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Activity related authentication using prehension biometrics

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A B S T R A C T

This paper presents an extensive study on prehension-based dynamic features and their use for biometric purposes. The term prehension describes the combined movement of reaching, grasping and manipulating objects. The motivation behind the proposed study derives from both previous works related to the human physiology and human motion, as well as from the intuitive assumption that different body types and different characters would produce distinguishable, and thus valuable for biometric verification, activity-related traits. A novel approach for analyzing such movements is presented herein, based on the generation of an activity related manifold, the *Activity hyper-Surface*. The authentication capacity of the extracted features on the activity hyper-surface is evaluated in terms of their relative entropy and their mutual information within a complete framework targeting user verification. Experimental results on two datasets of 29 real subjects each and a third one of 100 virtual subjects show that the introduced concept constitutes a promising approach in the field of biometric recognition.

1. Introduction

Biometrics have recently gained significant attention from researchers while they have been rapidly developed for various commercial applications, ranging from access control against potential impostors, to the management of voters to ensure no one votes twice [1]. These systems require reliable personal recognition schemes to either confirm or determine the identity of an individual requesting their services. A number of approaches have been proposed in the past to satisfy the different requirements of each application, such as unobtrusiveness, reliability, and permanence.

Biometric methods are categorized into physiological and behavioural [2], depending on the type of used features. Physiological biometrics are usually based on static biological measurements and inherent characteristics of each human. The most typical example in this area is the fingerprint [3], which is widely used in law enforcement for identifying criminals [4]. Further, static biometrics include DNA, facial characteristics [5], iris [6] and/or retina [7], and hand geometry [8] or palm print [9] recognition. Despite their high accuracy, a general shortcoming of these biometric traits is the obtrusive process of obtaining the biometric signature. The subject has to stop, go through a specific measurement protocol, which can be very uncomfortable, wait for a period of time and get clearance after authentication is positive. Besides being obtrusive and uncomfortable for the user, static physical characteristics can be digitally duplicated, e.g. the face could be copied using a photograph, a voice print using a voice recording and the fingerprint using various forging methods. In addition, static biometrics could be intolerant of changes in physiology, such as daily voice changes or appearance changes.

On the other hand, recent technologies in biometrics resemble more natural ways of recognizing people. Similar to the methods or techniques humans utilize in order to recognize each other, modern trends in biometrics focus on the recognition of dynamic face grimaces, gait, movements, etc. In other words, they tend to recognize liveness rather than static features as the aforementioned traits do (fingerprint, iris, etc.). In this respect, behavioural biometrics are related to specific actions and the way that each person executes them. On the whole, behavioural biometrics are less obtrusive and simpler to implement [2,10], although they are less reliable than physiological biometrics. This way, integral drawbacks of regular biometrics can be lifted; for instance, inborn physiological

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characteristics may be mixed with stylish and behavioural ones, so that even twins can be separated.

The imposed obtrusiveness by non-behavioural biometrics lies in both the utilized sensors (e.g. fingerprint or iris reader) and the authentication procedure to which the users are subjected to. Contrary to sensor-based recognition [11] using behavioural signals, recent research trends have been moving towards the vision-based methods [12]. Additionally, recent work and efforts on human recognition have shown that there is quite a number of behavioural traits on which recognition can be based (e.g. extraction of facial dynamics features [13]). However, the most well-known example of behavioural biometrics is the human body shape dynamics [14] or joints tracking analysis [15] for gait recognition. In the same respect, the analysis of dynamic activity-related trajectories [19] provides the potential of continuous authentication for discriminating people, when considering behavioural signals.

Not rarely, action recognition approaches are utilised in biometric systems either complementarily [19] or inspirationally. Such a view-, style- and appearance-invariant enhancement of the well know Motion History Images concept for action recognition has been proposed by Vitaladevuni et al. in [46], whereby ballistic dynamics are utilised in a Bayesian network. Another view-invariant action recognition algorithm has been proposed by Cuntoor et al. in [44], whereby the actions are recognised and labelled as abnormal per case, via the detection of significant spatiotemporal changes by properly trained HMMs. Similarly, dramatic changes in the speed and the direction of the trajectory are detected in [45] by estimating the spatiotemporal curvature of the latter, via a compact and view invariant representation based on dynamic descriptors. Finally, taking advantage of the hierarchical decomposition approach of specific actions based on the detection of notable characteristic changes in the motion sequence, Tanveer Syeda-Mahmood [43] tried to resemble human perception in the video segmentation process.

