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Time Variability Analysis of Photoplethysmogram Biometric Identification System

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Abstract

This paper presents the time variability analysis of photoplethysmogram biometric identification system. There have been few researches discussing about the effectiveness of PPG signal as a biometric identification system in different time instances. PPG signals of 5 subjects were obtained from MIMIC II Waveform Database, version 3, part 3 with a sampling frequency of 125 Hz. The signals were pre-process using low pass Butterworth filter. Then, discriminating features were extracted from the PPG waveform in varying time instances (different days). Finally, this PPG samples were classified using commonly known classification techniques for person identification. Based on experimentation results, PPG signals when using LMT and FT gives identification rates of 96% for both classifiers. For sensitivity and specificity test, both LMT and FT give the accuracy of 0.96 and 0.01. The precision test gives the result of 0.962 for LMT and 0.964 for FT. Thus, this outcome suggests the feasibility and robustness of PPG signals as a biometric modality in different time instances.

Keywords: Biometric, FT, LMT, PPG Signal, Person Identification, Time Variability

1. Introduction

1.1 Background Study

It is very crucial and important today that every person identity and privacy is being protected. The reliability of traditional security system have drawbacks. Therefore, biometric identification system was introduced. Traditional identification system which is based on user's knowledge, such as passwords or Personal Identification Number (PIN), can be forgotten, smartcards and cardkey can be lost and misplaced that indicates the weakness this system.

On the other hand, biometric can provide solution for better security system and has been recognized as one of the most reliable technologies for future human recognition[1]. It is believed that biometric can solve many of the security issues and have better potential in replacing the traditional security methods.

Biometric is the identification and verification of a person by measuring or estimating their physiological characteristics[3]. According to International Organization for Standardization (ISO), biometric is defined as "the automated recognition of individual based on their behavioral and biological characteristics"[4]. It is categorized into two types; static and dynamic. Fingerprints, eye retina and iris are the examples of static biometric. Static biometric are designed to supervise and restrict access to identification system. They are relatively universal, distinct, permanent and easy to collect. However, there are few drawbacks with this static biometric and needs to be improved. There is possibility that, for example, fingerprints can be duplicated. In order to rule out the probability of any fraudster duplicating replica of the finger, there is a need of crosschecking the identity of the person by scanning from the living person. Due to this issue, dynamic biometric identification approaches were introduced.

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DNA, face recognition and fingerprints are the most commonly used biometrics where each of this biometric features has its own strengths and weaknesses depending on the application. However, in order to improve the security and reliability of the existing identification system, an alternative forms of biometric is introduced by using bio signal. Heart Rate Variability (HRV), Interpulse Interval (IPI), Electrocardiogram (ECG) and Photoplethysmogram (PPG) are examples of dynamic biometric. The traits are better when compared with conventional biometric, as their characteristics are random and time-variance[3]. Numerous biometric measures have been studied for identification purposes, however, these method are not at the same level in term of system complexity, cost and accuracy.

Therefore, this study will propose the use of PPG signals as a biometric identification system for different time instances to test the reliability of the proposed technique. PPG signals are low in deployment cost, easy to use, smaller in size and conveniently can be used to various parts of the human body such as finger, ear lobe, wrist or arm[2]. PPG is a pulsatile signal that synchronizes with the heartbeat and possesses a waveform close to the arterial blood pressure waveform obtained through direct catheterization[4].

1.2 Fundamental of PPG Signal

PPG signals is obtained using pulse oximeters to monitor the blood pressure which are non-invasive devices. Figure 1 (a) shows how the PPG is measured and Figure 1 (b) shows the received signals[5].

Figure 1. (a) Fingertip is attached with pulse oximeter to monitor the blood pressure. (b) The PPG signals obtained.

