Finger ECG Signal for User Authentication: Usability and Performance

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Abstract

Over the past few years, the evaluation of Electrocardiographic (ECG) signals as a prospective biometric modality has revealed promising results. Given the vital and continuous nature of this information source, ECG signals offer several advantages to the field of biometrics; yet, several challenges currently prevent the ECG from being adopted as a biometric modality in operational settings. These arise partially due to ECG signal's clinical tradition and intrusiveness, but also from the lack of evidence on the permanence of the ECG templates over time. The problem of intrusiveness has been recently overcome with the "off-the-person" approach for capturing ECG signals. In this paper we provide an evaluation of the permanence of ECG signals collected at the fingers, with respect to the biometric authentication performance. Our experimental results on a small dataset suggest that further research is necessary to account for and understand sources of variability found in some subjects. Despite these limitations, "off-the-person" ECG appears to be a viable trait for multi-biometric or standalone biometrics, low user throughput, real-world scenarios.

1. Introduction

The study of Electrocardiographic (ECG) signals as a potential biometric trait can be traced back to the ground breaking works by Biel et al. [2] and Kyoso & Uchiyama [10]. Although many authors have continued to contribute to the field [8, 16, 17, 24], a limiting aspect of this modality has been the intrusiveness of the sensor device, which most often requires a multi-lead placement at the chest and limbs of the subject. The work on ECG biometrics has seen a new dawn through the introduction of "off-the-person" sensing [20], which makes the acceptability of the ECG comparable to that found in more established modalities such as the iris, palmprint, fingerprint, among others [11, 18].

In principle, the ECG is quite appealing for biometrics [18]; in light of the seven factors defined in Jain et al. [9], the ECG modality is admissible given that it can be found in virtually all living humans (*Universality*), its authentication capabilities for circumscribed groups of individuals has been shown (*Uniqueness*), it can be easily acquired using suitable devices (*Measurability*), it has been shown to perform accurately for subsets of the population (*Performance*), the "off-the-person" approach has made it acceptable (*Acceptability*), and it's not easily spoofed as it depends on an internal body organ, the heart (*Circumvention*).

Furthermore, ECG signals provide intrinsic aliveness detection and are continuously available, which are also highly desirable properties in biometrics. One of the open questions in ECG biometrics has been *permanence*, that is, the temporal invariance of the templates with respect to the matching algorithms. In this paper, we present the first small-scale study on the permanence of ECG signals collected under an "off-the-person" approach for biometric authentication, by comparing records collected at an interval of several months.

The use of ECG signals as a biometric modality can be quite useful in low security verification (1:1 matching). Also, the sensing device presented in this paper is more natural to the user, given that there is no need for an explicit interaction with the device. Our work provides two main specific contributions for the field of ECG biometrics: a) Further insight regarding the performance of "off-the-person" ECG data; and b) Across session data matching.

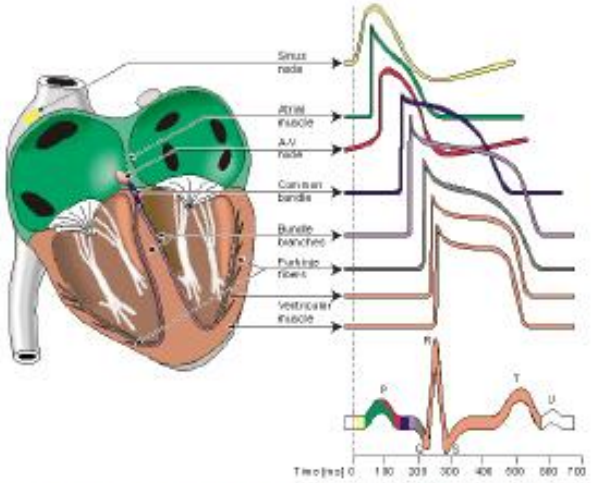

Figure 1. Waveforms collected from each of the specialized cells found in the heart, and their contribution to the prototypical heartbeat waveform (reprinted with permission from [13]).

