TOUCHI: Online Touch User Identification through Wrist-worn Inertial Measurement Units

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Abstract
User identification for multi-touch surfaces is a highly desirable feature that is not inherently supported by existing touch sensing technologies. We present TOUCHI, a novel approach for touch user identification through the use of wrist-worn inertial movement units (IMU). Our approach for user identification is based on identifying the wrist-worn IMU signal that shows the highest similarity to the touch data obtained from a touch sensitive surface. We also introduce a novel 6-axis conceptual model for user identification in multi-touch scenarios for characterizing the implications of different application requirements with regards to user identification, and with which we can contrast the strengths and weaknesses of TOUCHI compared to other user identification approaches.

Author Keywords
User identification; multi-touch; accelerometer; IMU; authentication; interactive surfaces; wrist-worn devices; collocated interactions

ACM Classification Keywords
H.5.3. Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces.

Introduction

Recent reductions in the cost of multi-touch interaction sensing technologies have seen multi-touch devices incorporated into work, education, and public settings. Multi-touch surfaces are inherently collaborative in that they allow a number of users to interact with the device simultaneously. This is particularly true for larger surfaces such as touch-based interactive boards, large displays and digital tabletops that are finding their way into the classroom [6], [7]. However, current mainstream and affordable multi-touch sensing technologies do not allow the identification of users associated with each touch input. In many multi-user applications, it is highly desirable to identify the user engaged in an interaction, or at least to distinguish between inputs due to different users. For example, in education applications, having the ability to sense the level and type of contribution made by distinct students at an interface allows for designing educational applications to explicitly promote collaboration as well as online and offline analysis of use [5], [6], [7], [8].

Related Work

A number of varying approaches to user identification at multi-touch interfaces have been proposed (e.g. [2], [4], [11], [12]). However, each existing identification technique has substantial practical limitations, including dependence on specific touch-sensing technologies (e.g. [2], [12]), the use of impractical infrastructures (e.g. [3], [11]), and/or restrictions placed on the mobility of the users while interacting with a surface (e.g. [2], [3]). On the one hand, some of these approaches can be classified as security-oriented, where the main goal is to identify users as unique individuals, and where the identification process is framed as one of "authentication". These systems generally seek to verify some unique characteristic of a user against a pre-prepared database of such features and keep identification constrained to specific actions before starting a session, rather than during an interaction. Prominent examples of such pre-session user authentication approaches are HandsDown [13] and MTi [1]. In the former, users are required to place their hands palm-down onto a surface and are identified based on hand contour analysis and comparison with a database of existing users. The latter achieves user identification based on features obtained only from the coordinates of the five touch points of a user's hand. Another approach is Fiberio [4], which is a bespoke camera-based touch screen that authenticates users biometrically using fingerprints for each touch interactions.

On the other hand, some of these approaches can be described simply as "identification". Here, the focus is just on distinguishing between interactions by different users in a session (as anonymous individuals), which may or may not require initial user registration. Of these, the most widely known is probably DiamondTouch [2], which uses a front-projected surface with an array of RF-emitting antennas. Touches are capacitively coupled through the user to a receiver connected to the user's chair. Other approaches utilized an overhead camera, for example Dohse et al. [3] tracked users based on skin colour segmentation techniques. Similarly, Martinez et al. [7] identified users based on depth images, using the shapes of the hands and arms of the users' positions around the table. Carpus realised more flexible user identification by identifying unique features on the back of a user's hand during an interaction and comparing these to pre-prepared user-feature pairs. Infrared (IR) was also

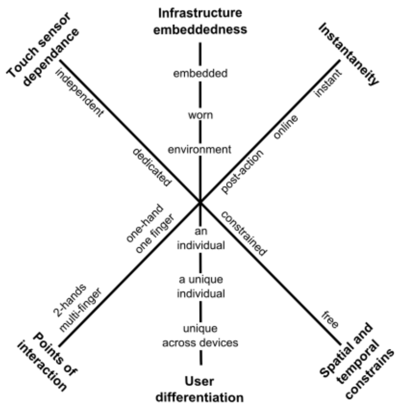

Figure 1 A 6-axes radar chart conceptual model for user identification support on multi-touch devices

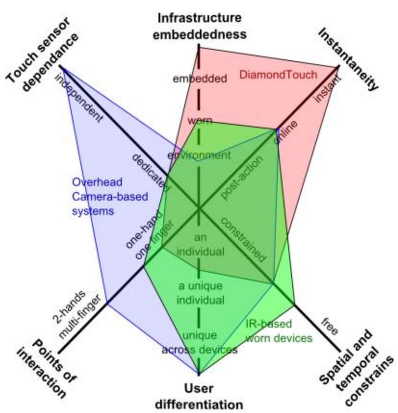

Figure 2 Mapping of the main user identification technologies on the proposed model

used by some (IR Ring [12] and IdWristbands [9]), although this only worked for touch devices equipped with a behind-the-screen IR camera.

