Biometric Identification Using Photoplethysmography Signal

Aya Al-Sidani, Bilal Ibrahim, Ali Cherry, Mohamad Hajj-Hassan
Electronics engineering/Emphasis on biomedical engineering
Lebanese International University
Beirut, Lebanon
11330247@students.liu.edu.lb, 11230199@students.liu.edu.lb, ali.cherry@liu.edu.lb, Mohamad.hajjhassan@liu.edu.lb

***Abstract*—*Due to the increase in the importance of the electronic data nowadays, finding a way to protect this data from hacking became a must. In this paper, the Photoplethysmographic signal known as the PPG signal is used as a biometric technique due to its several advantages, most importantly its unique form that differs between individuals. The PPG signal is taken using the Spo2 sensor which is a non-invasive method used for measuring the oxygen saturation from either the finger or the ear using 2 light emitting diodes (LEDs); using this PPG signal and its 2 derivatives 40 features depending on the signals' dimensions were extracted by Matlab, and then the K-nearest neighbor classifier was applied after tuning 2 parameters (the constant k and the distance metric) to check the efficiency of this method. The proposed algorithm was tested on dataset having signals previously processed. In future work, this technique is going to be implemented to unlock computers instead of using a password.*

I. *Introduction*

With the progress in the technology, people tried to find more secure ways for authentication in many applications such as banking, protecting their properties and data… Earlier, the only ways for authentication were keys, cards, passwords, PINs, but these are found to be of low security since the keys and cards can be either missed or robbed, similarly the passwords and PINs can be forgotten, guessed or hacked through software. For these reasons, new techniques were discovered which are the biometric techniques and are used widely in the world to provide high security.

The biometric techniques are measurements based on physiological or behavioral traits in the individual; these traits should be unique, quantitative, global and invariant over long periods and the system used to extract these features should be precise, real-time, user-friendly, and resistive to spoofing [1]. Another important characteristic in a biometric system is its ability to detect if the sample belongs to a living being or is stolen from a dead person; some techniques were able to accomplish this liveness detection while others are still facing some fooling techniques and need improvement.

Biometric techniques consist of 2 steps, first the admission of the data where the patterns and templates are saved in the database known as the enrollment stage, second the examination where each acquired pattern is matched with the archived templates after extracting specific features from it according to specific methods [2]. Biometric systems are used for 2 applications; the verification application is used to prove someone's identity by matching the acquired features only by this person's stored template this is known as the positive recognition (one-to-one matching), whereas the identification application or the negative recognition is used to identify an individual by comparing his/her template with all the templates stored in the database (one-to-many matching) [1].

The proposed design in this paper is based on the Spo2 sensor that provides liveness detection since the signal needed for feature extraction, the oxygen saturation, and heart rate cannot be taken except from a living person; this trait makes this technique very difficult to be spoofed. The system used is made up by inexpensive components, provides high accuracy, and is considered nonintrusive for users since it requires only the contact with one finger, operates in real-time and is not affected by environmental conditions such as light, noise… Finally, it provides an additional feature for improving security since the photoplethysmogram signal change with psychological conditions, the individual cannot be taken as a hostage and be forced to use his signal because the system will not recognize the individual unless he/she was in a relaxed mode.

II. *Related Works*

Biometric techniques are used worldwide in many applications; each technique has its advantages and drawbacks. There are many techniques such as the fingerprint, 2D and 3D face recognition, iris recognition, retina recognition, vein pattern, hand geometry, palm print, DNA, voice recognition, signature dynamics, gait behavior… only the most used ones are discussed in this paper.

A. *Fingerprint*

The fingerprint was and still is one of the most popular biometric techniques used due to its high accuracy and ease of

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use. It is characterized by the arrangement of the ridges and valleys found on the fingers, the fingerprint is so precise that it is different between identical twins and between the fingers of one person [1]. One of the problems still facing the fingerprint method is the tendency of the fingerprint to change with age and environmental factors, also a big sector of people doesn't feel comfortable in being in direct contact with the sensor already touched by people before them [1][2]. Another problem is the ability in fooling some fingerprint readers easily if it didn't include a liveness detection technique.

B. Face Recognition

The artificial face recognition technique can be 2D or 3D, this technique demands several conditions on the process of acquiring the image like keeping the surrounding and lightening clear, the more excellent the camera is, and the more precise the outcome will be. This method has a major drawback which is its variation with age and changes in appearance; also it is affected by the light and view angle [1].

