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A Framework for Assessing Factors Influencing User Interaction for Touch-based Biometrics

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***Abstract*— Touch-based behavioural biometrics is an emerging technique for passive and transparent user authentication on mobile devices. It utilises dynamics mined from users' touch actions to model behaviour. The interaction of the user with the mobile device using touch is an important aspect to investigate as the interaction errors can influence the stability of sample donation and overall performance of the implemented biometric authentication system. In this paper, we are outlining a data collection framework for touch-based behavioural biometric modalities (signature, swipe and keystroke dynamics) that will enable us to study the influence of environmental conditions and body movement on the touch-interaction. In order to achieve this, we have designed a multi-modal behavioural biometric data capturing application *"Touchlogger"* that logs touch actions exhibited by the user on the mobile device. The novelty of our framework lies in the collection of users' touch data under various usage scenarios and environmental conditions. We aim to collect touch data in two different environments - indoors and outdoors, along with different usage scenarios - whilst the user is seated at a desk, walking on a treadmill, walking outdoors and seated on a bus. The range of collected data may include swiping, signatures using finger and stylus, alphabetic, numeric keystroke data and writing patterns using a stylus.**

Keywords—Mobile Biometrics, Touch-dynamics, Behavioural Biometrics, User Interaction, Usability.

I. INTRODUCTION

The increased adoption of biometrics on mobile devices such as smartphones and tablets in recent years has paved way for the development of new authentication techniques such as continuous authentication using a user's behavioural traits. While the conventional authentication techniques such as PIN and password aim to authenticate users at point-of-entry, continuous authentication techniques aim to dynamically authenticate the user in a continuous manner for the entire session of usage. These continuous authentication methodologies may utilise behavioural biometric features such as touch-dynamics exhibited by a user on a mobile device in order to uniquely identify them. Touch-dynamics is a time-based assessment of how the user performs an action on the mobile device. Touch-dynamics require user interaction via a finger or stylus on the mobile device.

Users' touch interaction with mobile devices usually involves activities such as swiping, typing using a soft-keyboard and e-signing/writing using finger or stylus. The capacitive sensors integrated on the touchscreen detect and process these touch signals. The interaction between the user and the touch interface of the mobile device is unsuccessful at times. For example, when a user tries to swipe on the mobile device with wet fingers and the sensor does not respond. This may be due to failure of the sensor in sensing the finger's contact with the touchscreen. These failed interactions or errors attribute to overall performance deterioration of the biometric verification systems. It is therefore important to analyse the interaction between the user and the touch interface of the mobile device. In this work, we focus on the analysis of touch interaction factors with a mobile device assessing physical body movement and a range of environmental conditions. Our work aims to provide a data collection framework for experimentation in this area. Most existing studies on touch-dynamics based behavioural biometrics have analysed touch data obtained in a laboratory setting [1], [2], [3]. Mobile devices are, by their nature, portable and designed to be hand-held. This feature enables its use in diverse scenarios compared to personal computers and laptops, in both indoors (office, home, at the gym, etc.) and outdoors (walking, running, etc.) environments. Therefore, it is vital to analyse the touch behaviour under different usage scenarios. The user, touch sensor or a faulty interaction process can cause an interaction error. It is important to explore deeper into the cause and responsible element that result in an interaction errors.

Considering all of these issues, we have developed a data collection framework to monitor and analyse combinations of factors influencing user-interaction on touch-based behavioral biometrics. Our experimental scenarios follow specifications stated in ISO/IEC-19795-2 [4] and are designed to depict most natural mobile phone usage. The experimental scenarios are designed to be ceremony-based, prompting the user to perform activities such as typing a sentence and signing in the given box on the mobile device. In order to monitor the influencing factors on user interaction, sensors such as environmental and motion sensing devices are used and the data collection experiments are video recorded. Our evaluation framework focuses on four behavioural biometric modalities – swipe, signature, keystroke dynamics and writing pattern. This multi-modal approach investigates user interaction for each modality individually. Applying this framework, we can explore physical movement variations such as walking on a treadmill with a fixed speed and natural walking speed. Environmental variations considered are inside an office room, outdoors with natural daylight and travelling on a bus. Our framework obtains user's opinions and reactions at the end of the experiment in order to evaluate the satisfaction. Overall, this data collection framework enables the analysis of usability factors on various touch-dynamics based modalities as well as help in performing performance evaluation under different scenarios.

