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A Design of Remote Heart Rate Variability Analysis System

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Abstract
With heart rate variability analysis instruments being expensive and heavy until today, a remote heart rate variability analysis Server was designed. The server use hypertext transfer protocol to communicate with mobile clients and can receive the electrocardiograph data from the users uploaded stably. Afterstoring and analyzing the electrocardiograph data, the server can return the analysis results to the mobile clients and storage the results, thus making user query the history in the future. As to the implementation of theserver, some interactive business process and key algorithms used in its implementation were expounded. The test results show that users can get the analysis result of heart rate variability after they upload electrocardiograph data and get history information from the server. In this way, users can use the data to evaluate themselves physical conditions currently or recently.

Key words
Electrocardiograph data;Heart rate variability; Interactive business;Remote server; Evaluate physical conditions;

I. Introduction

Heart rate variability(HRV) represents the discordance of the successive heartbeat time periods. HRV can be one of the noninvasive indicators that can reflect the balance of autonomic nervous system, which can affect the heart and blood vessels dynamically. HRV has important clinical value on the evaluation of autonomic nervous function in cardiovascular disease, and can be used as a predictor of some cardiovascular disease [1-3]. Besides, it is closely associated with one's emotional status and the variation of HRV data behaves particularly evidentin anger, depression, anxiety and other emotional conditions.

Cardiovascular disease has the characteristics of intermittent and emergent, which means only the real-time monitoring and analysis can be helpful. However, the traditional HRV analysis equipment is expensive, poor mobility, and only few of medical structures have been equipped with. This situation makes that patients have to go to these specific medical structures to do ECG test and it cannot meet the demand of ECG monitoring at anytime and anywhere.

In 1990s, the research of remote monitoring on the cellphone began to expand with the development of mobile communication technology [4-6]. With the development of portable devices and the expansion of network coverage, a HRV analysis server is designed and built in order to realize intelligent and portable HRV analysis. The server can receive real-time ECG data uploaded by the mobile client through the network and return the HRV analysis result to the client at the same time. Besides, these data would be saved into the databases at the same time and provide data support for users' real-time or near-term assessment of cardiovascular status.

1. General Structure Design

Our data server acts as the server side in the general C/S models and transfers data between mobile clients using HTTP protocol through the network. The whole structure of the server is shown in Figure1, the server mainly has these functions: receiving, storing, processing and analyzing real-time ECG data uploaded from mobile phone client. After HRV analysis, the results will be sent back to the mobile phone client and saved as another copy to the database at the same time for history query. Due to the business needs, this design uses the MVC framework and is divided into three parts: interactive service module, HRV analysis module and data service module. The specific description of the components is as follows:

A. Interactive Service Module

Interactive service module is responsible for the interaction between the server and the mobile client. According to the request from the client, this module finishes the task by calling the HRV analysis module and the data service module.

B. HRV Analysis Module

HRV analysis module is responsible for the HRV analysis of the ECG data uploaded by users. This module processes the HRV analysis of ECG data from the interactive service module and generates analysis results.

C.Data Service Module

The data service module is responsible for storing and extracting the data information during the interaction between mobile client and server. Responding to requests from interactive service module or HRV analysis module, the data service module provides data service by operating the database.

