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Successive ECG Telemetry Monitoring For Preventing Sudden Cardiac Death

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***Abstract*—In this paper, a novel successive ECG telemetry monitoring prototype is developed to evaluate the effect of monitoring for those out-of-hospital patient who has serious arrhythmia and/or possesses the risk of sudden cardiac death (SCD). This system has such features as: real-time, continuous, telemetry monitoring, wide range, long distance, and long term etc.. The developed prototype consists a pocket-size patient-side monitor and a monitoring center placed in a hospital, which continually collects every patient's ECG through GPRS mobile network and automatically analyzes it, if any danger found, instantly send medical warning message to patient. Based on the subsequent experiments on three volunteers in daily activity situation, the preliminary results indicate three-channel ECGs of each volunteer and his localization information can be real-timely and continuously monitored in the center.**

I. INTRODUCTION

SUDDEN cardiac death (SCD) is a very serious cardiac event that it will deprive patient's life within several minutes[1, 2]. In China, there are 550,000 people every year being sudden death owing to different kinds of heart disease; but more than 80% are of arrhythmia, moreover near 80% of which belong to ventricular tachycardia or fibrillation (VT/VF) [3]. SCD may abruptly strike any person if he or she possesses of high risk heart disease, even young person, and athlete. Besides utilizing public access defibrillation (PAD) procedure to recue impending death patient while fell down, the better way is to prevent onset SCD by adopting medical aid prior to fell down. Thus, is it possible to make an early warning, even before crisis presenting half an hour?

For this purpose, we have being conducted a project on successive and wireless ECG monitoring. A novel tele-monitoring method was proposed in our prior arts [4-6] to overcome the limitations of conventional route ECG test and hours of Holter monitor. And more importantly, it offers some significant advantages than other current available mobile monitoring system, such as the CardioNet Mobile Cardiac Outpatient Telemetry Service [7] in the U.S. and the BodyKom Series Remote Patient Monitoring [8] in Sweden.

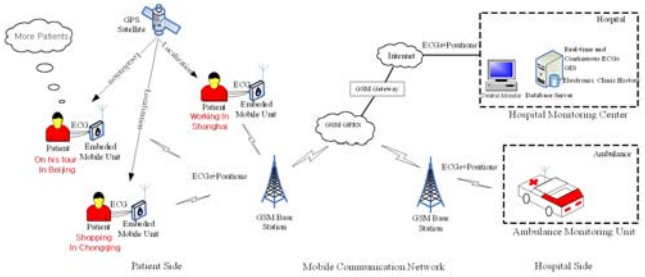

Fig. 1. The schematic diagram of the proposed method of real-time and continuous ECG monitoring [5]

In this paper, the subsequent works conducted on this project will be presented to provide insight into the proposed method in actual situation. Following a brief instruction of our novel method, the recently developed prototype will be disclosed in this section II, and the experimental results will also be presented in section III. Finally, the main contributions of this work will be concluded in the last section.

II. METHODS

A. System Framework

According to the clinic requirements, it is indispensable to obtain real-time and continuous dynamic ECG monitoring system for high risk heart patient because the crisis would present arbitrary at any time and in any place. Current dynamic monitoring system could not competent, cause of neither successive and real time nor located. Second, we need the system to work long-term, such as 1-3 months when patient is out-of-hospital, either at living in home or working in office. Third, ECG analysis result or diagnosis is further needed to issue in real-time, and a corresponding medical advice should be transmitted immediately to patient. Fourth, active range should wide so as patients can movement or travel free, .Hence, the public communication platform through GPRS transfer 1-3 channels ECG data is available. In this way, a novel and practical method to real-time successive monitoring is introduced [4], as shown in Fig.1, which mainly comprises three parts: tens of mobile patient units designed as a pocket-size terminal with several vital sensors, a hospital monitoring center, and two such parts are connected wirelessly by a mobile network of GSM/GPRS.

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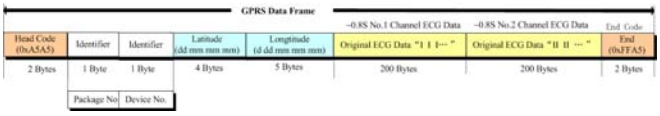


Fig. 2 The customized communication protocol based on GPRS network

Fig.3. The developed prototype of the mobile monitoring terminal

As shown in Fig. 1, the proposed tele-monitoring system possesses such technology features as following:

1) Continuously acquiring 1-3 channels ECG and location information of patient and transmitted by GPRS module.