The heart is pumping the blood to all areas of human body by arteries. Blood pressure is pushed against the walls of the arteries. Systolic pressure is where the maximum blood pressure occurs when the heart is pumping in and diastolic pressure is at the lowest blood pressure when the heart is resting. Figure 2 shows the location of systolic and diastolic peak on PPG signals. PPG signals imitate the fluctuations in blood volume which is triggered by blood vessel expansion and contraction[8].

Figure 2. Systolic and diastolic peaks of PPG signals.

The remaining sections in this paper are structured as follows; the next section will review the related works biometric identification system based on PPG signals. Later, Section 3, elaborates more on the method of the study which includes the data collection procedure, pre-processing, feature extraction and the classification mechanism. After that, in Section 4, the performance of our proposed system is discussed. Last but not least, in Section 5, the study is concluded based on the experimentation and results in the previous section.

Literature Review

2.1 Related Works

Current biometric identification system which mostly employs the use of fingerprint scan have the possibility to be impersonated. In[6], proposed the possibility of using PPG as a secondary identification feature to be used with the fingerprint scanner. The morphological signal of PPG differs from one subject to another but depends on the location of the pulse oximeter when the waveform is recorded. Therefore, the technique of acquiring PPG signals need to be standardized. The data is measured by taking the reading of each finger profiles with respect to other finger profiles of the same and different subject. The study found out that, the correlation of the pulse profile of the same subject with the same finger is always higher when compared to the same finger with different subject. Besides that, it is observed the autocorrelation of the same subject with the same finger is mostly higher when compared with the same subject with different finger.

Many researchers recommend the use of PPG signals together with other biometric components to enhance the security of the system. Unseen internal organs seems to be more reliable than visible body parts as the vulnerability and the possibility of falsity become the common weakness of conventional biometric. Therefore, in[7] also proposed the use of PPG signals as the complementary feature to current identification system. The PPG signals are recorded with 37 MHz sampling frequency. The experiment was conducted with 9 healthy subjects with the average age of 34. For each subject, 8 samples were acquired where 4 in relaxed state and the remaining 4 with stressed condition. The reason being is because the study want to identify the changes in PPG signals in dif-

ferent states. The results show that, all subjects produced identical waveforms during relaxed conditions but when distressed, the waveform generated is not identical due to motion artifact. Mahalanobisdistance is used to identify the subjects by generating a matching score by the selected features resulting in the smallest distance which was considered as a match. However, the study only focuses on healthy subjects which at some conditions, this technique may not be applicable to people with heart abnormalities.

One of the obstacles faced when recording the PPG signals is that there are chances that the signals is being contaminated by motion artifact due to the movement of the finger connected to the pulse oximeter and surrounding light variation because of the environment. Thus, in another study of[8] suggests the method to extract the features that perform to offer better differentiation among subjects by applying Fourier series analysis and Semi Discrete Decomposition. The normal PPG signal is used for the training purpose and the PPG with motion artifact is used for the testing samples after going through pre-processing. Matching score is generated by the selected feature then Euclidean's distance is estimated and compared with the set of samples stored. The results found out that, after applying Fourier series analysis and Semi Discrete Decomposition, it gives better outcome in classifying individuals. However, the study is limited to only healthy subjects and does not state the effect of this method for different category of ages.

In[3] also discussed on the concept of combining both static and dynamic biometric for identification. The characteristic of dynamic biometric which are randomness and time-variance is good for generating keys for identity encryption. The data of 5 subjects were sampled at 1000 Hz to generate keys. The data are first authenticated then encrypted. After the step is done, the authenticated signal is transmitted through the network. The normalized Hamming distance between two different keys of the same signal is then calculated. In addition, the study discovers that the keys generated by the different subject at various time are discrete. Therefore, even though fraudsters were able to reveal the key generated at a specific time, the key is incomplete as the information is not in its fullest form. The study concludes that there is high benefit by applying simultaneous biometric identification and encryption because of the random and distinct characteristics of the dynamic signals. The proposed method is also proven faster as it does not require complex computation operations. However, by using this method, the cost is expensive. To reveal a key cost $1 million in average of 3.5 hours which is not practical.

