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The future of remote ECG monitoring systems

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Abstract

Remote ECG monitoring systems are becoming commonplace medical devices for remote heart monitoring. In recent years, remote ECG monitoring systems have been applied in the monitoring of various kinds of heart diseases, and the quality of the transmission and reception of the ECG signals during remote process kept advancing. However, there remains accompanying challenges. This report focuses on the three components of the remote ECG monitoring system: patient (the end user), the doctor workstation, and the remote server, reviewing and evaluating the imminent challenges on the wearable systems, packet loss in remote transmission, portable ECG monitoring system, patient ECG data collection system, and ECG signals transmission including real-time processing ST segment, R wave, RR interval and QRS wave, etc. This paper tries to clarify the future developmental strategies of the ECG remote monitoring, which can be helpful in guiding the research and development of remote ECG monitoring.

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1 Backgroud

Remote ECG monitoring systems will soon be commonplace medical devices for remote and long term physiological monitoring, especially for that of the elderly and frail patients. The systems will consist of three major components: (1) a mobile gateway, deployed on the patient's mobile device, that receives 12-lead ECG signals from any ECG sensor; (2) a remote server component that hosts algorithms for accurate annotation and analysis of the ECG signal, and (3) a point-of-care device for the doctor to receive a diagnostic report from the server based on the analysis of the ECG signals.[1] The wireless physiological information collection nodes of the wearable network will be connected to the patient's portable terminal, such as a personal digital assistant (PDA), smart phone, or other communication device, to send data. At the same time, it will also be capable of uploads, backup, analysis, and feedback of data to a remote medical service center through the internet or mobile communications network.

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2 Wearable systems

The wearable health monitoring system can be based on a microprocessor and customization platform, smart textiles, body area network, commercial Bluetooth sensor, or mobile phone, etc. However, the variables involved in the performance of these systems are usually antagonistic, and therefore the design of usable wearable systems in real clinical applications entails a number of challenges that have yet to be addressed including sensor contact, location, rotation, signal correlation, and patient comfort, and two objective functions including functionality and wearability.[2] These variables were optimized using linear and nonlinear models to simultaneously maximize the objective functions. The methodology and results demonstrated that it is possible to overcome most of the design barriers that have thus far prevented wearable sensor systems from being used in everyday clinical practice.

Additionally, future wearable devices should rely on the body's own energy to operate. How to improve durability without reducing performance or increasing the size of the device is the challenge of designing a wearable device.

3 Packet loss in remote transmission

The use of wireless body sensor networks (WBSN) in the medical field aims at providing continuous monitoring of patients' physiological data.[3] However, the scarce resources in WBSN nodes limit their ability to cope with large amounts of traffic during multiple, simultaneous data transmissions. This will create a high tendency for congestion, causing severe performance degradation. Congestion may lead to a high number of packet loss and delays, which are dangerous and may lead to incorrect diagnoses. Yaakob, *et al*.[4] therefore, sought to improve this limitation using a novel congestion avoidance technique to avoid losing real time and life-critical medical data (e.g., electrocardiogram and electroencephalography), which are vital for diagnosis. The main idea was to integrate the existing rate control scheme of relaxation theory (RT) with a method known as max-min fairness (MMF) to achieve better performance. The MMF was accomplished using a progressive filling algorithm, which cut down excessive sending rates that could overwhelm the limited buffer in a WBSN. A preliminary analysis of the RT technique in single node was provided.

4 Hardware

The portable ECG monitor is developing toward a multichannel, new record, digital, intelligent, network sharing device that will use digital technology to improve work efficiency and accelerate timeliness. This will significantly improve the accuracy of clinical diagnoses. The research and development trends of ECG detection and analysis systems mainly include the following aspects: a compact instrument, and an acquisition synchronization of 12 channels. The portable ECG HOLTER system and the heart beeper are products of this developmental trend. Eventually, the multi-guide synchronous ECG detection system and the twelve-guide synchronous ECG detection system will replace the current application of a wide range of single-guide ECG detection systems.

5 ECG automated analysis

At present, the application of ECG automatic diagnosis technology is not very extensive; it still lacks a complete set of suitable algorithms. Therefore, much research is needed in the field of automatic ECG analysis. Abnormal change in ST morphology is an important indicator of heart disease, especially for myocardial ischemia. An automatic classification of ST morphology provides valuable information for physicians in the diagnosis of myocardial ischemia, especially in long-term and remote ECG monitoring environments. In order to provide more accurate and efficient ST morphology classifications for these applications, Xu, *et al*.[5] provided a simple rule-based ST morphology classification method that identified ST segments with the normal morphology type and five abnormal morphology sub-types, concave and convex elevation, up-sloping, down-sloping, and horizontal depression. The proposed method consisted of the following steps: (1) 0.05–45 Hz band-pass filtering; (2) Signal quality assessment; (3) R peak detection; (4) Removal of ECG beats with anomalous RR interval; (5) Identification of start and end points of ST segments; (6) Determination of sliding baseline; and (7) Rule-based morphological classification of each ST segment.

As long-term ECG recording devices continue to increase in normalcy, driven in part by the ease of remote monitoring technology, the need for automated ECG analysis also continues to grow. In Oster’s studies, a model-based ECG filtering approach to ECG data from healthy subjects was applied to facilitate accurate online filtering and analysis of physiological signals.[6] An extension of this approach was proposed, which modeled not only normal and ventricular heartbeats, but also morphologies not previously encountered. A switching Kalman filter approach was introduced to enable the automatic selection of the most likely mode (beat type), while simultaneously filtering the signal using appropriate prior knowledge. Novelty detection was also made possible by incorporating a third mode for the detection of unknown (not previously observed) morphologies, denoted as the X-factor.[6] Wrobel, *et al*.[7] presented a system for fetal home tele-monitoring with a smart selection of algorithms for signal analysis. Novelty of the proposed approach relied on smart fitting of the algorithms for analysis of abdominal signals in mobile instrumentation as well as control of the fetal monitoring session from the surveillance center. These actions were performed automatically based on the continuous analysis of signal quality and evaluation of the reliability of the quantitative descriptive parameters determined for the recorded signals. Using this approach, the amount and content of data transmitted through remote channels to the surveillance center could be controlled to ensure the most reliable assessment of fetal well-being at the lowest data throughput.

In the constrained resources of telemedicine systems, complex algorithms, delay of restrictions, and the characteristic wave location search time window should be suitably decreased for the real-time processing of dynamic ECG signals. ECG signals in the time domain, frequency domain, and wavelet domain of feature information will be extracted. The man-machine interface will be friendly and easy to operate. The pre-processing algorithm will demonstrate effective noise removal, accurate QRS wave detection, and strong anti-infection and robustness when used for the detection of unusually tall P waves and RR intervals in a large variety of abnormal waves, and also successfully suppress the effects of tall T waves, big P wave misdetection of R waves, ventricular tachycardia, and ventricular fibrillation. Furthermore, the algorithms will have the advantage in terms of false detection and missed detection rates.

6 Others

Future wearable equipment will pay more attention to the wearer’s psychology and emotional state. These devices will not only collect information, but also regulate information. Wearable medical devices will not only detect the wearer's psychological and physiological parameters, but also make regulations to the body according to the collected information. They will have more implantable and separated equipment. The terminal will also be able to collect data to be processed and send an alert of sudden illness to the patient’s family via the transmission of data.

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