Human Authentication Based on ECG Waves Using Radon Transform

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Abstract. Automated security is one of the major concerns of modern times. Secure and reliable authentication systems are in great demand. A biometric trait like electrocardiogram (ECG) of a person is unique and secure. In this paper, we propose a human authentication system based on ECG waves considering a plotted ECG wave signal as an image. The Radon Transform is applied on the preprocessed ECG image to get a radon image consisting of projections for θ varying from 0^o to 180^o. The pairwise distance between the columns of Radon image is computed to get a feature vector. Correlation Coefficient between feature vector stored in the database and that of input image is computed to check the authenticity of a person. Then the confusion matrix is generated to find False Acceptance Ratio (FAR) and False Rejection Ratio (FRR). This methodology of authentication is tested on ECG wave data set of 105 individuals taken from Physionet QT Database. The proposed authentication system is found to have FAR of about 3.19% and FRR of about 0.128%. The overall accuracy of the system is found to be 99.85%.

Keywords: FAR, FRR, Pairwise Distance, Pre-processing, Radon Transform.

1 Introduction

In the present times, security has become a critical issue in automated authentication systems. Biometrics is a science of identifying a person using their physiological or behavioral characteristics. Biometric traits are difficult to counterfeit and hence results in higher accuracy when compared to other methods such as using passwords and ID cards. Human physiological and/or behavioral characteristic can be used as a biometric characteristic when it satisfies the requirements like Universality, Distinctiveness, Permanence and Collectability. Moreover, one need to focus on some major issues like *Performance*, *Acceptability* and *Circumvention*[1]. Keeping all these requirements in mind, biometric traits like fingerprints, hand geometry, handwritten signatures[2], retinal patterns, facial images, ear pattern[3] etc., are used extensively in the areas which require security access.

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Most of the biometric traits mentioned above, have certain disadvantages which threaten the level of security. Some of the traits can easily be forged to create false identities. Some may be altered to hide the identity of an individual. And few other traits can be used even in the absence of the person and even if he is dead. Certain biometric traits like hand-vein patterns may fail in case of hand-injury. Though it is possible to authenticate a person with a damaged hand-vein pattern[4], it is impossible to achieve 100% accuracy as there is a limitation of threshold. To overcome these problems, several researchers moved to multimodal biometric systems. But, it is possible to have a stronger authentication system using ECG of a person as a biometric trait[5].

The heartbeat of a person is collected in the form of an electrocardiogram recording. The ECG of a person varies from person to person due to change in size, position and anatomy of the heart, chest configuration and various other factors[6]. The heartbeat of a person cannot be copied to fake identity and it cannot be altered to hide identity. And hence, ECG is becoming a promising biometric trait. Since the proposed algorithm uses single-lead ECG signal image, even a palm-held ECG machine is suitable for the authentication purpose. This kind of machines will be more robust and useful for real-time applications.

This paper is organized as follows: Section 2 deals with the related work and Section 3 presents the architecture and model. Section 4 defines the problem. Section 5 describes the implementation of the proposed algorithm and the performance analysis. Section 6 contains the conclusions.

2 Related Work

A brief survey of the related work in the area of identification using ECG waves and the significance of Radon Transforms is presented in this section. Biel et al.[7] showed that it is possible to identify individuals based on an ECG signal. The initial work on heartbeat biometric recognition used a standard 12-lead electrocardiogram for recording the data. Later a single-lead ECG was being used. Biel et al.[7] used 30 features like $P-$wave onset, $P-$wave duration, $QRS-$wave onset etc. for each person. Then the method SIMCA (Soft Independent Modeling of Class Analogy)[8] was used to classify persons. The other approach proposed by Shen et al.[9] uses template matching and a Decision-Based Neural Network (DBNN). The next promising technique for human identification using ECG was from Singh et al.[10]. In their approach, the QRS complex delineator was implemented. All these works are for human identification but not authentication. Moreover, the previous works have used geometrical features which tend to be error-prone, as a minute change in the features like angle might have been ignored during approximation and/or normalization.

Considering a graph of ECG wave signals as an image is a new approach. Swamy et al.[11] presented that the ECG wave images are more adaptable. And image processing techniques can be applied on ECG wave image, instead of taking ECG signals.

Radon Transform holds a distinguishable place in the field of biometrics. It is well known for its wide range of imaging applications. Radon transform plays a key-role in the study of various biometric traits like thyroid tissue[12], face recognition[13], gait recognition[14], iris recognition[15] etc. The Radon transform fucntion is used to detect features within a two-dimensional image. This function can be used to return either the Radon transform, which transforms lines through an image to points in the Radon domain, or the Radon backprojection, where each point in the Radon domain is transformed to a straight line in the image. In this paper, we propose a technique for human authentication by implementing Radon transform on an ECG wave image. The obtained Radon backprojection image is then used to find feature vector through Standardized Euclidean pairwise distance. Then the authentication is done based on correlation coefficient between two feature vectors.