PPG signals have great potential to serve as biometric identification system as they are easily obtained and low in deployment cost. In[2] proposed the feasibility of PPG signals as a biometric identification approaches in an automated way. In this study, PPG signals of 29 healthy subjects were examined with two biometric datasets. After pre-processing steps are done, Linear Discriminant Analysis (LDA) was used as feature extraction tool. The data was divided into two parts, half of the recording was used as training sets and the second half as testing sets. For classification algorithm, nearest neighbor and majority voting was implemented to identify the similarity of the input signal. Threshold is applied in order to accept or reject the input signal as the authenticated subject. The results from this study show the accuracy of this technique reaches 0.5% for false acceptance rate and false rejection rate. Although the accuracy of the PPG signals for biometric identification is high, however, the limitation of this method is that, the signals must be collected in a controlled environment in order to improve accuracy which is impossible for all conditions. A biometric identification system must be as flexible and reliable as possible in order to ensure the security of the system. Thus, the method is less practical.

In[5] suggest the continuous identification method based on PPG signals. As mentioned in[8], pulse oximeter is sensitive to the user's movements. Therefore, it is crucial to find a technique which can solve this problem. In[5] have implemented a basic automated approach to remove unwanted samples which is low in quality. For signal processing, high pass Butterworth filter is applied and the feature were extracted using modified Pan Tompkins algorithms. Based on the study, the experiment shows that, by using specific algorithm that is maximum cross-correlation, the accuracy of the biometric identification can be increased. The results also show the accuracy of the proposed method after being tested within different time period which suggests the PPG signals have sufficient distinctiveness to be applied in biometric recognition techniques. However, according to this study, analyzed features give low durability and can be improved if continuous enrollment method is adopted.

Nevertheless, most of the related works only focuses on how to obtain high accuracy of the system but neglecting some important variables that need to be considered.

3. Methodology

Figure 3 summarizes the proposed identification system which consists of the Data Collection, Pre-processing, Feature Extraction and Classification stages. Each stage will be elaborated further in the next sub-sections.

Figure 3. The proposed method used for PPG biometric identification system.

3.1 Data Collection

In this study, PPG signals were collected from Physionet, which is an online public database with the sampling rates of 125 Hz. A total of 5 PPG signals are chosen from MIMIC II Waveform Database, version 3, part 3 for two different days.

3.2 Pre-Processing

Raw PPG signals consist of unwanted and undesirable waveforms for instances noise and baseline wandering which is produced from the contiguous environment during PPG signal acquisition process. For the pre-processing stage, Butterworth filter which is a low pass filter is used to filter out these unwanted signals. The filter is a form of signal processing technique intended to have as flat a frequency response as possible in the pass band and also denoted to as a maximally flat magnitude filter. The choice of Butterworth as filter is because the advantage is it results in smooth, monotonically decreasing frequency response.

3.3 Feature Extraction

After obtaining the signals, it is segmented based on the amplitude distinctive characteristic of the wave. The highest peak as the reference point is identified and being pivot since it represents the maximum peak of the PPG signal. Based on the maximum peak, data points with equal numbers of 25 points were selected to the left and right as shown in Figure 4. This step is repeated for different time instances to collect more PPG signals for each subject to increase the accuracy of the data.

Figure 4. Segmentation of PPG signal.

3.4 Classification

In order to evaluate and classify the results, decision tree is used. Decision tree is a technique where a provided dataset is then generates a tree and a set of rules which represents the different classes of model that the data belongs to[8]. This classification method works by dividing a large number of data into a smaller set of data by utilizing a sequence of simple decision rules. For this study, FT Tree and LMT Tree are applied.

Logistic Model Tree (LMT) is a type of classification model that combines logistic regression and decision tree learning with an associated supervised training algorithm[9]. The algorithm is capable to deal with binary and multi-class target variables, numeric and nominal elements and missing attributes. Another classifier that will be used in this study is Functional Tree (FT). FT combines linear regressions with linear functions of the attributes[10]. The model is developed by using the constructor function where the number of new attributes is equal to the number of classes and the constructor function is then mapped to one new attribute. The value of each new attributes is classified by the probability to one class given by the constructed model.

