Analyzing Motion of Touching Screen for Inferring User Characteristics

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***Abstract*—Due to advances in technology, today's users can enjoy a variety of services more comfortably on a larger screen than in the past. However, due to the large size, it is difficult for the users to touch all of the display with one hand. Moreover, most smartphone applications have inflexible forms that fill the entire screen, and the placements of buttons are usually fixed. To overcome such limitations, we focus on diverse sensor data obtained while touching the screen and propose the analysis method to infer user characteristics. The proposed method utilizes different sensor data from not only a touchscreen but also a gyroscope and an accelerometer in combination. Moreover, the proposed method utilizes the unsupervised clustering algorithm to quantify how much of the screen the user could reach. We conducted experiments involving users to evaluate our analysis method. The results show that, by using the proposed method, it is possible to know whether a user is right-handed or left-handed. Furthermore, the results verify that our analysis method is able to distinguish the natural, reach, and unreachable zones on the screen well.**

***Index Terms*—Touchscreen, Gyroscope, Accelerometer, Unsupervised clustering**

I. Introduction

Many people have always wished to watch videos and surf Internet on a larger screen. By using the large screen, it is possible for users to enjoy various applications, such as note-taking, games with screen joystick, etc., more conveniently. To satisfy customer demand, today's smartphones have a bigger screen with thinner bezels compared to the past. Galaxy Note 20 Ultra and iPhone 12 Pro Max are the latest flagship smartphones of worldwide manufacturers, Samsung Electronics and Apple, and their display sizes are 6.9 and 6.7 inches, respectively. Smartphones have continued to increase in size, but human hands have not. As screens get bigger, it becomes harder for a thumb to reach all of the display [1]. To alleviate such inconvenience, some smartphones provide one-hand modes to users. However, in such modes, the horizontal to vertical ratio is fixed and users should adjust the size of scaled-down screen manually. Moreover, using the mode makes a lot of space on screen blank, which wastes the display resource and reduces users' readability.

Recently, many techniques have been proposed to analyze users' behaviors and motions by using various sensors in devices the users carry [2]. Many service providers utilize such valuable collected data to provide customized services that are personal for each user. However, the information obtained from the numerous sensor data created by the motion of touching the display is still not utilized well. Most smartphone applications have inflexible forms that fill the entire screen, and the placements of buttons are usually fixed. However, people of all ages and both sexes use smartphones nowadays [3], [4], and there are differences between the shapes of their hands. Moreover, due to the differences in hand size, finger length, thickness, etc., users hold a smartphone with different grips and hit certain targets on the screen in different ways [1], [5].

To overcome the aforementioned limitations, in this paper, we propose the analysis method to obtain user characteristics from sensor data created while touching the screen. We collected the data from users and analyzed it to extract the worthwhile information. We found that, by using the proposed method, it is possible to know whether a user is right-handed or left-handed. Furthermore, by utilizing an unsupervised clustering algorithm, the proposed technique quantifies how much of the screen the user could reach, and distinguishes natural, reach, and unreachable zones on the screen. Using the proposed technique, smartphone manufactures can provide user-customized functions. Also, application developers are able to improve user interface/experience by customizing the application design and button placement for each user. Our analysis method can be applied not only to smartphones but also to a number of devices utilizing touchscreens to provide user-friendly services.

The remainder of this paper is organized as follows. We introduce related work in Section II. After that, we perform various analyses of sensor data that is created when people touch the screen in Section III. Finally, Section IV concludes this paper.

II. Related work

In this section, we introduce some work related to our research. After that, we explain our research's novelty and differences compared to the related work.

There are some researches that utilize touch measurements to obtain user specific information. Vatavu *et al.* presented a technique that classifies users' age group, i.e., child or adult, from touch coordinates captured on touchscreen devices [6]. Shen *et al.* investigated the reliability and applicability on the usage of users' touch-interaction for active authentication on smartphones [7]. Some researchers focused on analyzing touch areas on the screen. Xiong *et al.* investigated the relationship between the movement coverage on smartphone touchscreens and the factors (age, thumb length, and screen size) affecting this [5]. Lee *et al.* investigated the touch area that can be comfortably reached by the thumb during one-handed smartphone interaction [1].

Compared to the above studies, our research has novelties and advantages in some respects:

- The proposed method utilizes various sensor data from a gyroscope and an accelerometer as well as a touchscreen in combination;
- By using the proposed method, it is possible to not only analyze sensor data but also obtain user-specific information;

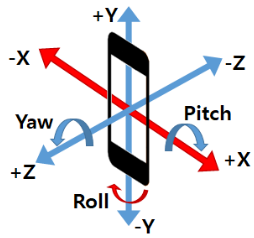


Fig. 1: Accelerations across and tilts along three axes.

