An Exploration of Inadvertent Variations in Mobile Pressure Input

Craig Stewart[1], Eve Hoggan[1], Laura Haverinen[1], Hugues Salamin[2], and Giulio Jacucci[1]

[1]Helsinki Institute for Information Technology
Department of Computer Science, University of Helsinki, Helsinki, Finland
{firstname.lastname}@hiit.fi

[2]Dynamics and Interaction Group
School of Computing Science University of Glasgow, Glasgow, G12 8QQ, UK
hugues.salamin@glasgow.ac.uk

ABSTRACT
This paper reports the results of an exploratory study into inadvertent grip pressure changes on mobile devices with a focus on the differences between static lab-based and mobile walking environments. The aim of this research is to inform the design of more robust pressure input techniques that can accommodate dynamic mobile usage. The results of the experiment show that there are significant differences in grip pressure in static and walking conditions with high levels of pressure variation in both. By combining the pressure data with accelerometer data, we show that grip pressure is closely related to user movement.

Author Keywords
Pressure, mobile interaction, accidental triggers, implicit interaction.

ACM Classification Keywords
H.5.2 User Interfaces: Haptic I/O, Input Devices and Strategies.

General Terms
Human Factors

NTRODUCTION
Mobile devices afford many different input techniques through their increasing power and range of sensors. Recent research has begun to focus on alternative uses for our sense of touch in mobile interaction. Tactile feedback (commonly vibrotactile stimulation of the skin) is the best understood and most used sub-modality within touch but pressure is also part of the same sensory system and can be used for mobile input [7]. The results of various different studies on explicit pressure input have shown that users can distinguish and apply up to ten pressure levels with high degrees of accuracy when navigating through a standard menu with visual and audio feedback [11].

Pressure does not have to be applied directly to the device display but can also be applied to the sides (if equipped with an appropriate sensor), which means that users can apply pressure to the device by squeezing it. We use squeezing in many everyday activities, for example squeezing a loved one's hand. Some previous research has been conducted on grip-sensing [6] [10], which has shown that grasping is an effective interaction technique.

Pressure created by squeezing the device is an ideal input mechanism for use during phone calls where the device is positioned at the user's ear making it difficult to interact via the display. Such pressure input can be used to augment phone calls with extra information. Adding an extra channel of information to speech communication has been investigated in some previous research. For example, Chang *et al.*[2] developed ComTouch a device that augments remote voice communication using pressure input. More specifically, the device converts hand pressure into vibration intensity with a single actuator. Robinson *et al.* [8] developed TapBack, which provides callers with an augmented experience with interactive voice sites by enabling touch-based gestures on the back-of-device to be used during a call.

Unfortunately, mobile environments can hinder the usability of an input technique. Although there has been a small amount of research on the effects of walking on explicit pressure input [4, 11] there has been little investigation of inadvertent changes in pressure input. As stated by Hinckley and Sinclair [5], 'because touch sensors require zero activation force, they may be prone to accidental activation due to inadvertent contact'. In order for systems to be effective in dynamic mobile environments, inadvertent forces applied to the device need to be examined and should perhaps be taken into account to minimize accidental triggering of the input mechanism. We hypothesise that there are high variations in pressure data due to the context of the user. In other words, different aspects of mobile environments may have an effect on the pressure levels applied to mobile devices; for example, a user's grip on the device may vary in force when walking as opposed to sitting or whilst walking at different speeds.

In existing systems, pressure levels from 0 to 3N have been used [9] because the sensor accommodates this range and it is an appropriate ergonomic range for humans. We argue that the pressure level ranges for robust explicit input should not only be based on the sensor's capabilities but should also consider inadvertent grip pressure changes.

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Our research questions were: what pressure range should be used for explicit pressure input? What are the differences between the average inadvertent pressure level applied to a mobile device when a user is walking and seated? What contextual factors influence inadvertent pressure levels? If we understand the inadvertent interaction better we may be able to design something more robust to mobile usage.

