International Journal of
Emerging Research in Management &Technology
ISSN: 2278-9359 (Volume-4, Issue-5)

Research Article **May 2015**

Electrocardiogram (ECG) as a Biometric Characteristic: A Review

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Abstract-

Biometric systems are mostly used as person identification or verification systems. In the last few decades, the Electrocardiogram (ECG) has been introduced as a most powerful biometric tool for personal/individual identification. ECG has unique cardiac feature to each individual which motivated its use in various identification systems. Recent developments have also shown that person identification by ECG give more reliable and accurate results than other biometric characteristics. The majority of publications in the ECG based biometrics system have focused on extracting fiducial based features for identification task of an individual. The main advantage of using ECG is that it guarantees high accuracy even in abnormal cases. Furthermore, it possesses low sensitivity to noise. In this paper, ECG is being discussed as a biometric characteristic.

Keywords- ECG; ECG fiducial method; ECG non-fiducial method; Feature extracted; Classification; PCA (principal component analysis); LDA (linear discriminant analysis); WT (wavelet transformation); LPC (Linear Prediction Coding)

I. INTRODUCTION

These days concentrated efforts have been made for the development of next generation of biometric characteristics that are inherently robust to various attacks. Various internal characteristics of human body such as veins, odour have been investigated in recent times. Similar to these characteristics there is medical biometrics that constitutes another biometric recognition category that comprises the signals which are typically used in clinical diagnostics [1].Examples of medical biometrics are the electrocardiogram (ECG), phonocardiogram (PPG), electroencephalogram (EEG), blood volume pressure (BVP) etc.

Medical biometrics has been actively investigated in last few decades [1]. However with dry recording sensors that are easy to attach even by non-trained personnel, the medical biometrics field flourished [1]. The strength of biomedical biometrics is robustness. Another advantage of using medical biometrics is there possibility to provide fresh biometric reading every couple of seconds. This paper is interested in ECG signal.

ECG (electrocardiogram) signal is one of the most prominent biomedical signal for abnormality detection. ECG captures cardiac features from individuals that are unique in nature. It describes the electrical activity of heart over time [1]. It is been recorded with electrodes attached at surface of body. The basic difference between ECG and other biometrics is that they are easy to mimic and forge, as they are external biometrics and due to this an internal biometric is far more reliable [2]. ECG is emerging as a particularly interesting biometric trait in multi-biometrics scenarios [3], as it is:

a) Originated in the body by a vital organ [4].
b) Permanently available, providing a continuous and near-ubiquitous means of recognition [4].
c) More difficult to mimic [4].

Human identification based on ECG signal can be categorized in two major classes, fiducial methods and non fiducial methods [2].

1. Fiducial methods- It rely on local features of heart beats for biometric template design, such as temporal or amplitude difference between consecutive fiducial points[1][2] [5] and utilized for identification purposes.
   The disadvantage of fiducial features is their sensitivity to noise. Moreover, detection of fiducial features in abnormal cases with arrhythmia may include errors in data [2].
2. Non fiducial method- It was originally proposed by Plataniotis et al. [12] in order to eliminate the necessity of fiducial point's localization of the ECG signal. It treat ECG signal or isolated heart beats holistically and extract features based on overall morphology of waveform [1].

The remainder of the paper is structured in the following manner. Section 2 reviews ECG as a biometric characteristic. Section 3 describes the previous literature associated with ECG data for biometric identification. Section 4 describes various steps involved in ECG system for identification purposes of an individual. Final conclusion is given in Section 5.

II. ECG AS BIOMETRICS CHARACTERISTICS

Today the use of ECG signals within a biometric system to identify individual's preliminary. ECG analysis is not only a very useful diagnostic tool for clinical proposes, but also is recently studied as a potential biometric [5]. ECG [6] is a method to measure and record different electrical potentials of the heart. Willem Einthoven developed the ECG method in the early 1900s [6].

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ECG biometric features can be grouped as either characteristic based features [7, 13] or waveform based feature [8, 9]. Characteristic based features are easy to obtain, since only the information of the ECG fiducial points in one ECG complex are required to start the extraction process. Fiducial points are the locations that correspond to the peaks and boundaries of the three major waves in an ECG trace – namely the P, the QRS, and the T waves. There are 3 peak locations (P, R, T) and 6 boundaries in a typical ECG complex.