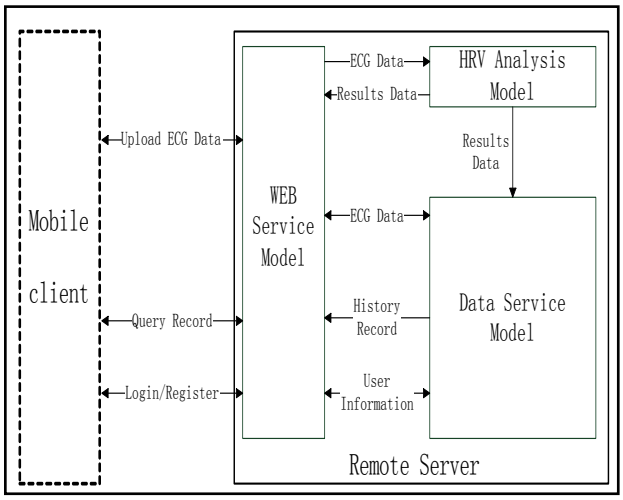

Fig.1 : Structure framework of server

II. Design of Interactive Service Module

The server plays a role of background service for mobile phone client. Through "GET" and "POST" via requesting URL, Mobile client can access to the server by sending the relevant request to obtain the corresponding server response. As shown in Figure 2, it represents the mobile user's status. After registering at the first time, users can not only login and upload real-time ECG data and get HRV analysis results sooner, but also check the historical

test records to see the recent trend of HRV changes. According to requirements, this module mainly includes upload data processing business and historical records query business.

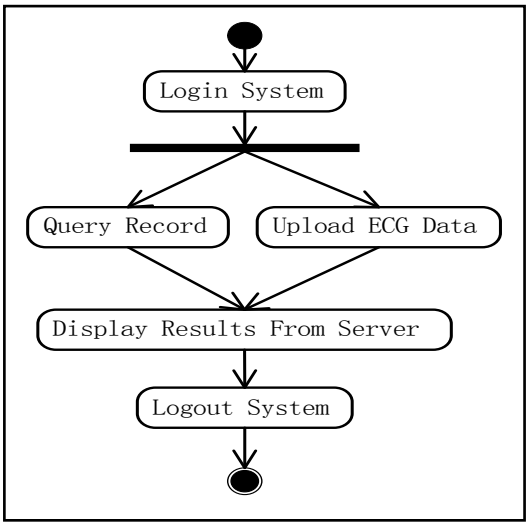

Fig.2 : Mobile phone user' state diagram

A. Upload data processing business design

After a successful login, the client can send the ECG data to the server through the internet. After receiving the ECG data from the client, the interactive service module firstly verifies the format and integrity of the data and then transmits the data to the HRV analysis module after a successful verification. Meanwhile, this module will back up an original copy and send to the data service module. Once received the original data, HRV analysis module processes the data analysis and then sends results back to the interactive module which will finish two tasks: sending results to the client for real-time presentation and transferring to the data service module for storing into databases. These analysis results include HRV time domain parameters, frequency domain parameters, and nonlinear parameters.

B. Historical business query service design

Long term ECG detection is conducive to the overall assessment of the cardiovascular situation. Users can estimate the trend of HRV change through historical query business. For the friendly user experience, the mobile client will display these historical records in a list. In order to make history recorded in the mobile phone client with the ExpandableListView display, the server, acting as the backend server, use sessions to record part of the operation for current user. If the user is online, it will return data which using all test date as index and a list will be generated by the mobile client.Secondly, using specific date as request parameters, the server will send all test results to the client at that date and record the date in session. Finally, after receiving the request combined by specific test time and record parameters in session, the data service module will query records and handle results over to the Interactive Service Module returns test records to the mobile phone client.

III. HRV analysis module design

After the HRV analysis module receiving the ECG data from the interactive service module, the HRV signal is obtained by accurately locating the R wave in the QRS wave and then the HRV parameters are obtained by using the correlation algorithm. The state diagram of the HRV analysis module is shown in figure 3.

