WhichHand: Automatic Recognition of a Smartphone's Position in the Hand Using a Smartwatch

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Abstract
As mobile users often operate their devices with one enhancing one-handed interaction. In this paper, we present WhichHand, a system that 1) automatically detects which hand is holding a mobile phone and then 2) enhances user interfaces by adapting layouts to left- or right-handed use. For WhichHand, we utilize orientation sensors from a smartphone and a smartwatch. The relationship of sensor data between two mobile devices plays an important role in our recognition system. We evaluated WhichHand in a controlled study with 14 participants and conducted a user study with 10 participants to receive feedback. The accuracy of over 97% and early feedback on WhichHand provide useful insights on the design for one-handed interaction.

Author Keywords
One-handed interaction; adaptive user interface; smart phone; smart watch; sensors; machine learning

ACM Classification Keywords
H.5.2. User Interfaces and Presentation (e.g., HCI): Miscellaneous

Introduction and Related Work

Mobile users often hold their smartphones with a single hand based on the individual user's preference, habit, personal comfort, or situational circumstances. For example, a person has only one hand available when s/he is carrying a bag. Also, while doing some activities such as walking, 65% of users manipulate their phones with one hand [10]. As one-handed interaction is commonly observed, understanding how users hold their devices with one hand is crucial for enhancing one-handed interaction. This is because hand postures, including grip style [6], hand poses [4], left- or right-handed use [11, 16], and so on, significantly affect the performance and usage of mobile devices.

One of the most significant aspects of mobile device use may be the hand with which the user operates the device. The screen area that is comfortably reachable by the thumb of the hand that is holding the device significantly differs depending on which hand—left or right—is doing the holding [2, 11]. The larger the screen size, the bigger the difference in the reachable area between left and right-handed use, which may considerably affect performance. Also, the handedness has a significant influence on the perceived effort of thumb movement directions [15]. Thus, the information about which hand is holding a mobile phone could be considered when designing input space and interaction for improving users' experiences when using the phone with one hand.

The information about which hand a user is holding a device with can be useful for making interfaces or interaction adjustable to the user's hand. Wimmer et al. [16] suggested adjusting GUI widgets or button mapping for right and left hands. Lee et al. [11] presented a personalized user interface dynamically adapted to the optimal touch area depending on the handedness (e.g., changing the accept call slide direction from right/left to left/right for a left-handed user).

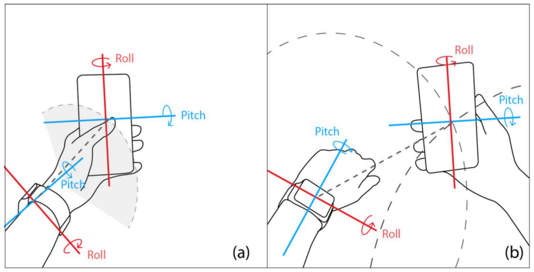


Figure 1: The device's orientation sensor derives the pitch and the roll, which are the degrees of rotation around the device's x-axis (blue line) and the device's y-axis (red line). WhichHand is a system that utilizes the rotational movement of devices to automatically recognize whether a smartphone is in a user's left hand (a) or right hand (b).

Researchers have explored various techniques to recognize which hand operates mobile phones by using multiple sources of information from on-device sensors. GripSense [6] leveraged touchscreen interaction and device rotation information to distinguish between the left and the right thumb use. Löchtefeld et al. [12] collected accelerometer, device orientation, and touch points during the unlocking process to develop an algorithm that detects which hand users hold their phone in. However, to our knowledge, these techniques require users to interact with the device (e.g., a set of touch events) to make inferences, which would make it impossible to provide optimized interfaces in advance.

