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HEART MONITORING VIA WIRELESS ECG

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Abstract- The monitoring of heart had been a complex task. Acquiring ECG of the chronic patient spending most of their time outside the hospital had been a trivial task. Recording of ECG of such patients using wireless method is further challenging. This paper presents various methods of wireless ECG acquisition, their limitations and challenges. Cardiomobile, Flexible wireless ECG are the examples of such systems that are available in the medical world for wireless ECG.

Keywords*- ECG, QRS-detection methods, Wireless ECG*

I. INTRODUCTION

An Electrocardiogram (ECG) is a bioelectrical signal that provides important information regarding the performance of the heart. The ECG is the most useful and feasible diagnostic tool for initial evaluation, early risk stratification and triage for cardiac ailments. ECG signal consists of a recurrent wave sequence of P-wave, QRS-complex and T-wave associated with each beat. An electrocardiogram is also known as EKG which is abbreviated from the German word Elektro-Kardiographie. Each electrode will give information about the functional status of the heart with a different point of view. This information has to be extracted and analyzed before any useful and meaningful ECG interpretation can be made. Extracting this information from ECG signal has been found very helpful in explaining and identifying various pathological conditions of the heart. ECG provides information for the detection, diagnosis and therapy of cardiac diseases. However, the complexity and the duration of ECG signals are often quite considerable making the manual analysis a very time-consuming and limited solution. In addition, manual feature extraction is always prone to error. The use of ECG during the routine clinical examination has lead to a large number of ECGs to be analyzed. In the past, cardiologists used to perform visual ECG analysis. Now a days computer programs are being used for ECG analysis to reduce the work load on physicians as well as to reduce the chances of error. Therefore, automated ECG signal processing has become an indispensable and effective tool for extracting clinically significant information from ECG signals, for reducing the subjectivity of manual ECG analysis and for developing advanced aid to the physician in making well-founded decisions. Over the past few years automatic analysis of ECGs has gained more and more significance in the field of clinical ECG diagnosis. ECG analysis systems are usually designed to process ECG signals measured under particular conditions, like resting ECG interpretation, stress test analysis, ambulatory ECG monitoring and intensive care monitoring.

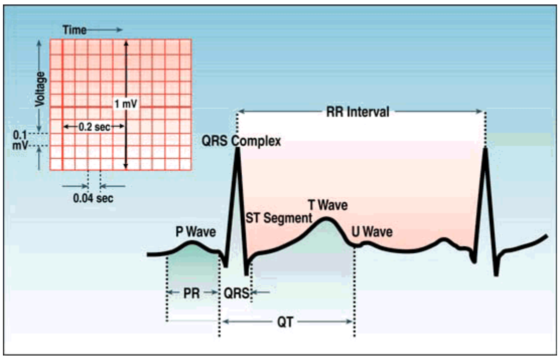

Fig. 1 ECG Signal

The shape of the ECG waves that are recorded by ECG machine may vary from patient to patient and they may assume various shapes even for the same patient. Additionally the ECG records may be corrupted by various disturbances such as power line interference and baseline wander. However, an ECG is a valuable source of information regarding activity of patient's heart.

In these days, computer based ECG analysis plays an important role in assisting physicians in the treatment of cardiac diseases. Significant amount of research has focused on the development of algorithms for the accurate diagnosis of cardiac diseases. Pipberger and his team were the first who attempted to differentiate between normal and abnormal ECGs with the help of a computer program in 1957. The first commercially available programs were introduced in the early 1970s. The computerized ECG analysis systems have now became more sophisticated but less expensive with the use of low cost and high speed computers with massive memory. The use of computerized ECG analysis has increased rapidly in health care over the last 30 years. In 2003, the American Heart Association and the American College of Physicians recommended the use of computer-assisted ECG interpreters in all the 12-lead ECG instruments. As a step towards automated health care, there is need to develop automated methods for ECG analysis and diagnosis. Considerable work has been contributed by many researchers; still lot of room is left to bridge the gap due to the shortcomings of these methods.