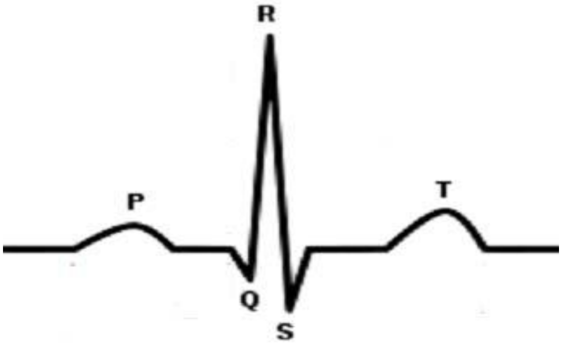

Figure1. ECG typical waveform [1]

1. The P wave describes depolarization of the right and left atria. The amplitude of this wave is relatively small, because the atrial muscle mass is limited. The absence of this wave indicates ventricular ectopic focus [1]. This wave usually has a positive polarity, with duration of approximately 120 ms, while its spectral content is limited to 10-15 Hz (low frequency) [1].
2. The QRS complex correspond to largest wave, since it represents depolarization of right and left ventricles, being the heart chambers with substantial mass [1]. The duration of this complex is approximately 70-110 ms in normal heartbeat. The anatomic characteristics of QRS complex depend on origin of pulse. Due to its steep slopes, the spectrum of QRS wave is higher compared to other ECG waves and is mostly concentrated in interval 10-40 Hz [1].
3. The T wave depicts the ventricular repolarization. It has smaller amplitude, compared to QRS complex and is usually observed 300ms after this larger complex. Its position depends on heart rate.

III. LITERATURE SURVEY

Papers Studied	**Methodology used**	**Type of Feature Extracted**	**Feature Selection Methods**	**No of subject used**
Biel[6] (2001)	1. Uses SIEMENS ECG apparatus to record. 2. Select appropriate medical diagnostic features for classification.	Temporal, amplitude and slopes	Inspection of correlation Matrix	20
Kyoso [7] (2001)	1. This system identifies the subject based on previously registered ECG feature parameters which are sampled from interval.	Duration and intervals	Second order derivative	9
Shen [8] (2002)	1. Use template matching and neural networks to classify QRS complex related characteristics. 2. This paper uses one-lead ECG signal to identify person from group.	Temporal and amplitude of the QRS complexes	Template matching and neural network	20
Palaniappan [9] (2004)	1. Uses two different neural network architectures for classification of six QRS wave related features. 2. It proposes the use of form factor of QRS segment.	Temporal and amplitude of the QRS Complexes	Form Factor	10
Israel [10] (2005)	1.Analysis fiducial based temporal features under various stress conditions. 2. ECG processed is followed is followed by logical series of experiments with quantifiable metrics. 3. Data filters are designed and fiducial points were identified.	Temporal features	Wilk's Lamda	29
Seachia[11] (2005)	1. Examined the effectiveness of segmenting ECG heartbeat into three	Fourier Coefficient of the P wave, QRS	Fourier Transform	35

	subsequences.	and T wave		
Plataniotis[12] (2006)	1. Analyze the autocorrelation of ECGs feature extraction and apply DCT for dimensionality reduction. 2. ECG biometric recognition method that doesn't require any waveform detection is introduced.	Auto Correlation	Discrete Cosine Transform (DCT)	14
Gahi[13] (2008)	1. In this paper system extract 24 temporal and amplitude features from ECG signal, which on processing are reduced to 9 most relevant features.	Amplitudes and Temporal	Information Gain Ratio (IGR)	29
Wang [14] (2008)	1. In this ECG signal is segment based on localized of R peak.	Combine analytic and appearance based feature	PCA or LDA	13
Agrafioti[15] (2008)	1. This paper demonstrates autocorrelation extraction approach. 2. It doesn't rely on feature extraction on fiducial points.	Auto Correlation Template	Matching, DCT, LDA	27
Fang [16] (2009)	1. It provides unsupervised ECG based identification method. 2. Based on phase space reconstruction of one-lead or three-lead ECG. 3. Saving from picking up characteristic points.	Phase space reconstruction	Portrait Comparison	100
Fatemian[17] (2009)	1. Less templates per subject in gallery set to speed up computation and reduce memory requirement. 2. Paper provides robust preprocessing stage that enables it to handle noise and outliers. 3. Design of personalized heartbeat template.	Discrete Wavelet Transform Coefficient	Maximum Correlation	307

IV. BASIC STEPS INVOLVED IN ECG

ECG biometric system is a pattern recognition system that operates by acquiring biometric data from an individual, extracting a feature set from the acquired data, and comparing this feature set against the template set in the database [19]. The steps involved in such a system are:

1) First the signal is acquired by the sensors.
2) The signal is preprocessed and described in a convenient representation.
3) Features are extracted.
4) A classification block processes the features and delivers a decision corresponding to system.