EXPERIMENT

To investigate inadvertent changes in grip force on mobile devices we chose to record grip pressure levels during phonecalls in static and mobile conditions.

Hardware

The prototype mobile phone used in this experiment (Figure 1) was developed by augmenting a standard Nokia N900[1] with a Force Sensing Resistor (FSR). The left-hand side of the device contains no buttons so this is a convenient location to place a large pressure sensor. The sensor itself measures approximately 100mm in length and 14mm in width, providing almost complete coverage of the side of the device. Additionally double-sided tape was used to affix the sensor to the device.

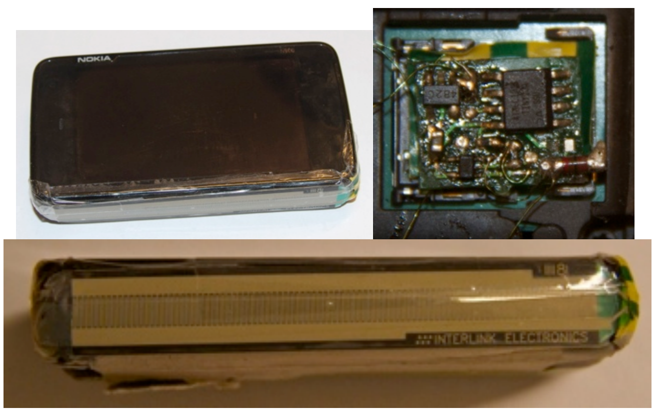

Figure 1: Prototype mobile phone with pressure sensor (top left). The sensor hardware design can fit within the microsd card slot (15mm by 11mm) of the Nokia N900 (top right). FSR attached to side of device (bottom).

The implementation of the Force Sensing Resistor-based pressure sensor is based on the design proposed by Stewart *et al.* [9] and supported by the datasheet of the FSR manufacturer[2]. The op-amp based circuit linearizes the sensor output such that changes in the amount of force applied, results in a similar change in output voltage across the range of pressure used. The output voltage from the op amp is then sampled by an 8-bit microcontroller (Atmel attiny13) at 40 Hz, and resulting data is sent to the host system by a hardware-based serial port. The digital representation of the sensor output is between 0 (no contact) and 195 (extremely firm grip). The range of the sensor was determined informally by asking various lab partners to squeeze the phone as tightly as possible and the sensitivity of the sensor adjusted to limit over saturation of the sensor output.

Logging

During the study we recorded 3D acceleration, FSR, location data and the conversation between the experimenter and subject. The resulting accelerometer and FSR data files were then synchronized and interpolated to a regular 40 Hz sampling rate.

Methodology

28 participants took part in the experiment. The participants were all right-handed, consisted of 16 females and 12 males and aged between 22 and 38 (mean 27.9, std 5.86).

We used a within-subjects design where the conditions were: walking (following a predefined route outdoors whilst talking on the phone) and static (seated at a desk in the lab whilst talking on the phone). All subjects performed both conditions and the ordering of walking and static conditions was fully counterbalanced.

During the walking condition, the participants were asked to follow a predetermined route of 1.4km with varying terrain. The average time to walk the route was 17 minutes 55 seconds. The researcher walked, at a reasonable distance, behind the participant to ensure the participants safety. Additionally, if participants became unsure of the route, the experimenter could provide directional information. The participants were asked to talk on the phone to the researcher and hold the phone in a natural manner.

RESULTS

Analyses focused on participants' inadvertent pressure applied to the device whilst seated and walking. The average pressure values for each mobility condition were calculated and a paired samples t-test showed a significant main effect of mobility condition($t=7.49$, $df=1$, $p=0.0001$) with significantly higher pressure levels occurring in the outdoor walking condition.

