Rich Tactile Output on Mobile Devices

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Rich Tactile Output on Mobile Devices

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Abstract. In this paper we assess the potential of rich tactile notifications on mobile phones. Many mobile phone users use vibration output for various types of notification on their phone. Currently, tactile output in phones is limited to one single actuator that can potentially present patterns based on different vibration intensity over time. To explore the possible design space, we conducted experiments with up to 6 actuators included in a phone prototype to find out about the user experience that can be created with multi-vibration output in a handheld device. The dimensions of the resulting design space are comprised of the location of the active actuators, the intensity of the vibration, and the variation of these parameters over time. Based on several user studies and interviews, we suggest design guidelines for rich tactile output facilitated by several distinct actuators. We show where vibration motors should optimally be placed and that different information can be reliably communicated by producing different patterns of vibration output using a small number of actuators.

1 Introduction

For mobile phones, notification is of great interest as many functionalities of a phone are triggered externally and require the attention of the user. Audio notification is the most commonly-used form of notification; however it is not suitable in many contexts as it may disturb others or may be inaudible due to environmental noise.

As audio engineering on mobile phones has become more and more sophisticated, using ringtones have become a popular way to personalize one's cell phone and therefore became a standard feature offered by cell phone providers. According to M:Metric[1], who measures the consumption of mobile content and applications, the number of users who say they made their own ringtone grew from 11.3 percent in May to 12.3 in November 2006 in Germany, from 10.2 to 12.6 percent in France, from 17.1 percent to 19.1 percent in the UK, and from 5.1 percent in to 6.6 percent in the U.S. Another standard feature of recent mobile phones is the option to configure different ringtones as event notification (e.g. incoming call, SMS, and alarm). With

[1]http://www.mmetrics.com/press/PressRelease.aspx?article=20070110-ringbacks (accessed July 2008)

incoming calls, ringtones can even reveal a caller’s ID by using different ringtones for individuals or contact groups.

In contrast, the means of personalization with tactile output is still very limited and not commonly used. Tactile output is used as a means of discreet notification and offers an alternative to audio output. Tactile or cutaneous sense is defined as a combination of various sensations evoked by stimulating the skin [14]. In combination with kinesthesia, tactile feedback is often referred to as haptic [19] and is crucial for us to interact with our physical environment. The vibration stimulus is an unobtrusive way to find out about incoming calls, messages, or reminders without disturbing others. Vibration pulses are a widely-used output mechanism in current phones and a common part of the phone interface.

Haptic interaction offers many potential benefits for the users of mobile devices, as these devices are designed to be carried or worn by users wherever they go. This may include noisy and busy environments where users have to multiplex their visual, auditory, and cognitive attention between the environment and the information device [1]. In such cases, haptic interaction offers another channel. Due to nature of tactile reception, it is a private medium that provides for unobtrusive modality for interaction. So by redirecting some of the information processing from the visual channel to touch, we can take advantage of this ability to reduce the cognitive load and make it easier to operate mobile devices. Skin is the largest human sensory organ (~1.8m^2) and with the exception of water and heat regulation, most of it is unused [14]. Since touch receptors can be found all over the body, it is usually possible to find a suitable location to provide a haptic stimulus without environmental interference [2].

2 Design Space for Multitactile Output

Skin sensation is essential for many manipulation and exploration tasks. To handle flexible materials like fabric and paper, we sense the pressure variation across the fingertip. In precision manipulation, perception of skin indentation reveals the relationship between the hand and the grasped tool. We perceive surface texture through the vibrations generated by stroking a finger over the surface.

Geldard et al. [15] in 1956 developed a vibrotactile language called *Vibratese* to transmit single letters and digits as well as the most common English words and demonstrated that trained subjects were able to receive a complex message up to 38 words per minute. This showed that with proper encoding, messages could be transmitted through the skin. We can take advantage of this while designing mobile interfaces. The message, however, does not necessarily need to be symbolic: touch has a strong emotional impact. Running a finger into a splinter, touching a cat's fur, or immersing into some unknown sticky substance all bring intense, though very different, emotional responses. Hence, touch is a very strong "break-in" sense: cutaneous sensations are highly attention demanding especially if they are used in unusual patterns [16]. Tactile feedback provides superior temporary discrimination, e.g. when rapidly successive data needs to be resolved, the feel of touch is about five times faster than vision [17]. Hence, it allows for precise and fast motor control: When we roll a pencil in our fingers, we can quickly and precisely readjust the 3D positions and grasping forces of our fingers by relying entirely on touch [18].

