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論文審査の結果の要旨

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学位論文題目

Research on ECG signal processing for QRS detection and compression in telemedicine system

遠隔医療システムへの応用を目的としたECGのQRS波検出と圧縮に関する研究

審査結果の要旨

本論文は、携帯電話/スマートホンなどのワイヤレス通信システムを利用した遠隔医療システムにおいて、心臓疾患をモニタリングするため、心電図(ECG)からパルス波形であるＱＲＳ波を検出する処理アルゴリズムとワイヤレス通信システムでは必須の心電図波形データ圧縮アルゴリズムに関するものである。

心電図の前処理によって、ベースライン補正、高周波ノイズ除去を行った後、本研究で新たに提案する、wavelet変換とMMMD (multi-resolution mathematical morphological decomposition) の複合処理によって高精度にRピークを抽出できるようになり、従来法より高い、false negativeとfalse positiveの和を最小化するＱＲＳ波検出率、99.8 %を実現した。

また、本研究で検討されたmulti-lead DCS-SOMP法によるデータ圧縮と復元では、46個のECG波形に対し、復元データと元データとの二乗平均誤差２%以下で、圧縮率５以上を可能とした。

以上本研究は、心電図モニタリングをワイヤレスで行う遠隔医療においてキーとなる高精度なＱＲＳ波検出法、心電図データ圧縮法を明らかにしたものであり、本論文は博士（工学）の学位授与に値するものと判定する。

なお，本論文の審査には、木内陽介名誉教授、芥川正武講師の協力を得た。

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論　文　内　容　要　旨

報告番号	甲　先　第　２００　号	氏　名	Pu Zhang
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内容要旨

According to research report by WHO, Cardiovascular diseases (CVDs) killed an estimated 17.3 million people in 2008, representing 30% of all global deaths. And the number of death because of CVDs will increase to reach 23.3 million by 2030. Eletrocardiogram (ECG) signals acquire cardiac electric activities, which indicate complicated depolarization and repolarization of ventricle and atrium. The waveform pattern and characteristics of ECG signals usually correspond to physiological and pathological changes of heart and human body. Therefore, it becomes a critical index for monitoring patients' situation. Also, ECG signals are the fundamental information to transmit when realizing Telecardiology system as an important sub-system in Telemedicine.

However, ECG signals collected by noninvasive surface electrodes are several kinds of noise, and pre-processing should be used for validity of following processing procedures. Also, waveforms variation is the main reasons for the hard realization of 100% waveform detection, auto diagnosis and RR interval decision. Besides, clinical ECG data with pseudo-periodicity bring heavy burden to data storage and transmission in Telemedicine systems. At the same time, it cannot be ignored that Telemedicine systems are usually based on wireless transmissions and terminals with limited resources.

Based on traditional ECG pre-processing methods and the characteristics of limited resources, ECG processing in Telemedicine system mainly relates to three aspects. Firstly, ECG generation models should be studied. This is helpful to unify performance evaluations for following processing procedures and algorithm design of waveform classification and auto diagnosis. Secondly, we should focus on implementation of acquisition of ECG signals, pre-processing, QRS detection and compressing method on resource limiting telemedicine devices. Finally, it is important to design a reconstruction algorithm with better fault tolerance ability at the receiver.

This thesis focuses on ECG processing methods in Telemedicine system, which include pre-processing, QRS complex detection, compression and reconstruction. And mainly five kinds of methodologies are adopted to design ECG processing algorithms: Wavelet transform, Hilbert transform, Mathematical Morphology, multi-resolution decomposition and compressive sensing.

Wavelet transform is an efficient time domain analyzing and coding tool and can be used in ECG signal denoising, QRS complex detection and compression, as described in Chapter 2. Hilbert transform is also useful in QRS complex detection. Furthermore, Hilbert-Huang transform can decompose the ECG signal by EMD method, which is more efficient in R peak detection. And Hilbert spectrum analysis has recently been adopted as a technique for measuring arrhythmia.

Then ECG pre-processing algorithms based on lifting scheme constructing morphological multi-resolution decomposition (LMMD) were studied. The target for pre-processing is to filter noises with as low as possible waveform distortion. The algorithm adopted cubic spline interpolation for predicting and updating operators

design to effectively reduce the block effect. The method has been tested in a standard simulated ECG signal with noise and baseline drift, MIT-BIH Arrhythmia Database and ECG signals collected from the hospital. All the simulation results show that the proposed pre-processing algorithm is effective in baseline correction and noise suppression.

QRS complex detection methods based on LMMD, Hilbert transform and combination of LMMD and wavelet transform (WMR algorithm) have been studied in this thesis. Also R peak search-back algorithm is necessary to avoid false detection and leak detection. These methods have been tested in MIT-BIH Arrhythmia Database and ECG signals collected from the hospital. And WMR algorithm is proved to have priority in detection accuracy and robustness to abnormal waveforms. R peak detection results can be used not only as cardiac cycle division for signal compression, but also in PTT calculation for BP estimation, which is also testified in Chapter 4.

Finally, ECG compression and reconstruction algorithms based on compressive sensing were studied. The particular requirements in ECG compression and reconstruction were to achieve the tradeoff between compression ratio and waveform distortion. This thesis improved compression and reconstruction algorithm based on distributed compressive sensing reformed the multi-lead ECG signals and reconstructed signals by distributed simultaneously orthogonal matching pursuit algorithm. Furthermore, by using part known conditions such as QRS complex position and sparse coefficients, it could reduce iterations further. Under high fidelity condition, this algorithm achieved superiority in compression ratio with robustness and easy implementation in transmitter. Also it could utilize the wavelet transforming results from QRS complex detection to reduce calculating quantities further.