C. Iris and Retina Recognition

The pattern in the iris is highly specialized, such that it differs between identical twins and between the 2 eyes of one individual; consequently, this technique is very accurate. Also, the iris recognition technique is not annoying for the users and is widely accepted more than the retina recognition technique due to its intrusiveness. However, the procedure done to implement the iris image is complicated; also the size of the pupil can vary greatly due to the lightening circumstances [2].

On the other hand, the retina pattern is constant in all the lifespan of the individual, however, it is highly intrusive for users and it requires an expensive apparatus [2].

III. METHODOLOGY

The aim of this paper is to design a biometric method using the Spo2 sensor by extracting 40 features from the signal and its derivatives and then applying the K-NN classifier.

A. Spo2 Sensor

The SpO_2 sensor is a non-invasive method that measures the oxygen saturation which shows the amount of oxygen that is being carried by the hemoglobin; it also measures the heart rate and gives a photoplethysmogram waveform by being placed on the finger of the individual.

The SpO_2 sensor as shown in Figure 1 contains 2 light sources (LEDs); they emit red and infrared signals with 660nm and 940nm respectively since the absorption trait of the hemoglobin differs with respect to its synthetic binding and the wavelength of the light sent. The non-oxygenated hemoglobin absorbs red light (660nm) whereas the oxygenated hemoglobin absorbs infrared light (940nm). These signals pass through the blood vessels in the finger where only the unabsorbed ones reach the photodetector on the opposing side of the sensor; these signals are then sent back to the monitor for processing where the oxygen saturation is calculated and displayed.

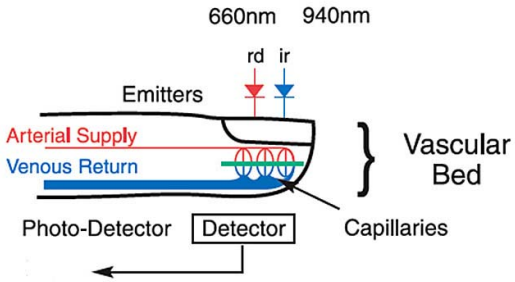

Fig. 1: SpO_2 sensor

B. Photoplethysmographic Signal

When the infrared and red light passes through the finger, they are not only absorbed by the blood vessels, but they are absorbed, scattered and reflected by other tissues, bones, skin, and arterial and venous blood. This leads to a photoplethysmogram waveform having both AC and DC components as shown in Figure 2; since the arterial blood is pulsatile and acquire AC components it can be extracted from the non-pulsatile blood and other tissues that acquire DC components.

The resulting signal has a unique form that differs between individuals which made it a good cause to be used as a biometric technique after extracting its features. It consists of 2 peaks, the first one is the systolic peak followed by a dicrotic notch and then the diastolic peak as shown in Figure 3.

C. Feature Extraction

The dataset used for feature extraction and classification was taken from the Vortal Study, National Clinical Trial no. 01472133, it consists of 57 subjects; 41 subjects belong to young people having ages between 18 and 40 years and 16 subjects to old people having ages above 70 years. All participants were healthy and no important distinction was found between female and male subjects. The data was collected for a period of 10 minutes where the participants rested down in a flat position and the PPG signals were taken from either the ear or the finger showing no difference in the signals between the ear and the finger [3]. Before the features were extracted, the first and second derivatives of the signal were computed and then 40 features were extracted using Matlab [4]. The features are shown in Figure 4 and Figure 5

- From the PPG signal: Systolic peak/amplitude (x), diastolic peak/amplitude (y), dicrotic notch amplitude (z), pulse interval (tpi), peak to peak interval (tpp), systolic peak time (t1), dicrotic notch time (t2), diastolic peak time (t3), time between systolic and diastolic peaks (ΔT), mean, variance, standard deviation.
- From its derivatives: The following points were located: from the first derivative (a1, b1, e1, and f1) and from the second derivative (a2, b2, e2, and f2), then the following feature were extracted: ta1, tb1, te1, tf1, ta2, and tb2.

- Calculated ratios: Augmentation index (y/x) and alternative augmentation index((x-y)/x), systolic peak output curve (t1/x), diastolic peak downward curve (y/(tpi-t3)), b2/a2, e2/a2 and (b2+c2)/a2, other ratios: t1/tpp, t2/tpp, t3/tpp, ΔT/tpp, ta1/tpp, tb1/tpp, te1/tpp, tf1/tpp, ta2/tpp, tb2/tpp, (ta1-ta2) /tpp, (tb1-tb2) /tpp, (te1-te2) /tpp, (tf1-tf2) /tpp.