2) An embedded mono-chip MCU used to analyze ECG data, and further to compress, manage, and transmit data with hospital center.

3) Transmitting data to hospital center in batches (seconds delay) through the GPRS module under UDP protocol.

4) Multi-user real-time ECG are simultaneously received and displayed on the CCU's screen in front of physician, as well as written in hard disk; furthermore, an alarm will be start up automatically while heart calamity event occur find out by central analysis system.

5) Stored ECG data in the monitoring centre, it would be retrieval for re-playing and re-analyzing.

6) GPS accompanying with electronic map enable doctor to trace a patient and know his exact position.

B. Communication Protocol

A set of Customized communication protocol for the mobile terminal and the monitoring center is developed with simultaneously considering low power consumption and transmitting efficiency, which is based on the GPRS network. The transmitted data frame between the mobile unit and monitoring center are defined three kinds: uninterrupted ECG data packaged in size of 415 bytes per package, GPS data, and other handshake command, as shown in Fig. 2. Thereinto, each package includes two channels of 0.8s ECG data segment.

C. Experimental Prototype

Furthermore, a prototype system including ten sets of mobile terminal and a set of central monitoring software is developed. The developed prototype of the mobile unit comprises five modules such as: a hybrid main module based on an ARM microprocessor, a two-channel ECGs acquirer, an integrated GPS and GPRS module, an LCD, and a power supplying module, as shown in Fig. 3.

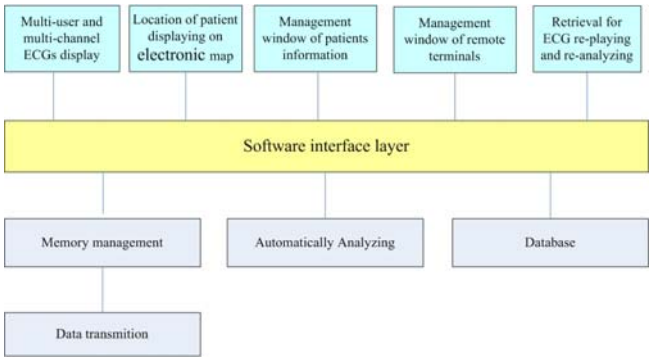


Fig . 4. The block diagram of software modules and algorithm used for the monitoring center

The monitoring center is crucial to the whole telemetry monitoring system. A prototype of the hospital monitoring center, including series of powerful functional software and infrastructural hardware system, is also developed to meet the requirement of real-time tele-monitoring of multi-patients' ECGs and their current localization information simultaneously. The software framework of the monitoring center is illustrated in Fig. 4. In addition, the inner runtime algorithm is developed for the completion of arrhythmia analysis, decision, and locating the patient's geometric position. The monitoring center is sit in a normal CCU, which is built on a powerful PC with 2.1GHz,16GB memory, 320GB hard disk, and two screen. One of screen is to display patients continuous ECG in 8 windows and two leads for each (see Fig. 5(a)); and the other is to display either electronic map (see Fig. 5(c)) or alarmed patient's information, such as the current three leads ECG, historic ECG, medical records and as well as send a medical advice (see Fig. 5(b)).

III. RESULTS

In order to validate the proposed method, subsequent experimental tests by using the developed prototype have been carried out on three volunteers moving along streets in Shanghai city of China. During experiments, such technique parameters of the developed system have been tested as following:

1) Number of patients monitored simultaneously: 3 (up to100) volunteers, 3 leads ECG for each.

2) Parameters of ECG acquisition: band width of 0.05–100 Hz, sample rate of ECG: 250 Hz with 10-bit resolution, and sensitivity of ECG amplifier: 1-5mV, AGC.

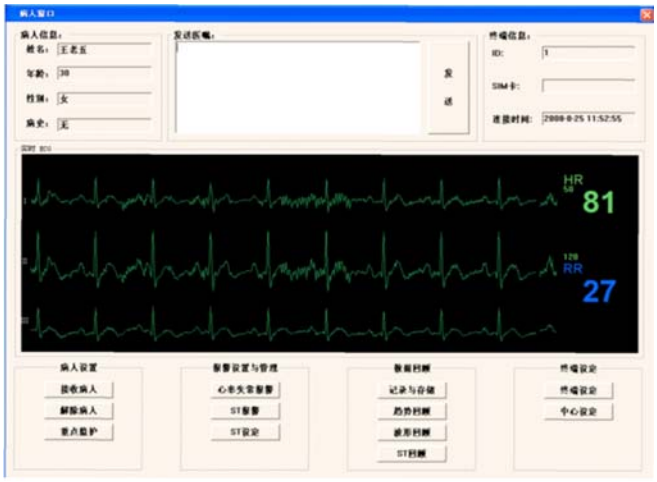
3) GPS location accuracy: 5-25 m, data updated in each second.