II. Related Work

Behavioural biometrics has gained research momentum in recent years, however there are a limited number of studies focusing on the usability aspects of behavioural modalities. The few studies that have focused on usability have explored factors such as body posture, orientation, and device holding positions, stylus style and stress testing in a constrained environment.

Blanco et al. [5] evaluated signature using an iPad with different styluses under different scenarios – sitting, standing, device placed on the table and device held in hand. Their experimental outcome proposed that stylus-based devices performed better when the user is seated or the device is resting on the table. On the contrary, finger-based devices performed best, when user handles the device without any support. Buschek et al. [6] used a Nexus 5 to capture keystroke data of 28 subjects with various hand postures and different phone orientations. They included a probabilistic classifier to predict the probability of each posture and used posture-specific user model for predicting probability of legitimate users-per-posture. Their evaluation also included cross-session comparison of mobile touch keystroke data. The results from this study showed that authentication is more accurate for some hand postures than others. Zhang et al. [7] captured touch behaviour under different lighting variations such as in a well-lit room, dimly-lit room and room with natural daytime illumination. Their results show a reduction in performance when testing and training data come from different sessions captured with different environmental conditions. Bo et al. [8] evaluated 'Silentsense', a non-intrusive continuous user identification mechanism with 100 users in both static and motion scenarios. Their results show that when the users are moving, the approach designed for static scenario deteriorates giving a false reject rate (FRR) of 18% after four strides. Such studies emphasize on the effect of change in usage scenario on the performance rate.

As illustrated, previous studies prove that external factors such as device-holding position, different stylus types etc. impact the performance of the biometric system. Therefore, it is important to look deeper into such factors, which may influence user-interaction with the mobile devices. Our framework provides a method for formally analysing such factors. Our research focuses on the influence of motion and environmental variations on touch interaction. Using this framework, we aim to analyse multiple factors such as typing errors occurrences in user in static and motion scenarios, touch pattern change due environmental change resulting in different typing, swiping speed.

III. Experimental Framework

To address our research question, we have designed a framework, which focuses on evaluating each influencing factor such as environment variations and physical body movement individually. This section describes the design considerations for the experiments with respect to the environmental variations, scenarios, test crew recruitment, device selection and framework design and specification.

A. *Environmental Variation Considered*

Previous studies on continuous authentication using swipe and keystroke dynamics involved data capture in a laboratory. The usage scenarios of mobile devices, however, may constitute a broader range of activities such as walking indoors and outdoors. It is important to consider such scenarios in order evaluate if the authentication algorithm accuracy is maintained during different usage conditions. If it is not, it is important to compensate for such variation. For our framework we propose a series of experiments with both indoors and outdoors environmental variations. The indoor scenario will be conducted in a room, where the participants will be seated at a desk while performing the touch activities on a dedicated mobile phone chosen for the experiment. Secondly, the user will be walking on a treadmill while performing the touch interaction with on a mobile device. The outdoor scenario will comprise of performing the touch activities whilst walking and travelling on public transport.