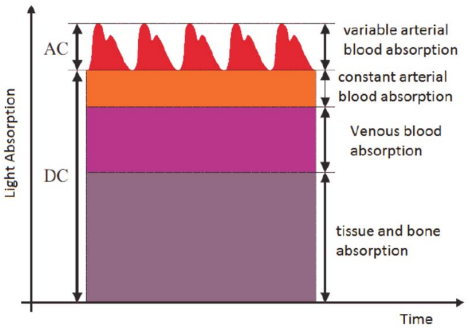

Fig. 2: AC/DC components of the signal

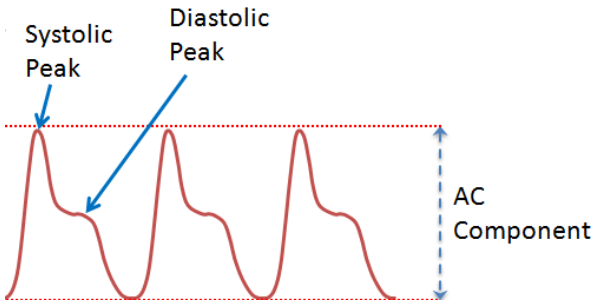

Fig. 3: The PPG signal

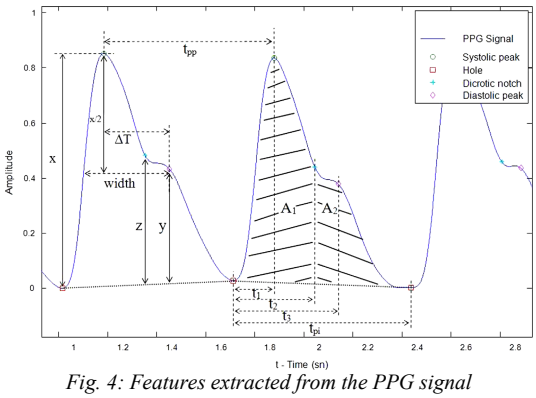

Fig. 4: Features extracted from the PPG signal

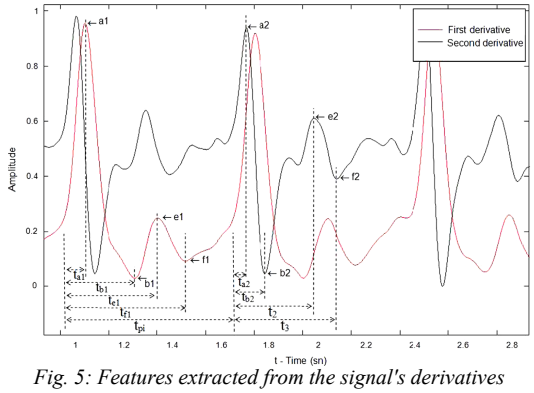

Fig. 5: Features extracted from the signal's derivatives

D. Classification

Data mining is the mechanism for finding a specific arrangement or template out of large data; Classification is one of the important data mining techniques; it is the process that estimates and forecasts the class or the category of a specific data. There are many classification techniques such as neural network, support vector machine, K-nearest neighbor, and fuzzy logic [5].

In this project we used the K-nearest neighbor method illustrated in Figure 6 since it can work with linear and non-linear data, requires only 1 parameter to be modulated (k), efficient when the training data is huge, doesn't require a training phase and doesn't demand a complicated implementation. Since it doesn't require a training phase and uses the training set at the testing phase instantly, it is considered one of the lazy learners or the instance-based learners' methods.

The K-NN technique depends on a distance metric where this distance is measured between the query points having unlabeled class and the saved training set, the k-closest samples which have the smallest distances are chosen. The most used distance is the Euclidean Distance represented by the below equation:

$$E(x, y) = \sqrt{\sum_{i=0}^{n}(x_i - y_i)^2} \quad (1)$$

In our case, the K was chosen to be 1, so that the only closest sample can be chosen to match the input signal. To make our results more accurate, the distance was tuned as well in a way that allows the rejection of the sample if the distance calculated was found to be bigger than the indicated distance; thus making our system function as a verification method rather than an identification method.

