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Heart sound as a biometric

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Abstract

In this paper, we propose a novel biometric method based on heart sound signals. The biometric system comprises an electronic stethoscope, a computer equipped with a sound card and the software application. Our approach consists of a robust feature extraction scheme which is based on cepstral analysis with a specified configuration, combined with Gaussian mixture modeling. Experiments have been conducted to determine the relationship between various parameters in our proposed scheme. It has been demonstrated that heart sounds should be processed within segments of 0.5 s and using the full resolution in frequency domain. Also, higher order cepstral coefficients that carry information on the excitation proved to be useful. A preliminary test of 128 heart sounds from 128 participants was collected to evaluate the uniqueness of the heart sounds. The HTK toolkit produces a 99% recognition rate with only one mismatch. Next, a more comprehensive test consisting almost 1000 heart sounds collected from 10 individuals over a period of 2 months yields a promising matching accuracy of 96% using the proposed feature and classification algorithm. A real-time heart sound authentication system is then built and can be used in two modes: to identify a particular individual or to verify an individual's claimed identity.

Keywords: Biometric; Authentication; Identification; Recognition; Verification; Heart sounds

1. Introduction

In recent years, the use of a reliable authentication and identification system to identify legitimate user is becoming increasingly important in commercial application, personnel security, military, finance, airport, hospital, digital right management systems and many other important areas [1]. In fact, performance-based biometric systems whereby a person is automatically recognized by him performing a pre-defined task using his own biometrics, are preferred over knowledge-based (e.g., password) or possession-based (e.g., key) access control methods. As a result, conventional biometrics systems like fingerprint, iris, face and voice that provide recognition based on an individual behavioral and/or physiological characteristics are becoming more popular [1–4]. However, a common weakness of these system is their vulnerability to the possibility to falsify these features [2,3,5,10,11].

For increased reliability and added security, one approach is the use of multimodal biometric systems which uses multiple biometric modalities (such as face and iris of a person or multiple fingers of a person) [2]. New biometrics such as hand vascular pattern, vein, gait, human tissue, knuckle, ear canal and even evoked brain signals have also been proposed [6,7]. Current works on these areas are mainly focused on increasing the reliability and convenience of data capturing, as well as improving the system accuracy and robustness.

Beside these, the study of using the electrocardiogram (ECG) [8,9] as a biometric has also been carried out, which yields a relative high result for human identification tasks [8,9]. In Ref. [8], ECG measurements are collected from 20 male and female adults over a six week period. The training and testing set consist of 85 and 50 measurement sets, respectively, and produce a 98% recognition rate. Israel et al. [9] further investigated the effect of the state of anxiety of an individual on its ECG features through a series of high and low stress tasks. Test results show that the features extracted from the ECG signal are unique

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Table 1
Weakness of various biometric technologies

Biometric	Vulnerability
DNA	Easy to steal a piece of DNA from an unsuspecting subject
Speech	A person speech can be pre-recorded and playback
Signature	Professional forger can reproduce signature
Fingerprint, palmprint, hand and finger geometry	Can be acquired by an object touched by the person and recreated in latex
Face and iris	Can be captured by camcorder

to an individual and invariant to the individual state of anxiety. Israel et al. [9] also found that the identification performance is independent of the electrode placements. However, we note that ECG for identification is generally cumbersome due to the many (at least three) electrodes required [8].

In this work, we investigate the possibility of using human heart sounds—an acoustic signal—as a reliable biometric for human identification based on the following requirements mentioned in Ref. [2]:

(1) *Universal*: Each living human being has a heart that keeps on pumping until his death.
(2) *Quantifiable*: Heart sound can be digitally captured and measured using an electronic stethoscope.
(3) *Vulnerability*: While there are many biometric systems that are commercially affordable and reliable in the market, most of these biometrics can still be forged by a determined and trained perpetrator as demonstrated in some Hollywood thriller. In other words, these stable biometric which provide static information about the user can be copied and reproduced to fool the biometrics system [2,3,5] with the intention to commit fraud. Table 1 [10,11] summarizes the vulnerability of some commonly used biometric.

    Unlike other biometric technologies that use fingerprints, pictures or static bio-signals to identify a person, heart sound cannot be copied and reproduced easily as it is based on intrinsic human biometric dynamic signals acquired from the body. When compared with voice, we feel that the heart sound exhibits two significant advantages. First, human voice can be easily obtained using a concealed recorder without the person knowing whereas to acquire a person heart sound, the recording device has to be placed on the person chest surface, with his permission, to capture the vibrations from the heart. Second, to reproduce the same heart sound of an individual, an artificial pumping heart with the same anatomy needs to be reconstructed; the physical attribute surrounding the artificial heart must also match the same individual body structure. Hence, heart sound cannot be easily recorded and simulated accurately.
(4) *Acceptability*: Privacy issue will affect the extent to which people are willing to accept the use of their heart sound as a biometric identifier in their daily lives [12]. As the auscultation of heart sound can be used as a diagnosis to heart disease, there are fears that these sensitive medical information might be abused unethically by some who may deny benefits to a person determined to be of high risk. To alleviate these fears, legislation might be necessary to ensure that such information remains private and that its misuse will be punished. Alternatively, instead of storing the sensed physical characteristics of the original heart sound waveform, the biometric systems can store a digital representation of the heart signal (in the form of a template). Hence, privacy is safeguarded as the actual physical characteristic cannot be recovered from the digital template. Encryption can be added to ensure that only the designated application can use this template.
(5) *Usability*: With the advancement in wearable computing, wireless sensors can eventually be placed on human to capture their heart signal when they are moving or performing other activities. These signals are fed wirelessly to a remote biometric recognition system which will determine the accessibility of the person. As a result, authentication can be done even before the user reaches the gate, resulting in time saving.

    The following three factors will also be validated experimentally in the next section.
(6) *Unique*: The physical state of an individual's health, age, size, weight, height, structure of the heart as well as the genetics factors all contribute to an individual's unique heart sound. The heart sounds of two persons having the same type of heart diseases also vary.
(7) *Variability*: In a controlled environment, the human heart sound remains sufficiently invariant over a specific period of time.
(8) *Performance*: The achievable recognition accuracy and speed of the recognition system will determine it's applicability. A real-time implementation of the proposed biometric system will be discussed in the later section.

Human heart sounds are natural signals, which have been applied in the doctor's auscultation for health monitoring and diagnosis for thousands of years. In the past, study of heart sounds focus mainly on the heart rate variability [13]. However, we conjecture that since the heart sounds also contain information about an individual's physiology, such signals have the potential to provide a unique identity for each person. Like ECG, these signals are difficult to disguise and therefore reduces falsification. Moreover, heart sounds are relatively easy to obtain, by placing a conventional stethoscope on the chest, for example.

In Section 2 of this paper, we will provide the problem formulation. The use of heart sound as a biometric will be evaluated on a number of assessment criteria in Section 3, with various experiments demonstrating the effectiveness and accuracy of the proposed scheme. Next in Section 4, we will introduce the proposed biometric system and provide a detailed description of its various operations. Finally, in Section 5 of this paper, we will conclude our findings.