II. QRS-COMPLEX DETECTION

ECG is characterized by a recurrent wave sequence of P, QRS and T-wave associated with each beat. The QRS-complex is the most striking waveform, caused by ventricular depolarization of the human heart. The QRS-wave is used as the basis for faithful heart disease diagnosis, for carrying out studies on HRV and for analysis of arrhythmia. A good amount of research work has been carried out during the last four decades for the accurate and reliable detection of QRS-complex in the ECG signal.

The QRS-detection algorithms developed so far can be broadly classified into the following following main categories:

a) Heuristic methods
b) Digital filters and correlation approach
c) Mathematical transformations
d) Pattern recognition techniques
e) Artificial neural networks and fuzzy logic
f) Genetic algorithm based techniques
g) Statistical pattern recognition techniques

a) Heuristic methods:
The first category uses heuristic methods, which are based on the temporal characteristics of the signal such as its amplitude, first and second derivative. These methods are noise sensitive but simple to implement. Pan and Tompkins have developed a real-time algorithm for the detection of QRS-complexes of the ECG signal. It reliably recognizes the QRS-complexes based upon digital analysis of amplitude, slope and width. Fraden and Neuman used amplitude and first derivative to detect QRS-complex, Fancott and Wong and Cox et al. used first derivative. When it exceeds threshold it detects QRS-complex. Murthy and Rangaraj used transformed first order derivative of amplitude for detection of QRS-complex. Ahlstrom and Tompkins used both first and second order derivative for detection of QRS-complex. Engelse and Zeelenberg used the sum of rectified smoothed first derivative and rectified second derivative is used to set primary and secondary thresholds. If the sum of first and second derivative exceeds secondary threshold, a QRS-complex is detected but this algorithm is noise sensitive.. The Hilbert transform and the squaring function performs better as compare to the second derivative

b) Digital filters and correlation approach
The second category of algorithms uses digital filters and correlation approach for QRS-detection. These include matched filters, band pass filters and notched filters. QRS detection algorithms use a filter stage prior to the actual detection in order to attenuate other signal components and artifacts, such as P wave, T wave, base line drift and in coupling noise. Whereas attenuation of the P and T wave as well as base line drift requires high pass filtering, the suppression of in coupling noise is usually accomplished by a low pass filter. The digital filter is followed by a matched filter for further improvement of the signal to noise ratio (SNR).

Okada reported a five step digital filter, which removes components other than those of QRS-complex from the recorded ECG. The final step of the filter produces a square wave and its on-intervals correspond to the segments with QRS-complexes in the original signal. Thakor et al. carried out power spectral analysis of ECG waveform, as well as of isolated QRS-complex and episodes of noise and artifacts. A band pass filter has been used to maximize the signal to noise ratio for the detection of QRS-complex. Due to the inherent variability of ECGs from different persons, as well as variability due to noise and artifact, the filter design is sub-optimal in specific situations. McClelland and Arnold developed QRS-detection algorithm using band pass filters for computerized ECG monitoring.

None of the algorithms were able to detect all QRS-complexes without any false positives with all types of noises at the highest level. Algorithm based on amplitude and slope had highest performance for the ECG corrupted with EMG. An algorithm using a digital filter had the best performance for the ECG corrupted with composite noise.

c) Mathematical transformations
In the third category, various mathematical transformations, namely Fourier transform, cosine transform, differentiator transform, Hilbert transform and wavelet transform are used for the QRS-detection. The use of these transforms on ECG signal helps to characterize the signal into energy, slope, or spike spectra and thereafter, the temporal locations are detected with the help of decision rules like thresholds of amplitude, slope, or duration. The transformation results in a single positive peak with no ripples for each ECG cycle with maximum value occurring at the end of the QRS-complex. The maximum value is used for QRS-detection. Saxena et al. developed an adaptive symmetric wavelet for the detection of the QRS-complexes. This wavelet adjusts its threshold according to the amplitude of the ECG signal. There are some algorithms, which work on the use of mathematical approaches like mixed mathematical basis function, mathematical models, mathematical morphology, spatial velocity function, entropy concept and averaging techniques. Naima and Saxena have presented two approaches for feature extraction of the ECG signal for computer-aided analysis. The first approach is based on mixed mathematical functions and second one on spline functions. These methods also identify and separate P, Q, R, S and T-