- The proposed technique infers diverse user characteristics by utilizing various techniques, such as an unsupervised clustering algorithm. However, the related work [1], [5] just investigated touch area based on observation, assumption, and prior knowledge.

III. Analyses of Sensor Data Created by the Motion of Touching the Screen

A. Analysis of sensors in smartphones

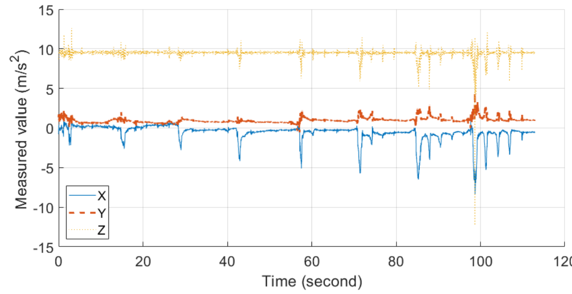
Today's smartphones are equipped with various sensors, such as proximity sensors, accelerometers, magnetometers, gyroscopes, etc. Among these sensors, the accelerometer and gyroscope are the sensors most affected by the motion of touching the screen because they measure the movement of a smartphone. As shown in Fig. 1, the accelerometer measures the phone's acceleration across three axes labeled as x, y, and z, and the gyroscope sensor measures the phone's tilt along any of the axes. Among such axes, as marked in red in the figure, the x-axis and the y-axis are most affected in terms of acceleration and rotation, respectively, because of the way of the user holding and typing on the smartphone. Fig. 2 shows sensor values measured by an accelerometer and a gyroscope when a user touches different points on the screen with the user's right hand. As shown in the figure, the fluctuations of x-axis data and y-axis data are larger compared to the others in Fig. 2(a) and (b), respectively. Thus, we use these values to analyze the motion of touching the screen.

B. Analysis of difference between using right and left hands

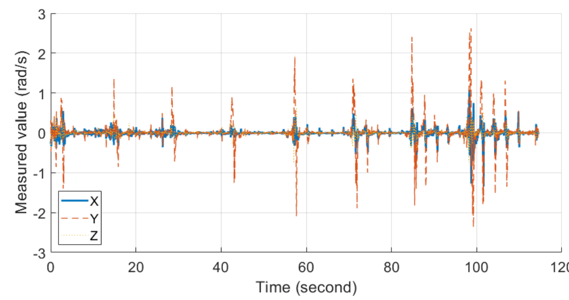
When a user uses the right or left hand to use a smartphone, the user generally holds the right or left side of the smartphone, respectively. Thus, even if the user touches the same place on the screen, the movement of smartphone changes differently depending on which hand the user uses. Fig. 3 shows sensor values measured by an accelerometer when the user touches the same points on the screen when holding the smartphone with the user's right, left, or both hands. When the user touches the screen while holding the smartphone with the right hand, the measured values go up and down in the negative domain. On the other hand, the measured values are placed in the positive domain when using the left hand. Unlike cases using the right or left hand, when using the both hands, values are distributed in the both domains around zero. Thus, by using such analysis method, it is possible to simply grasp which hand is used to hold the smartphone.

C. Analysis of sensor data depending on touching point

Motivated by the findings in the previous subsections, we analyze the sensor values obtained by users touching different



(a) Acceleration values measured by an accelerometer.



(b) Angular velocity values measured by a gyroscope.

Fig. 2: Measured values by an accelerometer and a gyroscope.

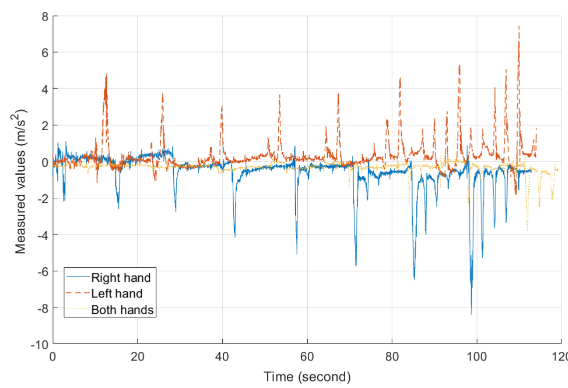
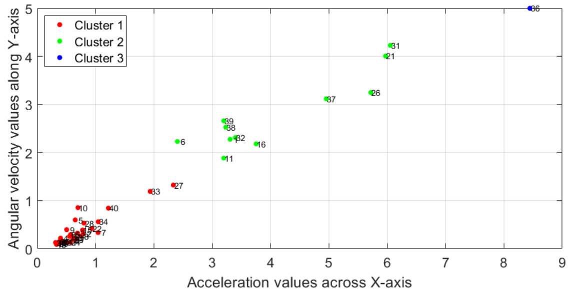