B. *Scenarios*

Our framework enables the study of touch interaction with mobile devices under diverse conditions. Our aim is to capture data when the user is static, in motion and when the user is static but the transport (bus) is moving. Our experimental procedure is divided into two sessions. The first session comprises of three scenarios – using the mobile device with a stationary body posture (seated at a desk), walking (on a treadmill at a controlled and comfortable walking speed) and walking outdoors (on a dedicated walking trail provided by the research team). The second, time-separated session comprises of three scenarios – seated at a desk, walking (in outdoors) and on a moving vehicle (seated in a bus). Each scenario will typically last for half an hour. Each session will be carried out with a time separation of one week. The participants will be asked to perform a number of tasks such as typing a sentence, swiping through images and signing using finger and stylus on the mobile phone provided to them during the experiment. These tasks are detailed in Section F.

C. Test Crew

The crew for the experiment will be recruited based on the inclusion criteria such as familiarity of using mobile phones. The participants are required to be able to walk as the experimental sessions involve walking and getting onto public transport. We plan to include participants with different ethnicity and have equal distribution of gender.

D. Mobile Device Selection

For the experiment, we choose an Android based mobile phone. In order to minimize the differences based on the device specifications and models, we will be using the same mobile phone for all the experimental sessions. Our experimentation will choose a mobile phone with built-in stylus pen for the experiment as tasks involves signature and writing capture using stylus pen.

E. Framework Specification

This section describes how the influencing factors of user-interaction on mobile device is monitored and evaluated. ISO 9241-210:2010 [12] defines metrics for evaluating usability which consists of quantitative factors such as effectiveness, efficiency and qualitative factors such as learnability and satisfaction. For the behavioral experimentation, we consider digital signature, keystroke dynamics, swipe modalities. Each of the usability metrics are individually dealt with for each modality.

- Effectiveness – NIST [13] defines effectiveness as the measure of how well the user can perform a task with respect to successfully and accurately providing the sample. Our framework records the following elements to enable the calculation of effectiveness. For keystroke dynamics, we store number of successful and unsuccessful completion of tasks (separated into numerical and alphabetical inputs respectively). For signature and writing tasks, we record the number of times the user produced the signature and text writing without pressing clear button. For swipe, we will log the number of times user's swipe action was captured successfully, triggering next action on the screen. Unsuccessful touches are also recorded as well in the background.

- Efficiency - NIST [13] defines efficiency as the measure of how quickly the user can perform the tasks and the number of errors committed during the process. We log the speed at which each signature, swipe, writing and keystroke task is performed. We also record number of errors committed while typing a word or number, swiping in wrong direction, the production of a user-certified unsatisfactory signature.

- Perception – At the end of the session, we will include a feedback or user perception form to obtain comments on the user experience. We will include questions that would focus on gathering opinion on continuous authentication techniques. The questions on the feedback form will also aim to capture the pain points while typing, swiping and signing on the mobile device in various environmental conditions. Example question – what was the most discomforting factor while performing the typing task on outdoors scenario – small device screen size, soft-keyboard key size, placement of characters on the soft-keyboard. Similarly, focusing on individual modality, user perception questionnaire is designed.

- Influence of Environment – As the data collection includes both indoors and outdoors usage scenarios, we would perform inter-session and intra-session evaluations to compare the results and calculate the effect of environment. We have included walking scenario in indoors and outdoors, which will enable us evaluate the variation of data quality due to the influence of environment.

- Influence of Body Movement – We will record the micro-movements of the mobile device during the experimental sessions. The difference in the motion sensor readings when the user is seated and while he/she is walking, will be calculated. We also use step counter and step detection sensors to trace and calculate the number of steps taken while performing the experiments, giving us information such as has the user stopped to correct a typing error. We measure the frequency of errors committed in both the static and dynamic scenarios. We will also analyse the variation in typing, swiping, signing speed in static and motion scenarios. During the scenario with the treadmill, the user will be walking with a fixed speed. The touch pattern will be evaluated against treadmill's fixed speed and the natural walking speed in outdoors.

Detailed features used for each individual modality are provided in Table I.