3 Architecture and Modeling

Every individual in the organization, which adopts the proposed system for authentication, will be given an identification number (ID). Having the database of ECG wave signals of all the people in an organization consumes more space and the complexity of the system will increase. So, we suggest to store only the calculated features of ECG against every ID. First, we will acquire ECG waves from a 10-second sample of every person. The conversion of ECG wave signal format into an image will improve the adaptability and also iterative image processing techniques can easily be applied[11]. So, the acquired ECG wave is converted as a gray-scale image. Pre-processing techniques are applied to remove the possible noise occured during image conversion. The pre-processed image will undergo Radon Transform to generate Radon feature-image. The pairwise distance between the columns of Radon image is computed and the feature vector is generated. This feature vector will be stored in the database against a particular ID. During authentication, the person has to provide his ID and his ECG is captured. The feature vector is generated for new ECG wave image. The correlation coefficient between the two feature vectors is used to decide the authenticity of that person.

The architectural diagram for the proposed algorithm is shown in Fig. 1. The steps involved in the proposed technique are explained hereunder.

3.1 Data Acquisition

The proposed algorithm uses one-lead ECG waves. The ECG signals for a specific time duration are captured from a person and are plotted as a graph. The plotted graph is then converted as an image for further processing. Fig. 2 shows the ECG wave sample for one of the subjects.

3.2 Pre-processing

The converted EGG image is in RGB format and is then converted into a gray-scale image. Morphological operations like erosion and dilation are applied on

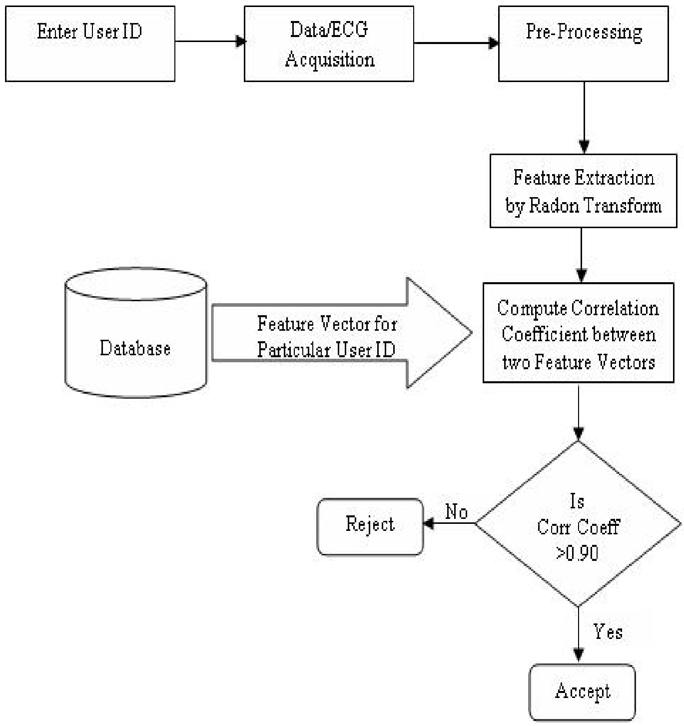

Fig. 1. Architectural Diagram

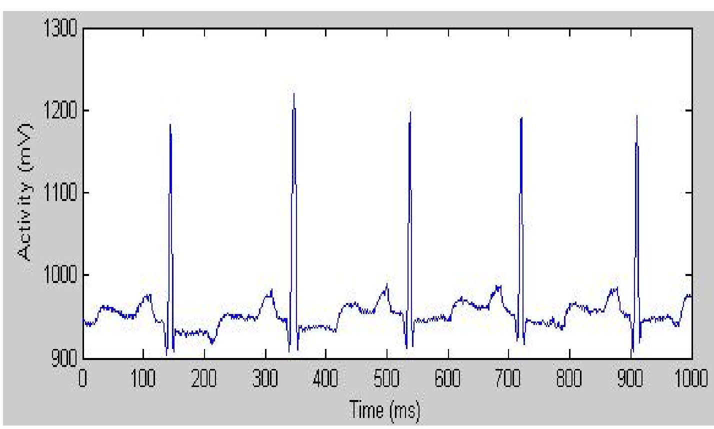

Fig. 2. ECG Wave Sample

the gray-scale image to improve its intensity. Then we apply median filter, a well-known order-statistic filter on the image. The image after pre-processing is shown in Fig. 3.