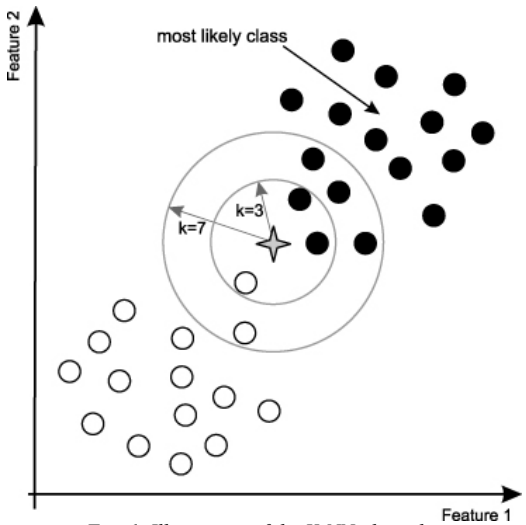

Fig. 6: Illustration of the K-NN algorithm

IV. Results

The subjects belonging to young people were divided into 2 groups, group (a) that consisted of 23 subjects where the shape of the PPG was normal consisting of 2 peaks and a notch as shown in Figure 7, and group (b) that consisted of 18 subjects where the shape of the PPG either have a smooth diastolic peak or didn't have one at all as illustrated in Figure 8, similar to the subjects of the elderly group shown in Figure 9 where the PPG waveform was changed due to aging.

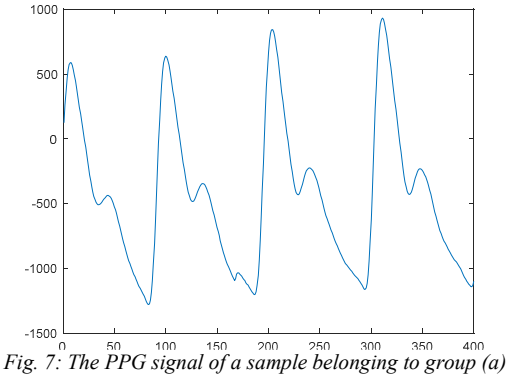

Fig. 7: The PPG signal of a sample belonging to group (a)

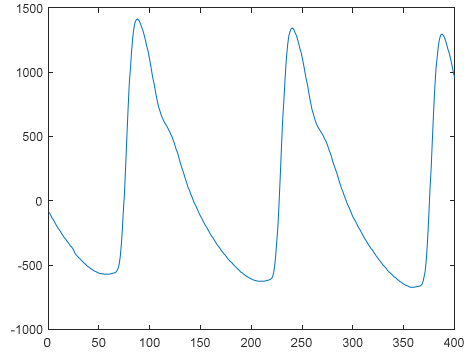

Fig. 8: The PPG signal of a sample belonging to group (b)

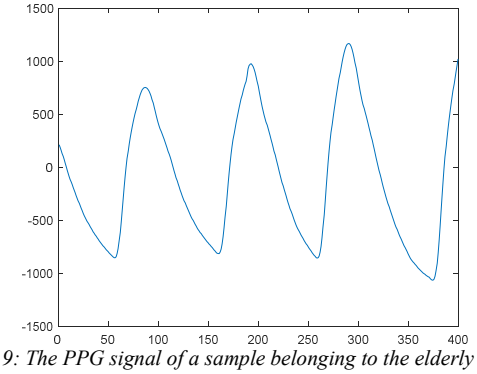

Fig. 9: The PPG signal of a sample belonging to the elderly group

A. Feature Extraction Results

The 40 features were applied to the 57 subjects found in the dataset mentioned above. The results were as follows:

- Group (a): the program functioned perfectly on all the subjects and the 40 feature were extracted correctly; the process took an average of 10s on Matlab.
- Group (b): the function wasn't able to extract the features due to the lack of the diastolic peak which is an important factor in the PPG waveform.
- Elderly group (70+): the results for this group were expected since with the advance of age the PPG signal changes its waveform and becomes smoother lacking a diastolic peak as well. So, there was no capability of extracting the features.

B. Classification Results

After applying the K-NN classifier on the 23 subjects belonging to group (a) where the features were extracted successfully, the distance was chosen empirically to be 10000 and all subjects belonging to the mentioned group were classified correctly, noting that the smaller the distance is chosen to be the more accurate the system will be.

V. Conclusion and Future Work

A. Conclusion

Feature extraction and classification were tested on a dataset containing different types of PPG signals. The results showed that the used feature extraction method was capable of extracting 40 features from the PPG signal and its derivatives in a condition that the PPG signal has its normal waveform consisting of a systolic peak, dicrotic notch and a diastolic peak. Moreover, we were able to apply the K-NN classification method in a verification manner after defining the constant k and the distance metric and the results were precise as well. However, the accuracy of using the PPG signal for biometric identification cannot be determined at this point since the signals were not being taken instantaneously but were already saved and processed using the previously mentioned dataset.

B. Future Work

This methodology is going to be implemented using Spo2 sensor and a raspberry pi and used as an application to unlock PCs instead of using a password.

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