segments. These methods are suitable for memory based manipulations and mapping type microcomputer based biomedical instruments. Mehta et al. used entropy criteria for the generation of feature signal for the detection of QRS-complexes

d) Pattern recognition techniques

Fourth category uses pattern recognition techniques for the detection of QRS-complex. In syntactic approach of ECG pattern recognition, the ECG signal is first reduced into a set of elementary patterns like peaks, durations, slopes and inter-wave segments and thereafter rule based grammar is used. The signal is represented as a composite entity of peaks, durations, slopes and inter-wave segments. These patterns are then used to detect the QRS-complexes in the ECG signal. The methods of this category are time consuming and require inference grammar in each step of execution for QRS-detection. Even then the motivation for using syntactic approach resides in the fact that human inspection of ECG waveforms is firstly an extraction of structural and qualitative information. Once this information has been obtained and some typical forms (like a QRS-complex) have been recognized, the numerical values of the durations and amplitudes useful for diagnosis are measured.

Mehta et al. used pattern recognition technique for the detection of QRS-complexes in the ECG signal. Lin and Chang, Pietka , Udapa and Murthy used synaptic method for QRS-detection. In this a set of primitive are decided which should provide adequate description of ECG. Then parameter such as slope and height are determined. This method is based on the assumption that the ECG is composed of peaks and segments, which are primitives that constitute the ECG. Peaks are combined to form complex. The complex and segments are combined to form cardiac cycles.

e) Artificial neural networks and fuzzy logic

Fifth category uses artificial neural networks and fuzzy logic to detect QRS-complexes. In these approaches, basic methodology is to learn and later on to generate the knowledge gained through the learning process to identify the known QRS-complexes out of an exhaustive set of the ECG segments. The accuracy and reliability of QRS-detection by these methods is dependent on the used training set. The artificial neural network based method developed by Vijaya et al., works on high prediction error to indicate the occurrence of QRS-complexes. Mehta et al. used error back propagation artificial neural network for the detection of QRS-complexes in 12-lead ECG. Garg used average slope of the 12-lead ECG signal for QRS-detection using artificial neural networks. Saini proposed a combined entropy criteria for the QRS-detection using artificial neural networks. Suzuki has developed a self-organizing QRS-wave recognition system using neural network. Osowski and Linh used fuzzy hybrid neural network for QRS-detection.

Chouhan and Mehta proposed a technique of adaptive quantized threshold for the detection of QRS-complexes in single-lead electrocardiogram. This adaptability approach enhances the QRS-detection rate by a considerable extent and reduces the percentage of false detections, but at the same time, increases the computations as it involves learning phase (determination of adaptive model parameters) and repetitive calculations to optimize the threshold limits for amplitude, slope and durations.

f) Genetic algorithm based techniques

The sixth category uses genetic algorithm based techniques. Genetic Algorithm is inspired by Darwin's theory about evolution. This very simplified model of genetics and natural selection is the basis of the genetic approach to optimization. Poli et al. used genetic design of optimum linear and non-linear QRS-detectors. Olmez et al. classified the EGG waveforms by using genetic algorithm. Gacek and Pedrycz developed genetic based segmentation technique of ECG. Bansal proposed a classifier for the delineation of QRS and Non-QRS regions by finding the optimal hyperplane using genetic algorithm in which signal entropy is used for the generation of the feature signal. Mehta and Lingayat applied Genetic Algorithm for ECG Pattern Recognition and Detection of QRS complexes in Pricordial Leads of ECG using Genetic Algorithm.

g) Statistical pattern recognition techniques

The seventh category uses statistical pattern recognition techniques. In syntactic approach of ECG pattern recognition, the ECG signal is first reduced into a set of elementary patterns like peaks, durations, slopes and inter-wave segments and thereafter rule based grammar is used. The signal is represented as a composite entity of peaks, durations, slopes and inter-wave segments. These patterns are then used to detect the QRS-complexes in the ECG signal. The methods of this category are time consuming and require inference grammar in each step of execution for QRS-detection. Even then the motivation for using syntactic approach resides in the fact that human inspection of ECG waveforms is firstly an extraction of structural and qualitative information. Once this information has been obtained and some typical forms (like a QRS-complex) have been recognized, the numerical values of the durations and amplitudes useful for diagnosis are measured.