The variety of the proposed approaches and their limitations shed light both on the importance of user identification and the complexity of the problem. Together, this provided motivation to develop TOUCHI as a user identification method to address the main limitations of these existing approaches, especially those related to hardware dependence, the use of complex systems, the inability to identify users across devices, and spatial and temporal constraints on users' interactions.

User Identification: A Conceptual Model

In an effort to systematically categorize user identification models, with a view to identifying application requirements and matching strengths and limitations of different approaches and technologies, we developed a conceptual model for user identification. Through an analysis of existing user identification methods, we identified six features that are essential for describing any user identification technology: *Instantaneity, Infrastructure Embeddedness, Touch Sensing Technology Dependence, Points of Interaction, User Differentiation, and Spatial and Temporal Constraints.* The resulting model can be visualized using a 6-axis radar chart (Figure 1) with the most desirable characteristic on the outer end for each axis.

With this model, we are able to express the main characteristics of a user identification technique and the requirements of a specific application. A user identification technique is a viable option if its associated region on the graph contains that of the application requirements. Figure 2 shows the main user identification methods that we have reviewed, mapped onto the proposed conceptual model. This clearly shows that there is currently no user identification technology that works instantaneously, works with all touch sensing technologies, does not restrict users' interactions and can accurately and uniquely identify users across devices.

TOUCHI

TOUCHI aims to overcome the main limitations associated with previous approaches. Hardware independence is achieved by relying only on the touch data from the device (time stamped position data which is an inherent feature of all touch devices) and inferring the users' identity based on the similarity of acceleration derived from such data with that of wrist worn IMUs (Figure 3). Using wearable sensors removes the need for any complex infrastructure to be embedded in the touch device or environment. By correlating touch data with a uniquely identifiable wearable sensor, users can be uniquely identified even when they move between devices, a requirement that is becoming increasingly important in multi-device environments. Figure 4 shows the operational space of TOUCHI as mapped on the proposed user identification model.

Study and Results

During a case study, three users were asked to cooperatively solve a puzzle game by concurrently dragging puzzle pieces. Participants each wore an open source OpenMovement AXi wrist-worn wireless 10-axis IMU [10], which includes a tri-axial accelerometer, gyroscope and magnetometer. The data was sampled at a rate of 40Hz and transmitted via Bluetooth to the

Figure 3 Correlating touch and sensor data for user identification

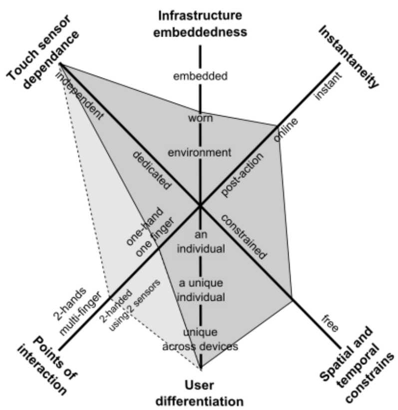

Figure 4 TOUCHI operational space for the proposed conceptual model

computer hosting the multi-touch applications. This puzzle game was completed for three different groups, and its implementation allowed us to capture a representative quantity of naturalistic multi-user (and largely concurrent) gestures required for a systematic validation of TOUCHI. Following this, the puzzle game was extended by incorporating the best performing similarity score (Kolmogorov-Smirnov test) into an online inference procedure that analyses a short history of touch and sensor signals (5s). If the confidence exceeds a threshold corresponding to an identification accuracy of 75% we indicate the inferred identity to the user. Results from the study show that, when the confidence threshold is chosen to retain 50% of all gestures performed on the touch surface (recall), TOUCHI is able to infer the correct identity in more than 95% of cases. In addition, it achieved the design goals of being technology independent, simple to set up, and allowing freedom of movement for users with identification made possible across devices.

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