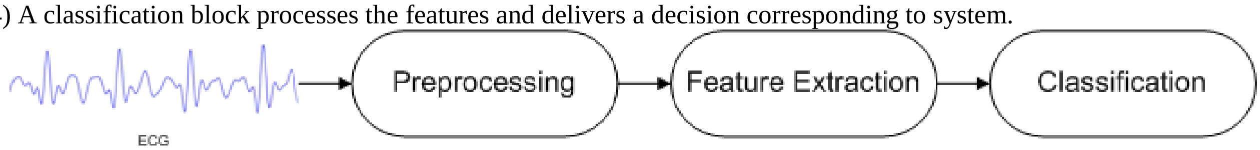

Figure2. Basic steps while processing ECG [20]

4.1 Signal Acquired

This is first most step in any recognition or verification system. In this step signal is being acquired by help of sensors and is stored in database, which is further used by system for matching purposes.

4.2 Preprocessing of ECG

ECG data collected usually contain noise. Due to presence of noise the feature extraction and classification becomes less accurate. For ideal data structure, the raw ECG data must be processed. The first step must be to identify the noisy sources. Based upon which a filter is designed and applied to the raw data. Then filtered data is used to perform feature extraction [19]. The steps involved in the preprocessing phase are: [20]

1) Digital filtering: It is most important step of preprocessing. It is used to filter unwanted noise in ECG signals. Example the digital notch filter used to remove the power line interference. A high pass band filter with a cut off frequency of 0.5 Hz is used to remove the DC offset on the acquired signal.

2) Down Sampling: It is a reliable solution for algorithm performance on high sampled signals.
3) Peak detection: In peak detection, the raw signal is digitally filtered and the peak index detected is used in the feature selection setup.
4) Segmentation: In this step particular peak of signal is identified and after identifying the points, ECG waveform is segmented into individual heartbeat.

4.3 Feature Extraction

After preprocessing features are extracted for identification purpose. The main purpose of this module is to convert the ECG waveform to some type of parametric representation for further analysis and processing [19]. A wide range of possibilities exist for representing the ECG signal for the human recognition task, such as:
1. Wavelet Transformation (WT): The wavelet transform is similar to the Fourier transform. The main difference is that the wavelet transforms uses functions that are localized in both the real and Fourier space whereas in Fourier signal are decomposed in sine and cosine waves. Wavelet Transformation is of two type's namely discrete wavelet transformation and continuous wavelet transformation.
2. Principal Component Analysis (PCA): It is dimensionality reduction technique that is often used to transform a high-dimensional dataset into smaller-dimensional subspace prior to running a machine learning algorithm on the data.
3. Linear Discriminant Analysis (LDA): It is a generalization of Fisher's linear discriminant, a method used in statistics, pattern recognition and machine learning to find a linear combination of features that characterizes or separates two or more classes of objects or events. The resulting combination may be used as a linear classifier or more commonly, for dimensionality reduction before later classification.
4. Linear Prediction Coding (LPC): Linear predictive coding (LPC) is a tool used mostly in audio signal processing and speech processing for representing the spectral envelope of a digital signal of speech in compressed form, using the information of a linear predictive model.It is one of the most powerful speech analysis techniques, and one of the most useful methods for encoding good quality speech at a low bit rate and provides extremely accurate estimates of speech parameters.

4.4 Classification

After preprocessing and feature extraction, next step is to classify the input. This is performed to check the robustness of system. There are various classification algorithms designed for this purpose, namely Bayes Network (BN), Multilayer Perceptron (MLP), Radial Basis Function (RBF) and K Nearest Neighbor (kNN) etc [24]. Based on these classifiers, it become easy for user to determine the reliability and efficiency of the any proposed technique.
1. Bayes Network:BN is a directed acyclic graph (DAG) over a set of variables called U, where U = {x1. . . xk} and k ≥ 1. BN is a network structure represented as BS and shown
as follows [31]:

$$BS = \{p\ (u|pa(u))|u \in U\} \qquad (1)$$

Where pa *(u)* is the set of parents of u in BS. Classification task begins by classifying $y = x0$ called the class variable given a set of ECG attributes, $\mathbf{x} = x1...xk$ [24]
2. Multilayer Perceptron:MLP is a feed forward artificialneural network model with one or more layers betweeninput and output layer in a directed graph. The input layerconsists of the output of the proposed biometric sample extractiontechnique, one or more hidden layers and an outputlayer which determines the subject's identity. Except for theinput nodes, each node consists of at least one neuron witha nonlinear activation function [24].
3. Radial Basis Function:RBF networks commonly have three layers:
1) An input layer.
2) A hidden layer with a nonlinear RBF activation function.
3) A linear output layer.
4. k Nearest Neighbor:kNN is an instance based learning algorithm. It defines hypothesis directly from ECG training instances and has the capability to adhere its model to previously unseen data. It searches for the most similar element to a given query element with similarity defined by the standard Euclidean distance [24].

V. CONCLUSION

ECG being non mimicable can more accurately identify a person and can offer more robust and effective human identification system. In order to provide more accuracy in identification and verification process of individual, ECG can be fused with other biometric characteristics like signature, speech etc.

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