Photoplethysmography as a Form of Biometric Authentication

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This paper explores the feasibility of using signals acquired from a photoplethysmogram (PPG) sensor, typically used in mobile devices for heart rate monitoring, as a valid input signal for biometric authentication systems. Signals were acquired from 10 individuals, generating 708 independent datasets using the Texas Instruments AFE4490/4400 integrated analog front end for pulse oximeters. Results indicate successful identification of individuals with a false acceptance rate of 4.2% and a false rejection rate of 3.7%. Because PPG signal morphology is dependent on the physical state of an individual, biometric authentication cannot occur under stress or coercion which introduces a deviation in heart rate. This technique has demonstrated to be a feasible and simpler replacement to upcoming biometric advancements such as electrocardiogram-based authentication systems, but dependence on consistent measuring conditions limits the capabilities in mobile systems.

I. INTRODUCTION

In the recent decade, proliferation of mobile devices has driven demand for high-strength security of personal and private information. While long alphanumeric passwords are the ideal method for user logon, the time required to input the characters greatly decreases the convenience of having such security. This is especially the case in mobile systems where an individual may switch the device on and off in a short period of time. Pattern-based unlocking on a grid is a more convenient alternative; however a third party looking over the shoulder would have no problem observing and memorizing the pattern. Ideally, an authentication system should both maximize the security while minimizing inconvenience. These two requirements lead us to the world of biometrics.

Biometric authentication takes advantage of the unique information that can be measured from our body. Because this data is both unique to an individual and convenient to measure, security researchers have been looking for ways to integrate biometrics as a mainstream form of secure authentication.

Fingerprints are the prevailing form of biometrics. Unfortunately, due to the ease of lifting and copying a fingerprint, all high-security fingerprint biometric systems require supervised authentication. That is, a third party needs to observe the authentication to ensure a false finger is not used. In cases where stored information is less valuable, individuals may find unsupervised fingerprint authentication acceptable.

With information requiring even higher security, we must investigate alternative forms of biometrics. Electrocardiogram (ECG) signals generated from the heart are showing signs of becoming a valid form of biometric authentication [1]. There are two main limitations with ECG biometrics. Firstly, additional electronics must be implemented into the device. This would require significant modification of the internal hardware as well as the addition of electrodes to the external chassis. Total implementation will make a great impact on device design and cost. Secondly, an ECG signal requires two hands to measure. If food is in the right hand and the device is held in the left, then ECG authentication cannot occur without awkward hand placement.

An alternative biosignal which only requires one hand would be the photoplethysmogram (PPG). A PPG sensor measures the absorption of light through a finger as the heart pulses. Current studies show that PPG signals are unique among individuals; however the results are limited with small samples sizes, poor performance, and/or little investigation into PPG variability [2,3]. With such little research available on PPG-based biometrics, we would like to further determine its potential as a valid, accurate, and secure biosignal for authentication. In addition, PPG sensors are already included in many devices and used as a heart rate monitor. Thus, no additional hardware modifications are necessary.

II. MATERIALS AND METHODS

The PPG system used for this research is the Texas Instruments AFE4490/4400 integrated analog front end for pulse oximeters. The system is small and similar to hardware that is implemented in mobile devices. A Nonin clip is attached to the device and then connected to a human finger for measurement. Raw data is recorded and exported as a text file.

For processing, MATLAB is used to import the PPG signal. To remove baseline drift and power line noise, a 6^{th} order Butterworth band-pass filter spanning 1-10Hz is applied. The result is a smooth waveform which can then be broken down pulse-by-pulse and combined to create a representative template for the individual's signal.

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The template is then used to extract physical features from the waveform as shown in Figure 1. Twenty-two features in total are computed, consisting of waveform angle, area, and inflection point data. The data is then stored as the registered user. This process is repeated for a secondary authorization attempt, and the newly computed features are compared to the stored features for determination of pass or fail.

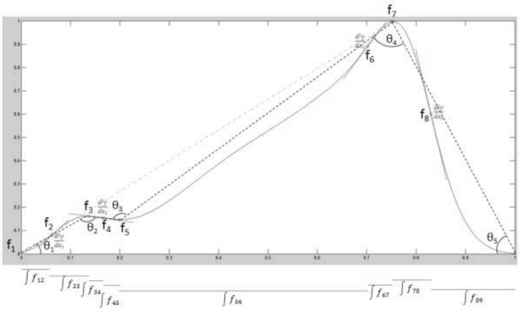

Fig. 1. Feature extraction from PPG waveform

Comparison of features can be performed using methods similar to ECG-based biometrics. Common techniques include nearest neighbor classifiers, neural networks, and support vector machines [4]. A feed-forward neural network was chosen due to the ease of programming and learning involved with small feature sets.

The experiment consisted of 708 independent data combinations from PPG data taken from 10 subjects. For neural network training, 531 of these data combinations were reserved, leaving 177 available for performance testing. After performance testing, PPG data was also tested for variability during different physical conditions.

III. RESULTS AND LIMITATIONS

Depending on the samples being compared, the biometric software will indicate "Accept" when it believes the user matches the stored profile. Otherwise, it will output "Reject." Results are shown in the confusion matrix of Figure 2. The data illustrates convergence of the neural network to a generalized set of data with false acceptance rate of 4.2%, false rejection rate of 3.7%, positive predictivity of 95.1%, and negative predictivity of 96.8%.

Based on these results, we can conclude that PPG biosignals contain uniquely identifiable information and have successfully differentiated among 170 independent measurements from ten individuals with only 7 false classifications. The next step is to investigate stability of the PPG biosignal itself.

Because the PPG waveform is determined by the flow of blood, physical conditions may impact the signal morphology. If significant changes are evident, then all variables must be held constant for PPG-based biometrics to be consistent. Figure 3 illustrates the impact of exercise on the shape of the PPG waveform. A significant increase in the amplitude of both the first peak and the dichrotic notch are evident after a moderate elevation in heart rate. In addition, arm position and skin temperature have shown to impact results.

		Expected Class	
		Reject	**Accept**
Output Class	**Reject**	92	3
	Accept	4	78

Fig. 2. Neural network performance for PPG identification

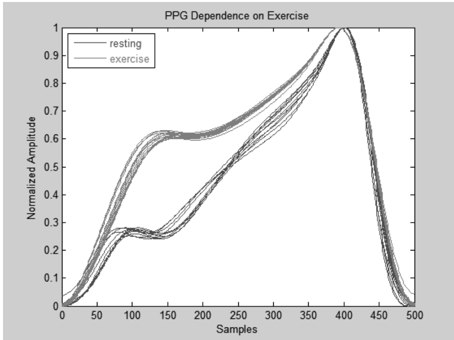

Fig. 3. Impact of exercise on PPG signal morphology

IV. CONCLUSION

In this study, biometric identification was successfully performed using a standard photoplethysmogram found in typical heart rate monitoring devices. Error rates of less than 5% indicate significance and potential viability as a biometric candidate. Future work involves expanding the dataset with increased sample size and environmental conditions. PPG sensitivity to physical conditions means the user must maintain stable conditions with respect to heart rate, arm position, and skin temperature. This additional requirement can be used as a means to prevent forced or unaware authentication by a third party, as the measuring environmental and physiological conditions will no longer be maintained.

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