Pressure Variations

For pressure input to be used in an explicit manner, the system needs filter out unintentional changes in sensor values. A simple approach to achieve this would be to apply a minimum threshold value that the applied pressure should exceed to be considered intentional as opposed to unintentional. However, if we were to suggest that the mean pressure level should be used as a threshold, inadvertent triggers would still occur due to the large variations in pressure levels as demonstrated in Figure 2. In order to avoid any accidental triggering of pressure input, the minimum pressure threshold at which input can be activated must account for the increase in pressure variability in mobile scenarios.

1 www.nokia.com/gb-en/products/phone/n900/

2 http://www.sparkfun.com/datasheets/Sensors/Pressure/fsrguide.pdf

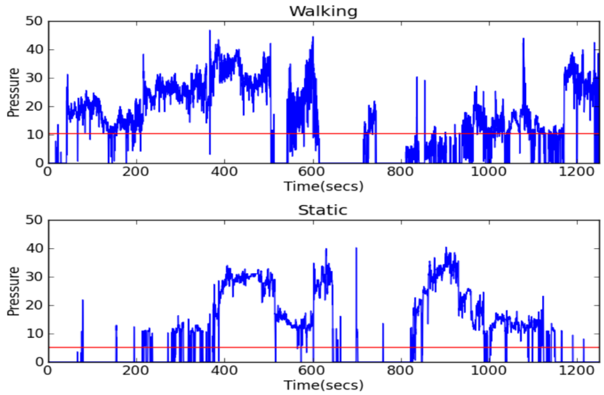

Figure 2: Example Pressure Traces for Participant 10 in the Static and Walking Conditions (with basic mean threshold level shown in red). The digitised sensor voltage 0 - 195 is mapped to voltage of 0 to 2.5v. approx. 0 – 3N.

Acceleration versus Inadvertent Pressure

To further test the effects of a dynamic mobile environment on inadvertent pressure applied to the device, we decided to examine the mobile pressure data in relation to the accelerometer data to determine whether there are any similarities between the inadvertent grip pressure and accelerometer energy in the walking condition. It has been shown in previous work that target selection time and accuracy in mobile tapping task depend on the gait of the user [1] [3]. Therefore it seemed possible that the variance in pressure is also affected by variance in accelerometer readings.

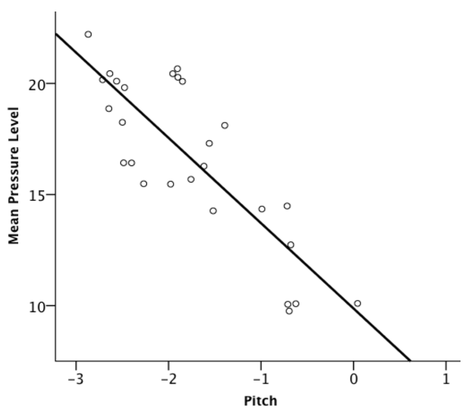

Figure 3: Predicting Mean Pressure Levels from Accelerometer Data[3].

A per sample linear regression analysis was employed to predict the pressure levels whilst walking from the accelerometer data averaged across the whole conversation (R^2 = .83) (Figure 3). Mean pitch of acceleration measurements was most strongly related to the mean pressure level. As the mean acceleration pitch moves towards zero, the pressure decreases. Additionally device roll (in radians) and acceleration magnitude mean had a non-trivial association($r>=.1$).

3 Pitch mean/std: the mean and standard deviation for the pitch (in radians) of the device as determined from accelerometer,.

The inadvertent pressure levels were also analysed with respect to the participants' walking speed. Figure 4 shows the linear trend between walking speed (meters per second) and pressure levels ($R^2 = 0.74$).

