Photoplethysmographic Authentication through Fuzzy Logic

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Abstract-**This paper presents a fuzzy logic approach to investigate the feasibility of using photoplethysmographic (PPG) signals as a new method for human verification. PPG signals were obtained from the fingertip with a group of seventeen healthy subjects, and four distinctive features extracted were used as the fuzzy inputs for classification. The successful rate of the fuzzy-based decision-making can reach up to 94% within the same trial, and 82.3% with two different trials. The result indicates that the new biometrics based on PPG signals is potentially applicable for human verification. This study is an addendum to our work carried out earlier. [1]**

Keywords - **Photoplethysmography, fuzzy logic, biometrics.**

I. Introduction

Automatic human authentication using biometrics is an emerging important technology to secure human interactions with safety systems. Biometric approaches today have been made possible by the explosive advances in computing power, and have been made necessary by the widespread connection of computers all over the world. Traditional ways of authentication, primarily passwords and identification cards, though still remain essential, their inevitable drawbacks with low degrees of security result in unreliable verifications. Instead, biometric applications, which use unique human physical or behavioral characteristics to automatically identify a person, are able to ensure much higher security.

Much work has been done on some biometric technologies, such as fingerprint identification, face recognition [2], retina/iris scan [3], and etc. Other human features used in this area include voice, lip [4], EEG [5] and ECG [6]. However, fingerprint can be recreated in latex; two faces can be alike, for example twins; voice can be imitated, and the methods based on EEG or ECG are to some extent cumbersome because several electrodes are required to pick up the bio-signals.

The photoplethysmographic (PPG) technique utilizes an optical sensor that produces a signal associated with change in the volume of red blood cells in the peripheral micro-vascular bed with each pressure pulse initiated by the heart [7]. Compared with other biometric approaches, PPG technique has several distinct advantages including low development cost, easy to use without any complicated procedure or special skill, and conveniently accessible to various sites of human body, such as finger, ear lobe, wrist or arm. The specific aim of this work is to study the feasibility of this new PPG approach through fuzzy logic.

II. Methodology

Experiments were conducted on seventeen healthy subjects aged 23-30. A reflective PPG probe, consisting of a LED and a photodetector, was attached on the fingertip (right index finger) by a belt. PPG signals were recorded continuously for about one minute from each person, and converted into digital signals at the sampling rate of 1K samples/s.

The raw data were preprocessed by filtering the low frequency and high frequency components. A typical PPG signal is shown in Fig. 1. Four feature parameters -- peak number, time interval, upward slope and downward slope – were extracted from the PPG signals of each subject (see Fig. 1). The enrollment template vector consisting of four averaged feature parameters was formulated for each subject. The four features are defined as follows:

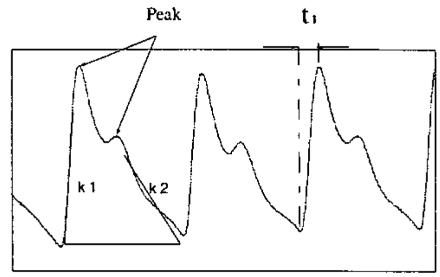

Fig. 1: A typical PPG signal with 2 peaks on each pulse of heart contraction circle.

1) The peak number M: the number of peaks on each pulse;

2) The upward slope k_1: the slope between the bottom of each waveform and the first peak;

3) The downward slope k_2: the slope between the last peak of each waveform and the bottom;

4) The time interval t_1: the time interval between the bottom point and the first peak point;

Fuzzy logic was implemented for decision-making, in which an output score was generated as the result of the comparison between the enrollment template and the newly generated one. The Gaussian Function was selected as the membership function (MF), which can be expressed as follows:

$$G\{x;\mu_{ij},\sigma_{ij}\} = \exp(-(x-\mu_{ij})^2 / 2\sigma_{ij}^2) \qquad (1)$$

where μ_{ij} is the averaged value of the jth feature parameter of the ith subject, and σ_{ij} is the standard deviation of jth feature parameter of the ith subject.

The degree of membership for each feature parameter was determined by the maximum value of the overlapped area created by the Gaussian curves of the two templates. Fig. 2 shows an example to illustrate how the approach works:

The enrollment template parameter is $t_i = 1.852 \pm 0.076$; while the newly generated template parameter is given by $s_i = 1.784 \pm 0.057$.

Inserting the two sets of parameters into (1) respectively generates two curves as shown in Fig. 2. The shadowed area is overlapped by the two curves and the maximum value is recorded as the membership degree. The values inclining towards 1 on the vertical axis indicate a good match, while those inclining towards 0 represent a poor match.

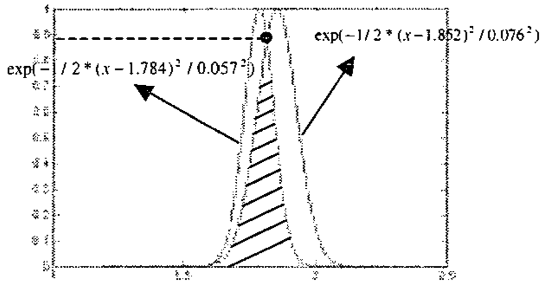

Fig. 2 The Gaussian curves generated by the two templates.

In this way, each newly generated feature parameter will produce a value compared with the enrollment template parameter. This leaves four membership values for a single subject, which must be consolidated using an AND operator to obtain a final output score that lies between 0 and 1. Normally, the fuzzy logic AND operator takes the minimum value of all the membership values [8]. However, in practice it shows that the mean value often does not reflect the true degree to which two templates match [9]. So finally, a type of MEAN operator was utilized, which takes the weighted average of the four membership values.

The verification was carried out under two situations: 1) the two templates were generated in the same trial but at different periods of time; and 2) the two templates were generated in two different trials, between two of which there was a few minutes' rest.

III. Results and Discussion

Only one out of the seventeen subjects could not be verified correctly, if the two templates were within the same trial. For those generated from different trials, the successful rate can so far reach up to 82.3% (three out of seventeen could not be verified). These false rejections were mainly attributed to the poor quality of the signals from the subjects, perhaps due to respiration and motion artifacts, which resulted in some variations in the template feature vector and a large standard deviation (SD), and hence a small degree of membership.

In this work, the PPG authentication as a new approach for human verification is investigated through fuzzy logic. The preliminary experimental results show that the PPG signals have predominant characteristics that can be used to identify different persons. With the fuzzy-based decision-making method, the rate of correct verification can reach up to 94% (one out of seventeen in error) within the same trial, and 82.3% with two different trials (three out of seventeen in errors).

The result for two different trials is not yet satisfactory, perhaps mainly due to the variations in the contacting force applied on the PPG sensor during different trials. Further research based on transmission PPG sensor is necessary, because the finger clip can possibly avoid such intra-subject variations. It is also desirable to further explore a better fuzzy implementation method such as new membership functions, to improve the performance of PPG-based authentication.

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