4) Transfer media: GSM/GPRS 900 /1800 MHz, Class 10, up to 57.6 kb/s.

5) Battery last time before charge: >12 hours, total weight of 250g.

6) Central monitor with Pentium Duo 3.08G/1GB, twin central monitor with Pentium Duo 3.08G/1GB, twin 19'LCD screen, one for 10 ECG real time display (see Fig 4(a)), other used for operation interface (see Fig 4(b));

(a)



(b)

(c)

Fig. 4 The experiment results shown in the central monitor: (a) multi-user, multi-channel, and continuous ECGs monitoring, (b) historical data replaying and instant medical advice sending interface, (c) real-time localization of management.

some time, it will show lapped ECG and current position of a patient on the electric map if alarm comes on him(see Fig 4(b) and (c)).

In brief, the preliminary test results (see Fig. 3 and 4) indicate that three-channel ECGs from each of three volunteers and their localization are real-timely and continuously transmitted from the mobile units carried by them to the central monitor through GSM/GPRS network; and the main clinic information are analyzed instantly and displayed on the monitor screen. Although no transmission errors or intermission were been observed, further tests will be expected to perform a full evaluation of this system in clinical trials, especially for patients who have high risk heart diseases.

IV. CONCLUSION

In this paper, a set of recently developed prototype and subsequent experiments in actual situation are disclosed to provide insight into the novel method of successive and wireless ECG monitoring. The main contributions of this work described above are to functionally evaluate the proposed method with the developed prototype system. According to the experimental results, this method provides practical potentials to be as an alternative effective approach of real-time and remote monitoring for out-of-hospital patients, especially preventing onset SCD by an early alarm. Due to not only real-time but continuous long-term tele-monitoring of ECGs, geographic position, and the functions of Real-time ECG analysis and early diagnosis, the proposed method and monitoring system in this paper is expected to overcome limitations of the current available tele-monitoring outlined by the literature of the Section I., and become a powerful aid for clinicians to prevent SCD SCD decrease the morbidity, mortality, and disability upon utilize rapid diagnosis and effective treatment prior to event emergence.

However, It is should be noted that, before the concept of real-time and continuous tele-monitoring and localization for the out-of-hospital patients with heart disease come into being used in industry, many further research works are still needed in the future.

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V. REFERENCES

[1] J. Lin, et al. "A few evidence in patient's ECG shown high risk existed inducing syncope or SCD," *Journal of Electrocardiology*, vol. 21 (4), pp. 95-198, 2002.

[2] X. Chen, "The patient with high risk of sudden cardiac death," *The Chinese Journal of Arrhythmia*, vol. 4 (4): pp. 307-308, 2000.

[3] H. V. Huikuri, A. Castellanos, R. J. Myerburg, "Sudden death due to cardiac arrhythmias," *The New England Journal of Medicine*, vol. 345, pp. 1473-1478, 2001.

[4] Z. Fang, D. Lai, H. Song, et al. "Real-time remote portable monitoring device with automatic first-aid and localization of patients," *China Patent*. No. CN1907214, 2007.

[5] D. Lai, Z. Fang, "Real-time remote monitoring of out-of-hospital patients especially with high risk heart diseases," in *Proceeding of*

IEEE International Conference on Complex Medical Engineering, Beijing, 2007, pp. 333-336.

[6] Z. Xu, Z. Fang, D. Lai, et al. "Development of embedded mobile terminal for real-time remote monitoring of out-of-hospital cardiac patients," *Chinese Journal of Medical Instrumentation*, vol. 31(2), pp. 108-111, 2007.

[7] A. K. Joshi, P. R. Kowey, E. N. Prystowsky, et al. "First experience with a Mobile Cardiac Outpatient Telemetry (MCOT) system for the diagnosis and management of cardiac arrhythmia," *The American Journal of Cardiology*, vol. 95 (7), pp. 878-81, 2005.

[8] M. F. A. Rasid, B. Woodward. "Bluetooth telemedicine processor for multi-channel biomedical signal transmission via mobile cellular networks," *IEEE Transactions on Information Technology in Biomedicine*, vol.9 (1), pp. 35-43, 2005.