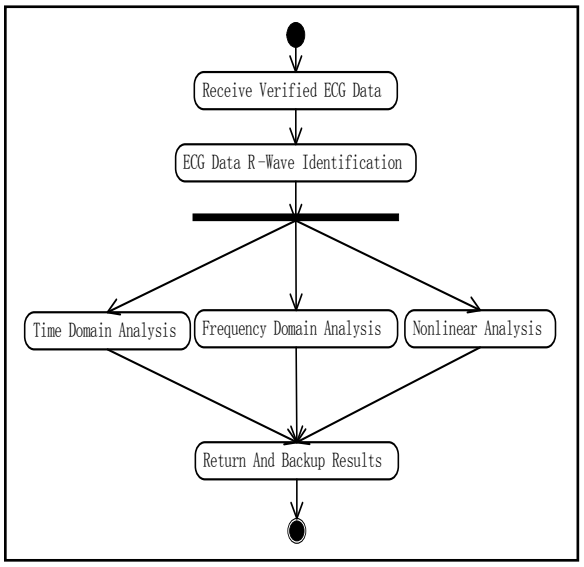

Fig.3 : HRV analysis module state diagram

A. R wave identification

Accurate positioning of the R wave is the premise of ECG signal analysis, but the ECG acquisition generally exists frequency interference, electrode contact noise, EMG interference and human motion interference and these situations make R wave detection become difficult [7]. Common detection algorithms in R wave are wavelet transform method, neural network method and differential threshold method [8,9]. With large computation, the neural network algorithm and wavelet transform are relatively complex and real time process ability is not so friendly. Taking into account the real-time interaction with the mobile client, we decide to combination the differential threshold algorithm and dynamic window function to achieve the accurate positioning of R wave. The R wave has the largest slope at the rising or falling waveform in the QRS wave group, and the position of the R wave is the first derivative at zero point or the extreme points of second derivative of the QRS wave group. Therefore, it is quit accuracy to determine the location of R wave by the processing of the ECG signal using first order difference or second order difference as well as combining the time window and the amplitude threshold of QRS wave.

B. HRV parameter extraction

In this design, the HRV signal is a sequence of two adjacent RR intervals, and the relevant HRV parameters are obtained by time domain analysis, frequency domain analysis and nonlinear analysis respectively [10-12].

(1) Time domain analysis: Using statistical methods for HRV time domain analysis. Statistical methods were used to obtain the time domain parameters SDNN (RR Interval Standard Deviation), RMSSD (Adjacent RR Interval Standard Deviation), NN50 (Numbers of the RR interval heartbeat that satisfy the adjacent RR interval greater than 50ms) and pNN50 (percentage of accounted for the number of all RR interval adjacent RR interval difference of more than 50ms).

(2) Frequency domain analysis: Using the periodic map method to obtain HRV frequency domain parameters TP (total frequency power), HF (high frequency power), LF (low frequency power), VLF (ultra-low frequency power), LF/HF (power ratio between Low-frequency power and high-frequency).

(3) Non-linear analysis: Using the scatter plot method to obtain

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scatter distribution plot data for qualitative analysis of HRV.

IV. Data service module design

The data service module is responsible for storing and extracting the data information during the interaction between the server and the mobile client. Data information mainly contains the user identity information, ECG data and HRV analysis of the data. To ensure the efficiency of data services, we use JDBC and database connection pool technology to operate the database. The database tables include the Users table and the Files table. The Users table holds the user's basic identity information. The ID number in the table is generated by the UUID algorithm to keep unique. The user password is encrypted by the MD5 algorithm to ensure the security of the user information. The Files table associates the Users table with the user_id field which was set to be a foreign key and holds the relevant data for each measurement of the current user. Date Filed and time filed save the test date; Result Field save HRV analysis results. The ECG data uploaded by user is stored as a file in the server hard disk. Filed location records the ECG data file storage path. Users table structure and Files table structure shows in Figure 4.