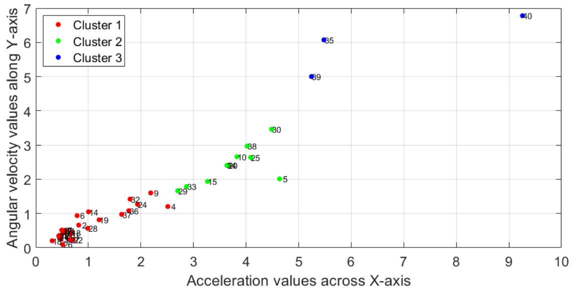
Fig. 3: Acceleration values across x-axis when using right, left, and both hands.

points distributed on the screen. For this analysis, we implemented the test-bed application which shows the points which are placed in the form of 8×5 matrix on the screen. The application collects acceleration values across x-axis from the accelerometer and angular velocity values along y-axis from the gyroscope while guiding the user to touch every button without missing it. 6 users participated in the experiment and we analyzed sensor data collected by the application.

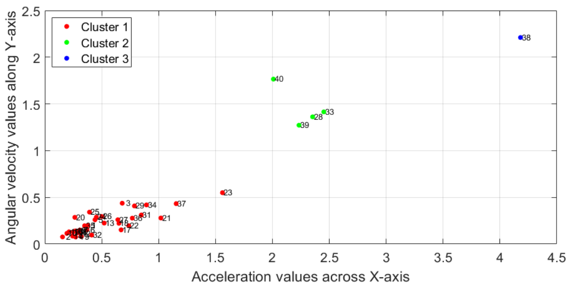
Using the touching inputs' position value, we classified the sensor values collected from actions of touching each point. After that, based on the values collected at each location, we calculated the various values, such as the average, the min, the max, the variation, and the difference between the max and the min. Among such calculated values, we found that the difference between the max and the min is most effective in distinguishing each location on the screen. Thus, using the difference values, we made data points placed in



(a) When using the right hand.



(b) When using the left hand.



(c) When using the both hands.

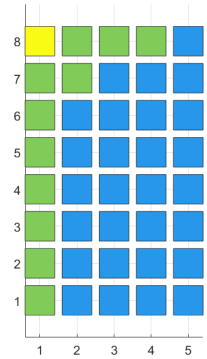
Fig. 4: k-means clustering result based on values collected by accelerometer and gyroscope sensors.

the domain composed of two dimensions, one is based on the acceleration across x-axis and the other is based on the angular velocity along y-axis. Based on theses data points, we conducted k-means clustering [8], and Fig. 4 shows the results of analyzing sensor data collected by one of the participants. Using the clustering results, we divided the area on the screen into natural, reach, and unreachable zones as shown in Fig. 5. The natural and reach zones mean that the areas where the user can touch it without difficulty and with a little difficulty, respectively. The unreachable zone literally means the hard area to be touched by the user.

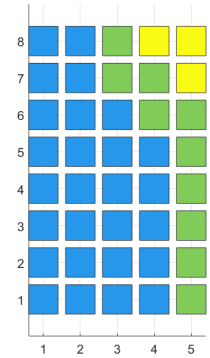
After the experiment, we collected responses from the participants to which points could be touched with or without difficulty. We compared the results with the responses, and Table I shows the average match rate of each case. As shown in the table, we can see that the classification results are correct with high accuracy.

IV. Conclusion

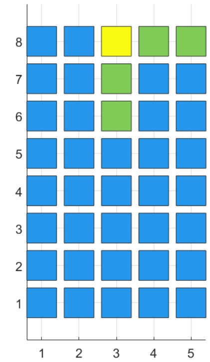
In this paper, we proposed the analysis method that analyzes diverse sensor data obtained while touching the screen and that infers user characteristics. The proposed method utilizes



(a) Using right hand.



(b) Using left hand.



(c) Using both hands.

Fig. 5: Classification into natural(blue), reach(green), and unreachable(yellow) zones on the screen.

TABLE I: Comparison between the predictions and responses

Average match rate of each case		
Right hand	Left hand	Both hands
89.6%	91.2%	93.3%

different sensor data from a touchscreen, a gyroscope, and an accelerometer in combination. By using the method, it is possible to know whether a user is right-handed or left-handed. Furthermore, the analysis technique is able to quantify how much of the screen the user could reach and to distinguish the natural, reach, and unreachable zones on the screen by utilizing the unsupervised clustering algorithm.

As future work, we have a plan to improve our analysis method to infer more diverse user characteristics by utilizing a wider range of sensors and cutting-edge unsupervised learning techniques.

Acknowledgment

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