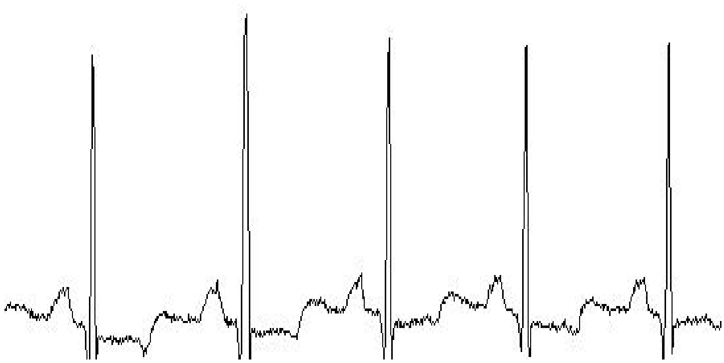

Fig. 3. Image after Pre-processing

3.3 Feature Extraction Using Radon Transform

The Radon Transform is the integral transform consisting of the integral of a function over straight lines. In other words, it is the projection of an image along specified direction[15]. Let (x, y) be the cartesian coordinates of a point in a 2D image and $u\,(x, y)$ be the image intensity. Then the 2D Radon transform denoted as $R_u\,(\rho, \theta)$ is given by -

$$R_u\,(\rho, \theta) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} u\,(x, y)\,\delta\,(\rho - xcos\theta - ysin\theta)\,dxdy$$

Here ρ is the perpendicular distance of a line from the origin and θ is the angle formed by the distance vector. In the proposed technique we have taken θ to be varying from 0^o to 180^o. The Radon transform is applied on the pre-processed ECG image. The resulting Radon image is as shown in Fig. 4.

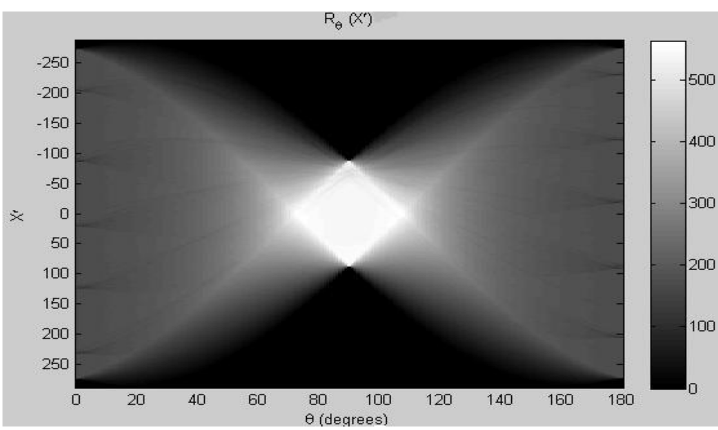

Fig. 4. Radon Image for Pre-processed ECG Image

On the obtained Radon image, we apply pairwise distance method. This method computes the distance between pairs of pixels in the image. In our algorithm, we use Standardized Euclidean distance for computing pairwise distance. Given an mxn data matrix X(in this case, image), which is treated as m (1xn) row vectors $x_1, x_2 \ldots x_m$, the Standardized Euclidean distance between the vectors x_r and x_s is defined as -

$$d_{rs} = \sqrt{(x_r - x_s)D^{-1}(x_r - x_s)'}$$

Here D is the diagonal matrix with diagonal elements given by v_j^2, which denotes the variance of the variable X_j over the m objects.

The implementation of standardized Euclidean distance on ECG image will produce a feature vector. This feature vector is then used for authentication.

3.4 Feature Matching

For authentication purpose, we use Karl Pearson's Correlation Coefficient. Correlation is a method of identifying the degree of relationship between two sets of values. It reveals the dependency or independency between the variables. If X and Y are two vectors of size mxn, then the Karl Pearson's correlation coefficient between X and Y is computed using the formula -

$$\rho_{XY} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(X - \overline{X}\right)\left(Y - \overline{Y}\right)}{\sqrt{\left[\sum_{i=1}^{m}\sum_{j=1}^{n}\left(X - \overline{X}\right)^2\right]\left[\sum_{i=1}^{m}\sum_{j=1}^{n}\left(Y - \overline{Y}\right)^2\right]}}$$

Here, $\overline{X}$ and $\overline{Y}$ respectively denote the means of vectors X and Y. The value of correlation coefficient ρ_{XY} may range from -1 to $+1$. If the value of correlation coefficient is -1, the vectors X and Y are inversely related. If the value is 0, then the vectors are independent and if the value is $+1$, then the vectors are completely (or positively or directly) related. Thus, the high degree of positive correlation indicates that the values of vectors are very much close to each other. So, if the correlation coefficient between the feature vector of database image and that of new image is nearer to $+1$, the person can be authenticated. Otherwise, the person is rejected.

3.5 Authentication

The organization which adopts this authentication technique has to create a database of feature vectors against the ID number for every individual using the process as explained in Section 3.1 to Section 3.3. The authentication process involves a series of steps as listed hereunder.

1. The person who undergoes the authentication process should first enter his ID and his ECG is captured.
2. The captured ECG signals are plotted as a graph and it is converted to an image.

