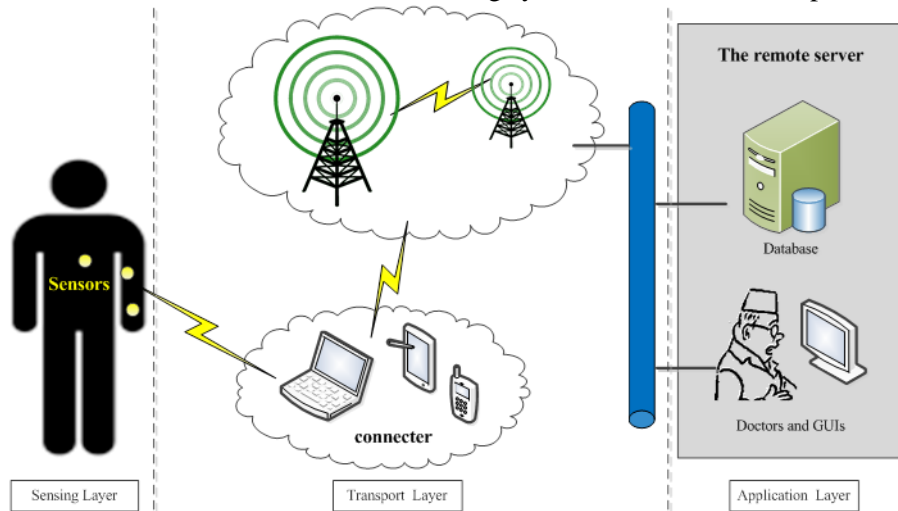


Figure 1. The architecture of the monitoring system.

#### 3.2. Data acquisition part of the system

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

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 | -                           |

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 the determination of parameters selection and sampling frequencies. Therefore, we conducted a series of interviews with several professors at Dalian Medical University and practitioners in its 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 demand, 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 provide to that patient. Thus, the patient location is sampled on demand, rather than continuously.

### **3.3. Data transmission part of the monitoring system**

#### **3.3.1. Communication technologies for two subparts of data transmission**

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 connector in short distance. Meanwhile, the connector should also be able to send data to the long distance 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 connector. After the data is received by the connector, 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 connector. 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 choose Bluetooth technology to be used in the first sub-process, and decide to use cellular technologies (e.g., GSM, and GPRS) as well as broadband wired technologies (e.g., ADSL) in the second sub-process.

### 3.3.2. The operation modes for data transmission

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 centre 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 so as to ensure rapid response would be provided whenever heart attacks happen. 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 analyse the mass monitored data from patients, and puts forward a higher demand to 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.

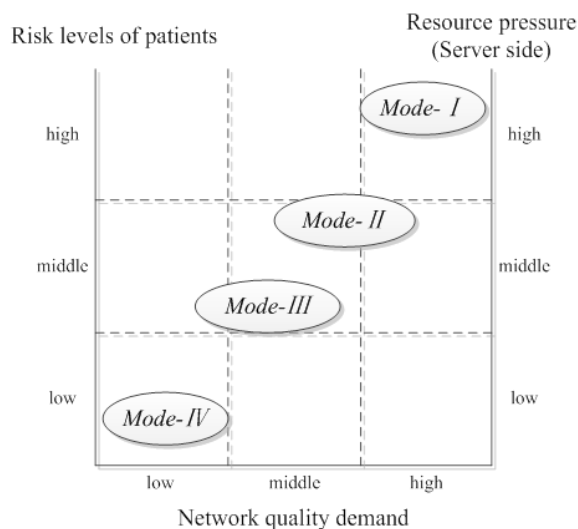


Figure 2. Four operation modes.

- *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 the doctors. Beside these dangerous periods, the connector is configured to select other periods randomly to send continuous monitored data as well in order to increase the chance to cover the potential attacks.
- *Mode-III*: Event triggered transmission. In this mode, the sampled data is stored in the connector first. And the connector (e.g., smart phones) will conduct an easy data handing process before any data is sent to the remote side. 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 connector 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. Figure 2 compares these modes from these aspects.

#### 4. System 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 connector plays an important role in the data transmission of the system. We used an Android smart phone as the connector due to the popularity of smart phones and the openness of Android platform. An application on smart phone is 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 is realized for the doctors to query monitored data.

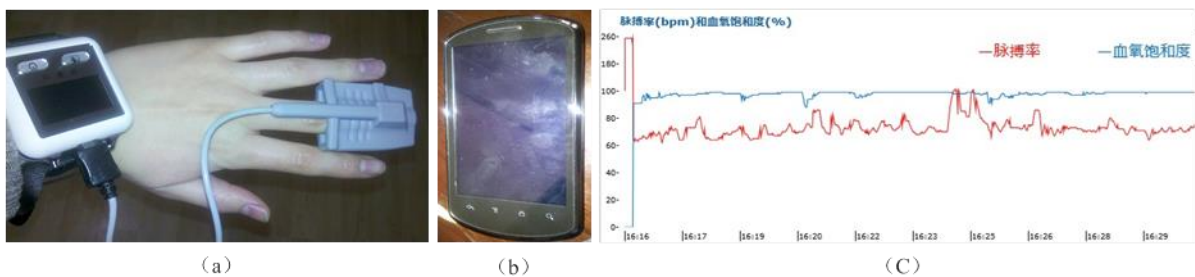


Figure 3. The prototype of the monitoring system.

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

#### 5. CONCLUSIONS

In this paper, we propose an IoT-based mobile monitoring system for patients with heart diseases. 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 the near future, we plan to integrate the Data Stream Management System (DSMS) technologies into the monitoring system in order to enrich its functions, such as continuous query, windowing, aggregation and so on. Afterwards, data stream mining and context awareness technologies are also considered so as to provide more powerful mobile services like early warning and real-time knowledge support to patients.

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