Modality	Features for Evaluation
Keystroke Dynamics	Typing speed, typing errors, soft-keyboard key pressure, multi-touch typing for numeric and alphabetical input
Signature and Writing	Finger pressure variation, signature presentation using finger and stylus, signing outside of the defined area, pen holding style (through video recording), multi-touch for erroreneous touch of the hand (video recording and operator notes)
Swipe	Swiping speed, swiping area, finger pressure variation in different scenarios, finger touch area variation, user-device position (through video monitoring)

TABLE I. FEATURES FOR EVALUATION OF USERS TOUCH INTERACTION

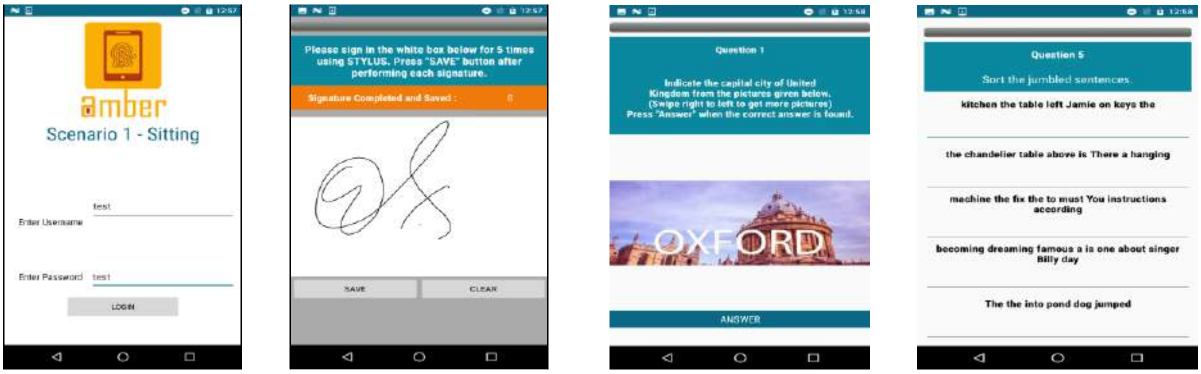

Fig 1. User Interface of the Touchlogger App a) Login page b) Signature task c) Swiping task d) Keystroke Input task

In order to design this framework, we have implemented an Android application, which captures multi-modal inputs of signature, writing, swipe and keystroke dynamics detailed in the next Section.

F. Touch Data Acquisition

Our "*Touchlogger*" mobile application collects raw touch and motion sensor data from the touchscreen of the mobile device. As the user performs common touch maneuvers in the user interface of the app such as swiping left-to-right, scrolling up-down, key typing and signing, this app logs the touch parameters continuously in the background. The background process starts recording immediately when a touch action is performed in the app. We use the embedded SQL database engine – SQLite to store the touch and other sensors information on the mobile device. The touch actions that are captured during the experiment are as follows:

- Horizontal swiping – right-to-left swiping, an action which is usually performed for sliding through the images or to flip through the next page of a document. We have designed photo-flipping activity in the app in the form of a quiz. For example, we ask the user to find out the capital city of United Kingdom from the list of various images of cities, which is obtained by swiping horizontally.

- Vertical scrolling – up-down/down-up scrolling is an action usually undertaken while reading a document or news article in mobile phone. We have included vertical scrolling of images in the app.

- Alphabetical keystroke inputs – For the keystroke entry task, the users will be asked to type a given sentence.

- Numerical input – For the numerical input task, the user would be asked to type a sequence of given numbers in a text field. The numbers appear in the form of a phone number, which comprises of all the digits from 0-9.

- Signature using stylus and finger – For our experiments we will use a mobile device that works with a stylus pen. For the signature task, the user will be asked to sign using stylus in a boxed signing area. Signature using finger task involves the signing using finger for multiple times in a boxed signing area.

- Writing using stylus – The writing task of the experiment involves the user writing "University of Kent" on the box using stylus.

