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Gaze-Based Biometric Authentication: Hand-Eye Coordination Patterns as a Biometric Trait

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Abstract

We propose a biometric authentication system for pointer-based systems including, but not limited to, increasingly prominent pen-based mobile devices. To unlock a mobile device equipped with our biometric authentication system, all the user needs to do is manipulate a virtual object presented on the device display. The user can select among a range of familiar manipulation tasks, namely drag, connect, maximize, minimize, and scroll. These simple tasks take around 2 seconds each and do not require any prior education or training [ÇS15]. More importantly, we have discovered that each user has a characteristic way of performing these tasks. Features that express these characteristics are hidden in the user's accompanying hand-eye coordination, gaze, and pointer behaviors. For this reason, as the user performs any selected task, we collect his/her eye gaze and pointer movement data using an eye gaze tracker and a pointer-based input device (e.g. a pen, stylus, finger, mouse, joystick etc.), respectively. Then, we extract meaningful and distinguishing features from this multimodal data to summarize the user's characteristic way of performing the selected task. Finally, we authenticate the user through three layers of security: (1) user must have performed the manipulation task correctly (e.g. by drawing the correct pattern), (2) user's hand-eye coordination and gaze behaviors while performing this task should confirm with his/her hand-eye coordination and gaze behavior model in the database, and (3) user's pointer behavior while performing this task should confirm with his/her pointer behavior model in the database.

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [Models and Principles]: User/Machine Systems—Human information processing H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces—Input devices and strategies (e.g., mouse, touchscreen)

1. Introduction

Biometric authentication is the task of determining whether the person is indeed who s/he claims to be. Traditional studies on biometric authentication use one (or a combination) of the following approaches to address this task: (1) proof by possession – focus on what the person owns (e.g. a key, a secure token), (2) proof by knowledge – focus on what the person knows (e.g. a password combination), and (3) proof by biometrics – focus on what is physiologically unique about the person (e.g. iris, fingerprint).

On the other hand, recent studies on biometric authentication focus on using behavioral characteristics such as gait, typing rhythm, and speech dynamics. These studies (that collectively constitute the emerging field of *behaviometrics* [NYEYM03]) measure and quantify unique human behavioral patterns to verify the identity of a person. The fundamental advantage of the studies on behavioral biometrics over the traditional ones stems from the fact that behavioral patterns are inherently very difficult, if not impossible, to forge. For instance, a key can always get stolen, a password combination can always be hacked, and an iris image can always be replicated. However, imitating a person's walking gait involves imitating the precise patterns of how the head, neck, legs, hips, knees, feet etc. move with respect to each other. Therefore, authentication systems based on behavioral characteristics are less susceptible to identity theft when compared with traditional authentication systems.

Eye gaze has fairly recently captured the attention of researchers studying behavioral biometrics. Eye gaze behavior is natural, unconscious, and therefore inherently inimitable – hence a great candidate for use as a biometric authentication trait. Two of the most prominent advantages of gaze-based biometrics systems are (1) higher resistance to identity theft due to the inherent difficulty of forging complex gaze patterns, and (2) ability to verify authentication in an implicit, covert, non-intrusive, and contactless manner. In this paper, we present a gaze-based authentication system (Fig. 1) that aims to capture these advantages. Note that in order to build our system, we adopt some machinery from our previous study on gaze-based virtual task prediction [ÇS15].

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2. Contributions

Our first contribution is a robust gaze-based biometric authentication system. Our approach consists of extracting and creating statistical models for gaze behavior patterns that naturally accompany daily interaction with pointer-based systems including, but not limited to, increasingly prominent pen-based mobiles devices. It is possible to employ our authentication system on its own or as a complementary soft-biometrics system to improve accuracy and counterfeit-resistance.

Our second contribution is a novel set of gaze-based biometric authentication tasks. Users are accustomed to performing simple tasks (e.g. swipe, draw a pattern) to unlock their pen-based mobile devices. We propose to use the following set of tasks for gaze-based authentication: *drag*, *connect*, *maximize*, *minimize*, and *scroll*. Our tasks are similar to what users are familiar with performing on their pen-based mobile devices [DP13]. On the contrary, state-of-the-art gaze-based authentication systems revolve around the same unfamiliar task, i.e. view a still image of a face for a predefined amount of time [REF12, CGN*15]. Moreover, our tasks are short (around 2 seconds each) compared to existing tasks that take 4 seconds [REF12] or 10 seconds [CGN*15]. Ease of use and authentication speed are especially important for mobile devices where authentication frequency is high (around 150 times a day [MW13]) and activities that follow authentication are likely to be urgent (e.g. calling 911, replying to a text message).

Our third contribution is the first multimodal feature representation for gaze-based biometrics research. All existing feature representations for gaze-based biometric authentication are solely gaze-based [BKMF05, DP13, KKHP12]. No existing work uses a multimodal feature representation for this purpose. Our feature representation fuses the spatio-temporal information collected via gaze and pen modalities in order to verify a user's authenticity. We propose to use three kinds of features, all based on human vision, and behavioral studies. The first kind is of multimodal nature and attempts to capture the dynamic aspects of human hand-eye coordination behavior. The second kind is of unimodal nature and attempts to quantify how the eye gaze data is structured in terms of saccades and fixations (i.e. two main modes of voluntary gaze-shifting mechanism). The third kind is, again, of unimodal nature and attempts to summarize the image-based properties of the pen data.

Our fourth contribution is the first multimodal database for gaze-based biometrics research. We present a multimodal dataset that consists of gaze and pen input collected from participants completing the before-mentioned authentication tasks using a pen-based interface. This carefully compiled database is the first of its kind, and we believe it will serve as a reference database for future research on gaze-based behavioral biometrics.

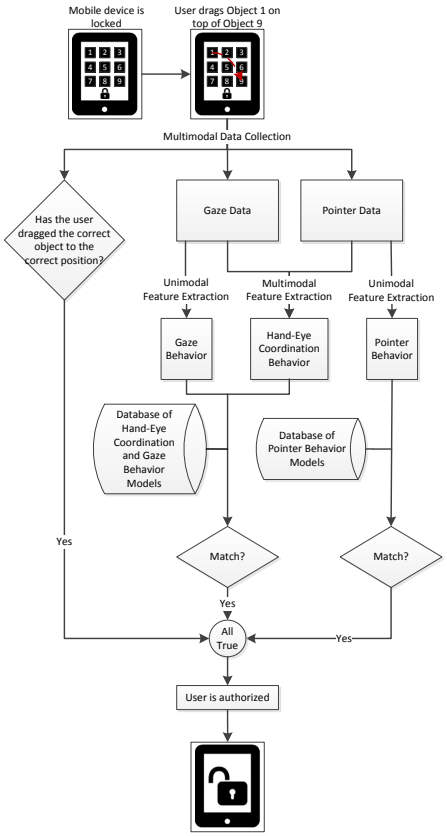

Figure 1: *Flow diagram visualizing our overall approach to gaze-based biometric authentication.*

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