Classifiers like Support Vector Machine, K-means algorithm, Fuzzy C-means algorithm are also reported in literature which detects QRS-complexes successfully in the single lead as well as 12-lead simultaneously recorded ECGs. Mehta and Lingayat applied support vector machine for the detection of QRS-complexes in single lead as well as simultaneously recorded 12-lead ECG signal. Slope, entropy, and combined entropy criterion has been used for the generation of feature signal which is further used for the detection of QRS-complexes using support vector machine. Digital filtering techniques are used to remove power line interference and baseline wander present in the raw ECG signal. They obtained encouraging results, when validated on the data-set 3 of the CSE multi-lead measurement library. Classifier like Fuzzy C-means algorithms is also applied by Mehta et al. effectively for the automatic detection of QRS-complexes.

III. LIMITATIONS OF CONVENTIONAL ECG OVER WIRELESS ECG

A wireless ECG monitoring system solution is to replace the leads used in normal ECG monitoring system with a wireless solution. The ultimate goal would be that the patient would simply have electronic patches on and hence be free to move about. For a wireless solution to exist, the solution must be easy to operate, capable of handling hospital conditions, reliable and extremely low powered as wireless devices need to obtain power in some manner. Following are the limitations:

- Conventional ECG System has the main limitation of conventional ECG equipment using wired electrodes is that the patient is hard wired to the monitor thereby limiting the mobility of the patient.

- Another limitation of conventional ECG equipment is false detection of cardiac alarms due to the lead wires rubbing together as well as poor transmission signal in lead wires.

- Another limitation of conventional ECG equipment is the tangling of lead wires and the time spent attaching and detaching lead wires when moving a patient in the care facility.

- A very serious limitation of conventional ECG equipment is that 77% of ECG telemetry leads are cleaned by standard hospital methods with one or more antibiotic-resistant pathogens. These pathogens enter the blood stream through open wounds which put at risk the health of injured and post-surgical patients.

IV. LATEST WIRELESS ECG SYSTEM

The design of portable systems for remote monitoring of cardiac activity is one of the most important fields in telemedicine and telecare. A mobile monitoring system with low-cost hardware equipment will be described together with wireless transmission utilizing Bluetooth for real-time ECG acquisition, measurement, archiving and visualization in both mobile phones and PCs. The mobile phone in turn analyzes and plots the received ECG signal using special application software. Modern smart phones are very capable of this kind of task thanks to their good transmission performance and processing capabilities. Many systems include a location-based service (GPS module) to localize a patient in case of emergency.

CARDIOMOBILE

The device known as 'Cardiomobile' which is a heart monitoring system acts as a mini ECG that can be carried anywhere anytime. This is conceptualized by scientists at Queensland University of Technology's Institute of Health and Biomedical Innovation. The mini ECG is a unique device that is developed by Alive Technologies a Gold Coast company. This system allows people who have been in hospital for a heart attack or heart surgery to undergo a six-week walking exercise rehabilitation program wherever it's convenient, while having their heart signal, location and speed monitored in real time. All that a patient needs to do is attach the mini ECG monitor to their chest and wear a cap having a lightweight GPS receiver attached to it. Both these ECG and the GPS receiver are then supposed to be connected to a mobile phone via Bluetooth. Patient's phone is at the start of their scheduled session and then their heart signal, location, speed and gradient are monitored in real-time over the web by a qualified exercise scientist, who guides the patient's program and checks their progress. Cardiomobile proves to be successful. It will not only help people to recover without undergoing the conventional rehabilitation process but also cut down the number hospital visits and re-admissions.

Fig 5. Cardiomobile

WIRELESS ECG MONITOR

Electrocardiogram monitoring system uses two-way radios that facilitate patient mobility and ambulation. Fig 3.shows the LifeSync Wireless ECG System. This technology has been used in the hospital's Intensive Care Unit (ICU) and Cardiac Care Unit (CCU), ECG (electrocardiogram) system enabled by Bluetooth wireless technology. The LifeSync System is the first monitoring system that eliminates lead wires and trunk cables between patients and bedside, 12-lead or transport ECG monitors.