The data is also evaluated by using statistical measure that are acquired after classification test. True-positive rate or also known as sensitivity indicates on how accurate the test is in identifying the positives. A test can cheat and maximizes this by always returning value "positive". Another statistical measure is false-positive rate or specificity is defined as how reliable the test avoiding false alarm. A test can cheat and maximizes this by always returning value "negative". Precision or also called Positive Predictive Value (PPV) is how much of the positively classified were relevant. A test can cheat and maximize this by only returning positive on one result it's most assured in.

4. Experimentation and Results

In this section, the experimentation and result using the proposed identification system as shown in Figure 4 is described in detail. To briefly recap, the phases involved are Data Collection, Pre-processing and Classification stages. Figure 5 shows the raw PPG signal which is taken from the Physionet.

Figure 5. Raw PPG signal from subject 1.

For biometric identification purpose, the PPG signal from the same subject is taken several times in two different days in order to evaluate the reliability of the propose identification system. Figures 6, 7 and 8 illustrate the PPG signal for the same subject at different phase of time. As can be seen, the shape of the signals is consistent

and almost identical. Therefore, we can first deduce that identification using PPG signals are reliable and can be trusted.

Figure 6. PPG signals for subject 2 on different day.
Figure 7. PPG signals for subject 3 on different day.
Figure 8. PPG signals for subject 4 on different day.

Different person gives dissimilar readings of PPG signals. The shape of the waveform, its amplitudes are also not alike. Each person has dissimilar value of heart rate which gives various readings of PPG signal. It can be seen clearly as shown in Figure 9 when we compare the PPG signal between subject 2 and 5.

Figure 9. PPG Signals for subject 2 and 5.

After acquiring the raw PPG signal, the signal is then filtered to remove all unwanted signal by using Butterworth filter in order to obtain better results as the signal will be in noise-free condition. Figure 10 shows the signal before and after the filtering process.

Figure 10. Before and after filtering process for subject 4.

After the filtering process is done, the data of PPG signals is then evaluated by using a classification tool which is Weka. Weka is a free and open source software Data Mining programming bundle written in Java. The data is classified by using LMT and FT as they give higher accuracy when compared to other classification algorithm. The purpose is to determine the accuracy of the proposed scheme. Table 1 summarizes the results.

Table 1. Classification results of LMT and FT classifiers

Classification Model	Results (%)
LMT Tree	96
FT Tree	96

Table 2. Statistical measures of the performance of the classification test

Classifier	LMT Tree	FT Tree
True – Positive Rate (Sensitivity)	0.96%	0.96%
False – Positive Rate (Specificity)	1- 0.01 = 0.99%	1-0.01 = 0.99%
Precision (Positive Predictive Value)	0.962%	0.964%

As can be observed from Table 2, after classification, the results give high value of accuracy. The system is able to classify the attributes of the PPG. Therefore, we can conclude that, PPG signal is reliable as a biometric identification technique as it is capable to detect a person even at different time period.

Table 2 shows the statistical measure of the performance for the classification test. Both LMT and FT give the sensitivity values of 96% indicating the high accuracy this test in determining the positives. For specificity, LMT and FT give the values of 99%. LMT gives the results precision of 0.962% and FT with the value of 0.964%. These results show the feasibility of the proposed system and can be implemented as biometric features.

5. Conclusion

As a conclusion, based on the results obtained, it is possible to determine a person's identity by using PPG signals even during different phase of time. Biometric mechanisms are suitable as a complementary feature for security and privacy purpose. Furthermore, the classification outcomes approach suggests that the proposed method gives significant person identification with a classification accuracy of as high as 96%. Therefore, this output indicates that PPG signal is one of the dependable and alternative sources for biometric identification.

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