G. User Interface

The user interface of the *Touchlogger* app has been carefully designed with sufficient information for the users to carry out the experimental tasks without any assistance. The app has been designed as a general knowledge quiz containing 15 questions for each scenario involving typing, swiping and signing tasks. Before starting the quiz on the app and in between the quiz, the user is prompted to sign for five times. After which the user performs swiping tasks involving 15 questions with minimum number of swipes per question being 10. During the keystroke tasks, the user is prompted to sort five jumbled sentences and enter numeric values repeatedly for five times. Example tasks in the app for capturing signature, swipe, and keystroke entry are shown in Fig. 1.

H. Database tables

Android provides an API for tracking touch and pointer movements on smart devices. *Touchlogger* app makes use of this API. The app records the data on a continuous basis in the background as the user performs the experiment on the mobile device. Sensor values from the accelerometer, gyroscope and environmental sensors from the mobile device are also stored in the database.

Table II lists the raw data captured from the sensors and are stored in the database. X-coordinate is the X component of the pointer/finger movement. Y-coordinate is the Y component of the pointer/finger movement. The pressure field returns the pressure applied onto the device by a finger or other pointer tool. The pressure value is a binary value ranging from 0 to 1, where 0 represents no pressure applied at all and 1 represents normal pressure applied on the touchscreen of the mobile device. Touch size is stored as a normalized value depicting the size of active touch area on the screen. The timestamp field is stored in date/time format in milliseconds. Tool type returns a variety of values: -1 is invalid pointer_ID, 1- finger, 2- stylus, 4 – eraser. During a multi-touch activity, two set of touch values for each pointer is generated and stored. The key-pressed field stores the information on the character of the key pressed on the soft keyboard along with timestamp. This enables an evaluation of the hold-time and flight time of the key presses in the soft-keyboard of the mobile device. For signature and writing activities, we store the pen-up and pen-down timestamps and pen coordinates. Using these touch-based data captured during the experiment, we would evaluate the factors influencing touch behaviour such as key logging time variation, swiping speed variation, writing speed variation under various physical body motion and environmental factors.

Modality	Parameters
Touch data	Timestamp, Touch_Action (ACTION_DOWN (when a pointer (finger or stylus) touches the screen), ACTION_UP and ACTION_MOVE (when the pointer moves on the screen)) , X-coordinate, Y-coordinate, Tool_Type, Orientation, Multi-touch pointer_X-coordinate, Multi-touch pointer_Y-coordinate, Pressure, Size
Keystroke data	Timestamp, key-pressed, key-deleted
Signture data	Timestamp, X-coordinate, Y-coordinate, Tool Type, Orientation, Multi-touch pointer_X-coordinate, Multi-touch pointer_Y-coordinate, pressure
Writing data	Timestamp, X-coordinate, Y-coordinate, Tool_Type, Orientation,Multi-touch pointer_X-coordinate, Multi-touch pointer_Y-coordinate, pressure,
Accelerometer data	Acceleration force along the x axis (including gravity), Y axis and Z axis, minor-movement of the phone or stationary position of phone
Environmental sensor data	Ambient temperature, light, pressure, relative_humidity, device temperature
Gyroscope data	Rate of rotation X, Y, and Z axis in rad/s

TABLE II. INFORMATION ON FEATURES CAPTURED

IV. CONCLUSION AND DISCUSSION

In this work, we present an evaluation framework for analysing factors influencing user interaction in mobile devices with respect to touch interactions. The novelty of our work lies in collection of dataset containing touch data in diverse usage scenarios such as travelling on a bus and walking on a treadmill. The aim of the experiment is to evaluate the effect of movement and environment on the user interaction with the mobile device. In order to do this, a multi-modal "*Touchlogger*" app has been developed on the Android platform. The experimental scenarios have been designed to evaluate the influencing factors on the user interaction. Such an analysis would help in development of robust behavioural biometric authentication algorithms. This data collection framework can be used for further to perform the performance assessment of various touch-based behavioural biometric modalities using mobile devices.

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