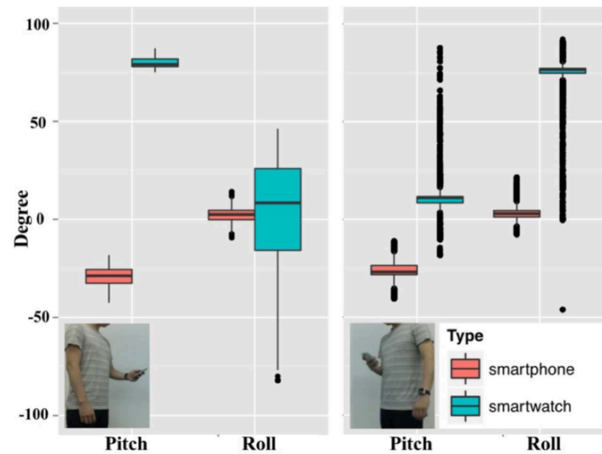
Our aim is to detect which hand is holding the mobile phone even before a user starts to interact with the phone. Previous studies showed that detecting a phone's position in the hand by only using the phone's sensor data is virtually impossible without user interaction with the device [6, 12]. Thus, a wrist-based wearable device, a smartwatch, is used as an auxiliary sensor in our recognition system. In this way, the system can provide interfaces immediately adjustable to the user's left or right hand whenever switching hands or picking up his or her phone. We focus on the relationship between each orientation sensor from two devices, a smartphone and a smartwatch.

In this paper, we introduce WhichHand, a system that 1) automatically recognizes which hand a user is holding a smartphone with prior to user interaction and 2) provides user interfaces, in advance, specifically optimized for left- or right-handed use. For WhichHand, we employed orientation sensors from a smart phone and a smartwatch. By using a machine learning technique, we classified the phone's position in the hand. To measure the effectiveness of the system, we performed a controlled study with fourteen participants. The recognition system achieved an accuracy of over 97%. Also, we applied WhichHand to existing one-handed interaction techniques and then received feedback from ten participants.

The high accuracy of and favorable feedback on WhichHand suggests that the proposed technique has a great potential for various handheld devices.

The Design of WhichHand

A suite of new recognition techniques has taken advantage of the availability of both a smartphone and a smartwatch [5]. WhichHand is the recognition system



(a) Two devices are on the same side of the body **(b) Each device is on the same side of the body**

Figure 2: Box plot of the pitch and the roll from a smartphone and a smartwatch when (a) two devices are on the same side of the body (left arm) and when (b) the phone is in the right hand and the watch is on the left wrist.

that utilizes orientation sensors from the phone and the watch to infer whether the phone is in a user's left hand or right hand. The device's orientation sensors derive the pitch and roll (Figure 1), which lets the device monitor the position of the device to the earth's frame of reference and movement of the device [1].

The key idea of our recognition system is that when a user is holding a smartphone with the hand that she wears a smartwatch on, it is very likely that the motion of the two devices will be synchronized. To keep track of the orientation and the movement of two mobile devices while a user manipulates the phone, the pitch and the roll of each device is derived from the orientation sensors, as shown in Figure 1.

To assess the effectiveness of using the pitch and roll values as features for WhichHand, we performed a pilot study with four participants. We collected the data at 200Hz in each posture (Figure 2) from a Samsung Galaxy Note 4 (a smartphone) and a Samsung Galaxy Gear Live (a smartwatch). We asked the participants to wear the watch on the left wrist and to use the phone as usual for one minute.

As shown in Figure 2, we were able to observe that there are typical patterns for the pitch and roll values based on the way a user holds the phone. When a user interacts with the phone with the left hand (Figure 2.a), the pitch and roll of a smartwatch tends to converge to a specific region.

On the other hand, when the phone is in the right hand (Figure 2.b), the pitch and roll exhibit quite different patterns, since the tight relationship between a smartphone and a smartwatch becomes broken as the smartwatch (left wrist) can move freely regardless of the movement of the phone (right hand)

From our initial insights, we selected the following six features to detect the holding hand. Instead of using a single point value, we used the average of the pitch and roll as well as their variances in a small time window (up to 1 second, see Experiment 1) to cope with noisy signals.

- the average of the pitch from the smartphone and the smartwatch;
- the average of the roll from the smartphone and the smartwatch; and
- the standard deviation of the pitch and the roll from the smartwatch.