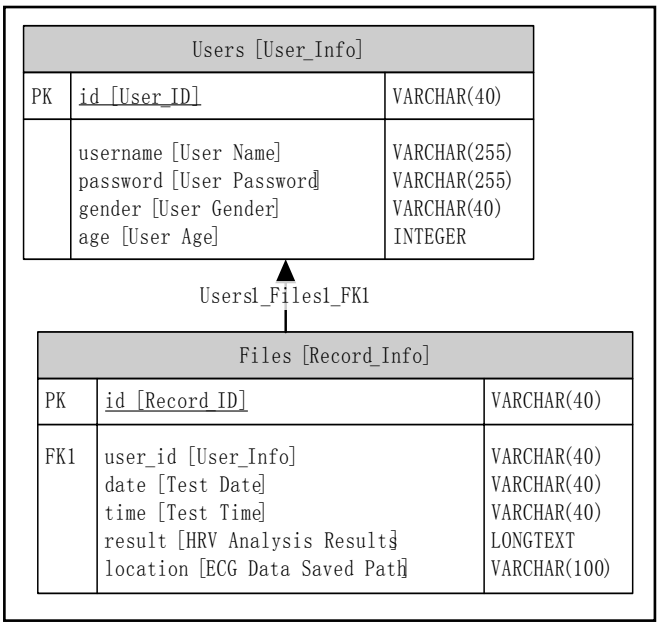

Fig. 4 : Database table structure diagram

V. Results tests

This server was built on a cloud server, which using Mysql5.5 as the data storage container and tomcat8.0 as a running container. Besides, the data presentation is completed by the mobile phone client. This experiment has collected plenty of data by the Android smart phone from several volunteers.

A. Upload Data Processing Business test

The mobile client receives and collects a real-time data which contains 5-minute ECG test through the OTG line and transfer the data to the server. After processing, the server will generate the analysis report and resent it to the mobile phone client. This test data is nearly 1MB and it takes about 12 seconds, which is within the acceptable range, from the beginning of uploading the data to receive the report in a WiFi environment with 4Mb/S speed.

For the same test data, it is almost identical from the R-wave position in Matlab simulation and the R-wave position of the server environment. The errors are relative negligible to the RR interval and hardly affect the analysis of heart rate variability. Table 1 shows the statistical comparison of R-wave position both in local Matlab simulation and in cloud server environment from three persons' ECG data.

Table1 : R wave location in Matlab and server

Sample 1		Sample 2		Sample 3	
Matlab	server	Matlab	server	Matlab	server
610	610	402	402	662	663
1072	1072	662	661	1028	1027
1293	1293	904	904	1402	1401
1514	1515	1139	1140	1772	1772
1745	1745	1381	1381	2154	2155
1986	1986	1670	1671	2511	2511
2233	2234	2002	2002	2876	2877
2488	2489	2327	2327	3244	3243
2747	2749	2632	2633	3594	3595
3005	3005	2935	2936	3967	3968
…	…	…	…	…	…

The HRV time domain and frequency domain parameters are obtained according to the HRV calculation formula under the precondition of accurate positioning of the R wave. Compared with Matlab simulation, the error of the cloud server simulation result is less than 1%. Table 2 and Table 3 show HRV time domain and frequency domain parameters obtained by three volunteers.

Table 2 : HRV time domain parameters

sample	SDNN(ms)	RMSSD(ms)	NN50(ms)	PNN50(%)
1	50.03	54.37	42	8.22
2	37.85	28.10	11	1.96
3	32.28	24.84	8	1.57

Table 3 : HRV frequency domain parameters

sample	TP(ms^2)	VLF(ms^2)	LF(ms^2)	HF(ms^2)	LF/HF
1	1249.35	498.75	384.24	365.94	1.05
2	1728.57	524.35	491.57	649.27	0.76
3	1803.16	735.03	453.39	473.92	0.96

B. History Query the service test

Receiving data from server, the mobile phone client will display the test results at the order of date. By Clicking one of the date records, the server will return related test results of that date and then click the selected specific time period, the server will return the detail test data of that time to client and displayed by the mobile client.

VI. Conclusion

With describing the overall design framework including interaction mode and algorithm in detail , this paper presents and implements a remote server for HRV analysis and is verified by the mobile client. As a mobile client service background, the remote server can not only analyze the user's real-time ECG data for HRV in cardiovascular conditions to provide data support, but also storage

the user's original ECG data and HRV analysis results for long-term, which is conducive to long-term health assessment. This design facilitates the portable ECG detection equipment and has a broad application prospect. It will provide the appropriate services for doctors to take remote monitoring of patients and services in future.

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