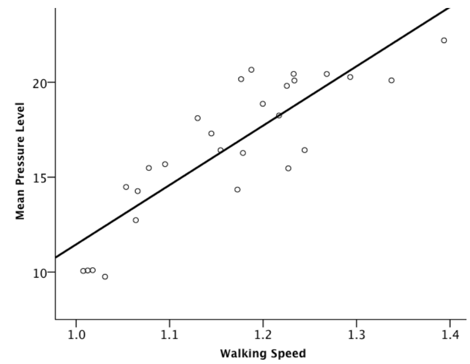

Figure 4: Predicting Mean Pressure Levels from Walking Speed (meters per second)

The significant difference in pressure variations between the stationary and walking conditions (Figure 2) showed that walking increases the amount of pressure variations applied to the device. The increasing linear trend between the walking speed and pressure levels shows that an increase of 1.1 to 1.2 meters per second results in a significant increase in pressure, $t(12)=4.74$, $p<0.01$.

Sensor Usage Analysis

By taking all of the above results into account, we wanted to explore the remaining design space for explicit pressure input. We were interested in determining the range of pressure levels available for explicit pressure input. Figure 5 shows the range of pressure values obtained (walking and static) with respect to the overall range of the FSR.

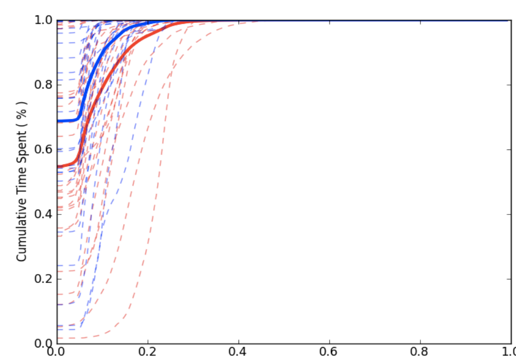

Figure 5: Cumulative Time Spent vs. Normalized Pressure Range (Indoor/Outdoor: Blue/Red, Dashed/Bold lines: Individuals / Mean).

On average, the inadvertent pressure applied to the device by participants was 20% (up to 0.6N) of the overall range of the FSR. This result suggests that the remaining 80% of the sensor range could still be used for explicit pressure input.

DISCUSSION AND CONCLUSIONS

The exploratory experiment described here investigated the inadvertent pressure levels applied by users when holding and talking on a mobile device in a static lab-based and mobile walking environment. In response to our research questions:

What are the differences between the average inadvertent pressure level applied when a user is walking and seated?

The results show that significantly higher levels of inadvertent pressure occurred in the walking condition compared to the static condition. However, there was also more pressure variation in the walking condition than the static condition which makes it difficult to create an explicit threshold based on the average pressure levels.

What pressure range should be used for explicit pressure input?

The FSR data shows that inadvertent pressure levels commonly ranged from 0 to 0.6N. This means that thresholds above 0.6N would be more robust for explicit pressure input.

What contextual factors influence inadvertent pressure levels?

The analysis showed a relationship between the mean pressure levels and acceleration. For example, as the mean acceleration magnitude, the mean and standard deviation for the roll of the device, walking speed and the mean acceleration pitch increase, the pressure levels increase. This means that, as users' movements increase, they increase their grip on the device. These results suggest the possibility of using accelerometer data to dynamically adapt a threshold level for intentional pressure input. However the analysis with the accelerometer data did not fully explain the variations or changes in inadvertent pressure during phone calls whilst users are walking. There may be other contributing factors in mobile environments.

Future Work

Future studies will examine additional factors that may affect a user's grip on a mobile device. For example, weather, terrain, conversation topic or emotional state of the user. Additionally the physical dimensions of the device may affect the user's grip. By using multiple pressure sensors we will be able to access more informative data about subtle changes in grip pressure and assess ergonomic factors. This would enable us to develop an adaptive threshold that takes these variances into account. This would lead to a more robust approach to designing explicit pressure input mechanisms that can tolerate dynamic mobile usage. Although this experiment focused on grip pressure during voice calls, it is likely that the results could be applied to other mobile use case scenarios too. Another interesting use for the data collected in this experiment and future work revolves around implicit interaction. We may be able to infer additional information about users through their inadvertent grip pressure such as conversation dynamics or as an extra measure of context to allow feedback to be adapted based on the user's situation.

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