Every 0.5 second, the features, the average, and the standard deviation of the pitch and the roll data were calculated for a given time window. Then, we applied the decision tree (J48 from Weka library [13]) to detect the holding hand. The J48 was chosen since it can be implemented efficiently on an Android platform and has a low computational complexity. The detection interval was determined heuristically considering the transition time from one hand to the other.

Evaluation

We performed a controlled study to evaluate the performance of WhichHand. Fourteen participants (six males and eight females with ages between 21 and 34) were asked to wear a smartwatch on the left wrist and to use a mobile phone with one hand. Each participant conducted typical mobile activities [10] while standing or walking in a natural setting: "reading" (e.g., email reading), "writing" (e.g., messaging writing) and taking photos. The experiment was conducted in two steps. We first asked the participants to hold a smartphone in one hand and perform the tasks. Then, we asked them to switch the phone to the other hand and perform the same task again. The order was randomized. The tasks took approximately ten minutes in total.

Apparatus

We used a Samsung Galaxy Note 4 (smartphone) and a Galaxy Gear Live (smartwatch). Both of them have accelerometer and geomagnetic field sensors that are needed to get the pitch and roll values. To get reliable values, we utilized the functions "getRotationMatrix()" and "getOrientation()" to process the raw sensor data, which are recommended by the Android platform [1]. The data from a watch is transmitted to a phone via Bluetooth at the rate of 200 Hz.

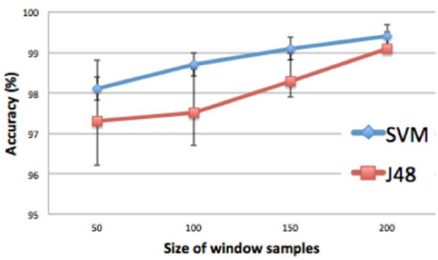


Figure 3: Accuracy with different window sizes and classifiers (ten-fold cross validation)

	SVM	J48
10-fold cross-validation	99.5% (1.6%)	98.7% (2.2%)
Per-user classifiers	97.2% (5.6%)	96.1% (6.1%)
General classifier	96.1% (2.2%)	95.5% (3.6%)

Table 1: Accuracy (SD in parentheses) of recognition from SVM and J48: ten-fold cross-validation with all data, per-user classifiers, and general classifiers

Experiment 1: The Effect of Window Size and Classifiers

First, we examined the effect of the window size since it could have an effect on the performance of classifiers [7]. Four types of window size (50, 100, 150, and 200 samples) were examined, respectively. We also validated the performance of J48 compared with SVM from LIB-SVM library [3,9].

The results (Figure 3) show that the accuracy improves as the time window gets bigger and both classifiers achieved more than 97% accuracy in all window sizes. Based on the results, we decided to use the window size of 200 for the following evaluation.

Experiment 2: Per User vs. General Classifier

Inspired by Chen et al. [5], we evaluated our system in three different conditions: ten-fold cross-validation using all data, per-user classifiers, and general classifiers.

Ten-Fold Cross-Validation with All Data: We ran a conventional ten-fold cross-validation using all data from fourteen participants. As shown in Table 1, the ten-fold cross-validation showed a high accuracy of over 98% with small standard deviations (99.5% with SVM and 98.7% with J48). This result gives us a basic evaluation where the data from a group of users is known a priori, and we can train a model adjusted to a particular group of users. Two additional evaluations and analyses were conducted to examine our techniques in more realistic situations.

Per User Classifiers: It is important to understand how the features perform at a per-user level [8]. We divided the data between the participants and conducted a ten-fold cross-validation within the data of each participant. The features are informative to specific users (see Table 1, accuracy > 96% for SVM and J48).

General Classifiers: It is also necessary to evaluate how the features can be generalized to new users whose data has not been used for training [8]. To simulate this scenario, we separated out one user's data as a test set (new user), and others' aggregated data as a training set (existing users). We repeated this process fourteen times (i.e., all the combinations from the fourteen users). We then calculated the average and the standard deviations of the accuracy. There was a small difference between participants (see Table 1, SD between 2.2% and 3.6%).