Fig.2 LifeSync Wireless ECG System

The LifeSync System employs two-way radios that collect and transmit patient ECG and respiration data to existing ECG monitors and replaces lead wires with a disposable LeadWear system. The LifeSync System is designed to save critical nurse. Time by eliminating the need to detach and reattach lead wires when transporting patients and also facilitates patient mobility and ambulation. The system provides the opportunity for enhanced patient comfort and may reduce the risk of cross contamination from reuse of lead wiresECG and other vital sign monitoring are conducted continuously in critical care environments such as the intensive care unit (ICU), coronary care unit (CCU) and cardiac catheterization and diagnostic stress testing labs. ECG is also routinely performed in physician offices and other medical facilities.

Fig.3. Monitor & Patient Transceiver

WIRELESS ECG PATCH

The ECG patch is a hybrid system combining electronic assembly on a flexible Polyimide substrate and textile integration. This allows achieving flexibility and stretchability. Standard ECG electrodes are used for attachment to the body. The ECG patch can fit body curves and allows optimal, personalized, placement of the electrodes. It can therefore be used to monitor cardiac activity 'on-the-move' in daily-life conditions, thus opening new perspectives for cardiovascular disease management. It can be placed on the arm or on the leg. The core of the wireless ECG patch consists of a miniaturized wireless sensor node integrated on a flexible Polyimide substrate. It includes a miniaturized rechargeable Lithium-ion battery. The battery is placed under the electronic components to ensure the local rigidity required for long-term functioning of the electronic components. In addition, the sensor node features a fork-antenna and a snap-on connector (for connection to the electrode).

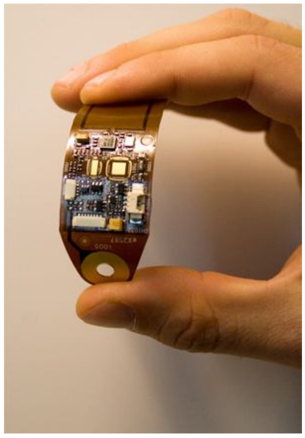

Fig.6. Wireless ECG Patch

The wireless ECG patch can work in continuous monitoring mode in which the ECG data is continuously transmitted to the receiver (sample frequency between 250 and 1000Hz). For cases in which only heart rate information is required the heart rate can be computed locally on the node and then sent over-air to the receiver. This allows drastic reduction of the use of the radio and hence increases the autonomy of the system. The embedded miniaturized rechargeable battery offers a capacity of 175mAh which allows for an optimal autonomy of the system varying from one day in continuous monitoring to several days for simple heart rate monitoring. The signal is sent to a receiver connected to a PC or to a data-logger for later download on a computer.

V. CONCLUSION

The ECG signal provides important information about the electrical activity of the heart. Each electrode will give information about the functional status of the heart with a different point of view. This information has to be extracted and analyzed before any useful and meaningful interpretation of ECG can be made. Extracting this information from ECG signal has been found very helpful in explaining and identifying various pathological conditions of the heart. Therefore, automated ECG signal processing has become an indispensable and effective tool for extracting clinically significant information from ECG signals, for reducing the subjectivity of manual ECG analysis and for developing advanced aid to the physician in making well-founded decisions. The effectiveness and the accuracy of various methods have been established by testing it over large number of ECG cases of different types. With technology advances being seen all around us in our everyday life, it is extremely important to use such technology for the benefit of the community at large. Monitoring of a patient's heart condition is presently being achieved by a system using several cables wired to specific points on the patient's body to produce an ECG signal. The Wireless ECG Design reduces cables making easy and comfortable for patients. Therefore, a wireless ECG patient telemetry monitoring system that eliminates the use of wired ECG electrodes on patients which permits mobility of the patient and that utilizes disposable electrodes that communicate wirelessly with the ECG monitoring equipment. Therefore, these methods can be used for monitoring patients in intensive care units (ICU) in hospital beside routine medical check-ups.

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