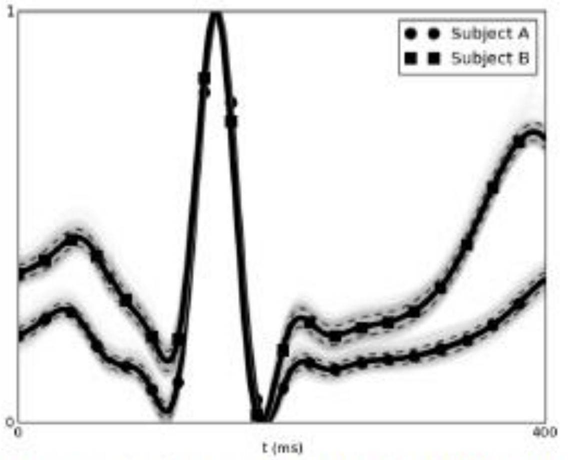

Figure 2. ECG heartbeat waveforms for two different users, illustrating the intra- and inter-class variability. In light gray we show the individual heartbeat waveforms, the solid black line depicts the mean of all heartbeat waveforms belonging to the subject, and the dashed black lines highlight the standard deviation.

The rest of the paper is organized as follows: Section 2 provides an introduction to key concepts within ECG biometrics; Section 3 describes the methodology adopted in our study; Section 4 describes the tested matching approaches; Section 5 summarizes the experimental results on real-world data; and Sections 6 and 7 present the discussion and conclusions.

2. Background

The human heart is characterized by a complex bioelectrical system, at the core of which are a set of myogenic cells whose main property is the periodic self-stimulation capability, which ultimately generates the cardiac cycle and rhythm. Today, both the heart cycle and rhythm are perfectly well-known concepts, extensively studied in the healthcare domain; the cycle is characterized by the typical heartbeat waveform (Figure 1), while the rhythm is commonly known as the heart rate. We refer the reader to the book by Malmivuo & Plonsey [13] for a detailed description of the physiological, and electrical properties of the heart.

Throughout the years, several authors have argued about the properties of the ECG as it pertains to biometric recognition [1, 14, 18]. This research has mostly focused on: a) *Recognition Methods*; b) *Template Extraction*; c) and *Sensing Devices*. Figure 2 shows an overlay of heartbeat waveforms from two subjects, illustrating intra- and interclass diferences that can be found in the ECG.

In terms of *Recognition Methods*, authors have mostly explored instance based learners [11, 16], neural networks [3, 16], statistical pattern recognition [8], and information theoretical approaches [6]; wavelets, support vector machines, and adaptive filtering techniques can also be found [5, 12]. To date, benchmarking of ECG recognition methods has been mostly based on single-session data from clinical sources or public repositories (e.g. Physionet [7]) [2, 8, 24], or acquired using custom free-living protocols [1, 17].

Regarding *Template Extraction*, existing approaches can be defined as fiducial, partially fiducial and non-fiducial. Fiducial methods use latency, slope, angle and other measurements derived from anchor points within the signal (e.g. P-QRS-T complexes), to create feature vectors that are used as input to the recognizer [2, 8, 17]. Partially-fiducial methods typically only use the R-peak to perform heartbeat waveform segmentation, adopting either the full waveform or a subset of it as input to the recognizer [11, 19, 24]. Non-fiducial methods extract information from the structure of the signals, without the need for any reference points [4, 5, 6]; these methods are especially advantageous given that the process of identifying fiducial points can be challenging.

Finally, several variations of the *Sensor Devices* can be found. Most of the work has been focused on signals collected through "on-the-person" approaches, which include multi- and single-lead clinical-grade ECG acquisition devices [2, 6, 8, 16, 17]. More recently, researchers have pivoted towards "off-the-person" approaches, enabling unobtrusive data acquisition at the hands and/or fingers [4, 11, 15, 19, 20, 26]. In this approach, methods have evolved from a 3-electrode setup (positive, negative, and ground) [11, 15, 26], to a 2-electrode setup [4, 19]. The former has been used in short- [11, 15] and long-term performance evaluation studies [26], while in the later, only short-term validation has been performed [4, 20] (i.e. using data collected over a period of a few minutes or over the whole day).