WhichHand for One-Handed Interaction

WhichHand can be applicable to a diverse array of applications in a smartphone. In this section, we combined WhichHand with one-handed interaction techniques and received feedback from ten participants.

Applying WhichHand to One-Handed Applications

To enhance one-handed interaction, commercial products provide users with a diverse array of one-handed interfaces. For example, the Samsung Galaxy Note 4 offers three one-handed interfaces (Figure 4). Once one-handed mode is set to left- or right-handed use, however, users need to manually change the mode whenever switching hands, which may be inconvenient for them.

One of the potential uses of WhichHand is to be combined with existing one-handed interaction interfaces. To explore the opportunities, we developed three prototypes, WhichHand with Reduced Screen, One-handed Input, and Side Key Panel, respectively,

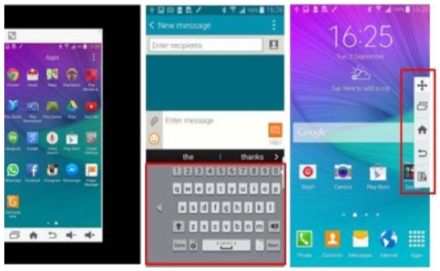


Figure 4: Commercial products provide one-handed operation: Reduced Screen, One-Handed Input, and Side Key Panel [13]

Figure 5: WhichHand makes a Reduced Screen interface automatically adjustable to a user's left or right hand whenever switching hands

and performed a qualitative study. WhichHand makes these interfaces automatically adjustable to a user's left or right hand.

Users' Feedback on WhichHand

With the three techniques, we gathered feedback from ten participants (six males and four females, ages between 21 and 27). After demonstrating the three one-handed interaction techniques enhanced with WhichHand (see Figure 5), we asked participants to try the three techniques one by one. After the session, we asked them to describe their experiences with the prototype. Each session took about ten minutes.

Overall, participants gave positive feedback. When they manipulated the phone single-handedly, they unanimously agreed that WhichHand could be useful. In particular, all participants found it helpful that WhichHand automatically adjusted for left- or right-handedness as they picked up the smartphones.

Some participants, nonetheless, gave suggestions for improvement. For example, P06 and P10 asked whether there was a function to move "back" to the normal mode from one-handed mode. Furthermore, a couple of participants (P04 and P09) said that it could have been better if the backspace key and the space bar could be rearranged. The two keys are still a bit far away when the phone is used with the left hand. Lastly, P02 said that she would still prefer using both hands with her smartphone, even while she agreed that WhichHand could potentially offer convenience.

Discussion and Future Work

The high recognition accuracy and users' favorable feedback suggest that WhichHand has the potential to improve users' experience when using a smartphone with one hand.

With the automatic recognition of the holding hand proposed in the paper, we believe that one-handed interaction could be improved. The adjustment of the user interface could be achieved without changing settings every time. Also, as observed in the user study, WhichHand is able to detect the holding hand prior to a user beginning to interact with his or her smartphone. As a user picks up his or her smartphone, the system immediately recognizes the holding context and then automatically adjusts user interfaces accordingly. While WhichHand requires a wearable device, with the recent push of fitness trackers and smartwatches, we believe it has a promising potential for one-handed interaction.

WhichHand focuses on one-handed interaction at the moment. However, users often switch back and forth between two-handed and one-handed interaction. The missing part of WhichHand is to detect the case when a user holds a smartphone with two hands. Future work should include the detection of holding a smartphone with both hands. In addition, as a few participants suggested, a quick and easy way to return to the default interaction model should be considered.

Conclusion

This paper introduces WhichHand, a recognition system that utilizes orientation sensors from two mobile devices, a smartphone and a smartwatch, to infer whether the phone is in the user's left hand or right hand. We designed and evaluated WhichHand to improve one-handed interaction in mobile devices. The results provide useful insights into the design of one-handed interaction in the future.

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