In the present paper, the term *prehension-based biometric authentication* is introduced as the combination of a reaching movement and a grasping activity. This concept derives from the simple observation that a person uses/manipulates the objects in the surrounding environment (e.g. answering a phone call) with his/her own style. Prehension biometrics belong to the general category of behavioural biometrics and can also be thought of as a specialization of activity related biometrics [16,17].

Given that most of the activities performed in everyday life include the human's physical interaction either with other people or with objects, the current work attempts to detect and to evaluate a series of stable, invariant, time lasting and unique activity related biometric characteristics for each human. In this paper, the focus is on the arm's movement [19] and on the movement of the fingers. Thus, both movements are thoroughly studied during specific actions that include people manipulating objects. Although palm dynamic features have not been employed in the field of biometrics yet, significant amount of research has been performed on various aspects of dynamic palm gestures [28].

The core topic with which this study deals is introduced in Section 3 and the proposed feature extraction methodology is described in detail in Sections 4 and 5. The tools used for feature evaluation are presented in Section 6.1, while the case-study scenarios, along with the obtained results can be found in Section 7. Finally, the conclusions follow in Section 8.

2. Motivation

As mentioned earlier, recent trends in biometrics deal with analyzing the dynamic nature of various biometric traits, targeting user convenience and optimal performance in various realistic environments. Activity-related biometrics have been recently studied in [16,17], where signals from various modalities are measured, while the subject is performing specific activities. These signals are then used to create unimodal or multimodal activity-related biometric signatures of each subject. Moreover, activity-related biometrics have been proven to have the potential to discriminate accurately between subjects, while remaining stable over time for the same subject.

However, not any movement can be seen as a potential identifier. The requirements that a biometric trait should satisfy are defined below [2]:

- *Universality*: Each user should posses it.
- *Distinctiveness*: The extracted features are characterized by great inter-individual differences.
- *Reproducibility*: The extracted features are characterized by small intra-individual differences.
- *Permanence*: No significant changes occur over time, age, environmental conditions or other variables.
- *Collectability and automatic processing*: It is possible to recognize or verify a human characteristic, which can be measured quantitatively, in a reasonable time and without a high level of human involvement.
- *Circumvention*: It should be difficult to be altered or reproduced by an impostor who wants to fool the system.

Additionally, there are a number of other issues that should be considered when designing a practical biometric system, like its recognition performance (i.e. achievable recognition accuracy and speed) and the resources required to achieve the desired recognition accuracy and speed. Further operational and environmental factors, such as the frequency with which a given activity is performed on a daily basis and the degree of approval of a certain technology by the society, are also significant issues to be taken into account.

In the concept of the current study, the *Universality* requirement is satisfied by definition. Moreover, there are plenty of models which depict that the user seeks the "most convenient" and the less effort demanding way of performing each movement. Specifically, there is the *Flash and Hogan's Minimum Jerk Model* [29] which indicates that the hand paths in extrinsic space should be straight. Curved hand paths can be generated, of course, but according to this model, they must be produced by concatenating straight-line segments. Similarly, the *Uno, Kawato and Suzuki Minimum Torque Change Model* [30] assumes a hand movement according to the minimization of the torque during the movement. Based on these observations, but also on Turvey et al.'s [31] and Goodman et al.'s [32] findings, it can be claimed that not only the *Distinctiveness*, *Reproducibility*, but also the *Permanence* requirements are also fulfilled, since all these parameters are related to the user's anthropometric variables, that exhibit significant variance within the population. Of course, like all biometrics, there is the issue of aging, which can only be overcome via the update of the biometric signature over time. However, expressions of behaviour are less vulnerable to sudden changes (i.e. a fingercut is much more frequent and has a direct and quick effect on the authentication than a change in the movement due to arthritis or other diseases).

Similarly, the *Permanence* requirement is guaranteed, given that the human body remains unchanged over the years, in terms of anthropometric proportions, like the distances between the joints. Moreover, the proposed approach utilizes a combination of physiological with stylish and behavioural characteristics. Thus, the proposed biometric traits are very *hard to circumvent*, if not impossible, by an impostor. Furthermore, provided the fact that recent technological achievements, especially regarding miniaturized sensors and accurate vision-based tracking algorithms, allow