3. Now, the ECG image will undergo pre-processing to remove the possible noise and to increase the intensity.
4. Radon transform is applied on pre-processed ECG image to get a Radon image. Then pairwise distance is calculated for this image to get a feature vector.
5. The correlation coefficient between the feature vector retrieved from the database and newly created feature vector is computed as explained in Section 3.4.
6. If the computed correlation coefficient is greater than a threshold value 0.90, then the person can be authenticated. Otherwise he will be rejected.

4 Algorithm

4.1 Problem Definition

Given an ECG wave signal, the objectives are:

(1) To convert plotted ECG wave format as an image.
(2) To convert RGB image into gray-scale image and to apply pre-processing techniques.
(3) To apply Radon transform to get a Radon feature image and to apply pairwise distance to get a feature vector.
(4) To find correlation coefficient to check the authenticity of a person.

4.2 Algorithms

Four major functions are involved in the proposed technique. The first function is for pre-processing the ECG image. The next function is for applying Radon transform to get a Radon image. The third function is for computing standardized Euclidean distance for each pair of rows in the Radon image. The last function is for computing correlation coefficient to check the authenticity of a person. The algorithm for computing correlation coefficient is given in Table 1.

5 Implementation and Performance Analysis

The implementation of proposed technique is developed using MatLab 7.5. The proposed algorithm is tested on ECG wave formats taken from Physionet QT database[16]. The sampling tool provided by Physionet database reads signal files for the specified record and writes the samples as decimal numbers on the standard output. By default, each line of output contains the sample number and samples from each signal, beginning with channel 0, separated by tabs. The simulation of proposed technique is done on ECG signals of 105 individuals. Various research works based on ECG waves proposed earlier like[7] and[10] were focused on Human identification but not authentication. Also, the previous works on identification based on ECG uses geometrical features which are error-prone and increases computational complexity. In our algorithm, the problems

Table 1. Algorithm for Calculating Correlation Coefficient

```
//Input: The feature vectors X and Y.
//Output: The Correlation Coefficient between X and Y.

begin
   Intialize SumX = 0, SumY = 0, SumSqX = 0,
   SumSqY = 0 and SumXY = 0
   for i = 1 to rows
     for j = 1 to columns
       set SumX = SumX + X (i, j)
       set SumY = SumY + Y (i, j)
       set SumSqX = SumSqX + X (i, j)^2
       set SumSqY = SumSqY + Y (i, j)^2
       set SumXY = SumXY + X (i, j) * Y (i, j)
     end for
   end for

   AvgX = SumX/(rows * cols)
   AvgY = SumY/(rows * cols)
   EXY = SumXY/(rows * cols)
   StdX = sqrt(SumSqX/(row * cols)AvgX^2)
   StdY = sqrt(SumSqY/(row * cols)AvgY^2)
   Corr = (EXY AvgX * AvgY)/(StdX * StdY)
end
```

Table 2. Simulation Results

Database Image	Test Image	Corr Coeff	Expected Result	Actual Result
I1	I1	0.9983	Accept	Accept
I2	I1	0.1165	Reject	Reject
I3	I2	0.1204	Reject	Reject
I4	I3	0.9106	Reject	Accept
I5	I4	0.2317	Reject	Reject

in having mass storage of ECG data is overcome by storing the features of Radon image. Since the Radon transform is used with the angles varying from 0^o to 180^o, projection in all directions has been considered. This will improve the performance of the system.

The results obtained for some of the subjects from Physionet QT database is given in Table 2. The simulation results on ECG waves of 105 individuals resulted into a confusion matrix as shown in Table 3. With the help of confusion matrix, the false acceptance ratio is found to be 3.19% and false rejection ratio is 0.128%. And the overall performance of the system is found to be 99.85%.

Table 3. Confusion Matrix

		Actual	
		Genuine	Non-Genuine
Tested	Genuine	91	3
	Non-Genuine	14	10917

6 Conclusions

In this paper, we propose an efficient way for human authentication using ECG images. The proposed technique uses Radon transform and standardized Euclidean distance to find image features in an ECG image. The features are calculated for the ECG wave format of a specific time interval taken from a person who undergoes authentication process. To infer whether the newly extracted features matches with the features stored in the database for a particular ID, we compute Karl Pearson's correlation coefficient. The proposed technique is easily adoptable in real time situations as it is based on image processing techniques rather than signals. The computational complexity found in previous works for extracting geometrical features from wave signal is reduced by considering Radon image features. The proposed algorithm uses single-lead ECG signals for imaging and authentication. Even a palm-held ECG device is sufficient to acquire the data. Hence the proposed approach is suitable for real-time application in the organization. The proposed algorithm produced promising results with 3.19% of FAR and 0.128% of FRR. The overall performance of the system is found to be 99.85%.

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