Particularly, mobile phones typically are still not aware of the contexts in which they are being used. Many cell phones support profiles that allow the user to manually set an appropriate response for different context, however the user should remember to set the correct profile. So providing vibration (silent) feedback and output is needed in mobile phones. There are many possibilities for tactile feedback in mobile interfaces. Here, we are particularly interested in a small subset of this design space: using touch as the ambient, background channel of output and feedback. In a mobile setting the user's attention is not fixed on the device, but on real-world tasks.

To understand the current use of audio and vibration feedback with mobile phones, we surveyed 30 people about their personal use of each type of notification. Our surveys consisted of 13 females, 17 males, 21 to 42 years in age with an average age of 26. We found that 80% use vibration as a form of notification for incoming call (as silent mode). However, a great majority of the users used the preset vibration output. Furthermore, 70% of the participants were not aware that their own phone model supported the use of different vibration alerts for different events such as incoming calls, receiving SMS or MMS, and low battery.

Vibration alerts found in mobile phones are generated based on a vibration actuator made of a small motor with an eccentric weight on its shaft. The rotation of the motor then generates the vibration stimuli. The control signal can switch the motor on and off; and in some cases; it is possible to control the intensity of the vibration by controlling the speed of the motor (typically using pulse-width modulation). Thus, using different pulse intensities and timings with a single motor, as present in many current phone models, seems to either leave little impression on users or is processed subconsciously.

The idea in this research was to integrate more than a single vibration motor in a mobile phone and to find out if multi-tactile output/feedback is achievable and can be used to enhance the interaction between users and the device. As previous research showed that providing tactile feedback and output increased the performance of interaction (see the next section), our hypothesis is that multi-tactile feedback in different locations on a mobile phone is feasible for users. Having more than a single motor for generating the vibration alert helps us to have stimulus all over the surface on the phone (of course it depends on how the motors are integrated in the mobile phone), and provide multi-tactile output and feedback as well as different vibration patterns. Based on how many motors are used, different patterns can be defined and each one can be associated to a special feedback, output, or event.

Looking conceptually at tactile output we can discriminate 3 distinct dimensions that describe the basic design space:

- Temporal change in the vibro-tactile output signals
- Spatial arrangement of vibro-tactile output elements
- Qualitative sensation created by an output element

To create rich tactile output, those dimensions are combined. In Fig. 1 this is explained for temporal and spatial aspects.

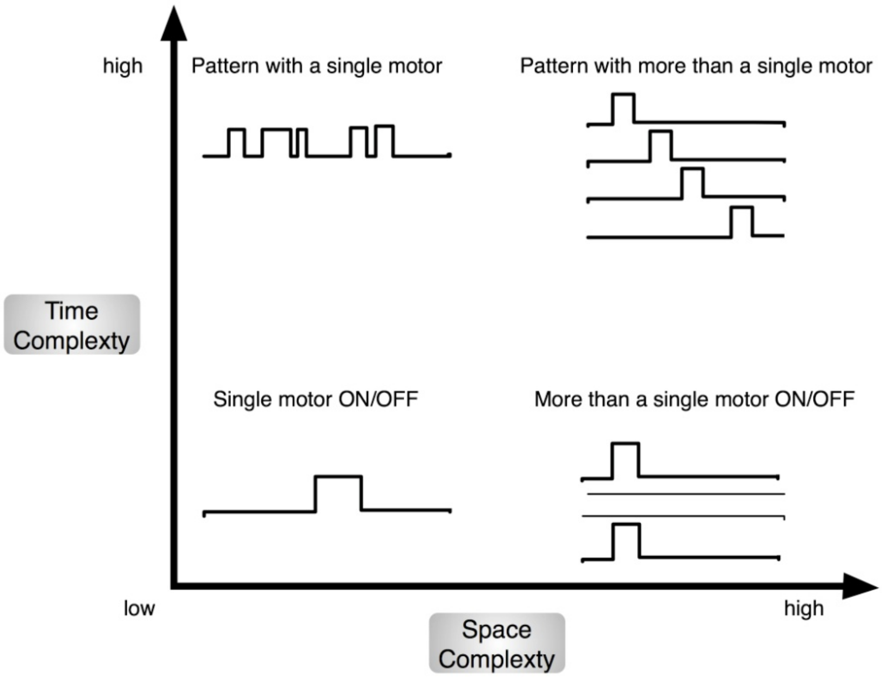

Fig. 1. Time-Space complexity to generate vibration stimuli. By increasing the number of the motors, the space complexity is increased too. Also providing vibration patterns has a higher time complexity than simple vibration output.

With a larger number of motors it is obvious that the space complexity is increased. However the overall number of motors is limited by the physical properties of the device and the ability of the user to discriminate different vibrating locations. On the other hand, the time complexity of a single motor setup is limited by the switching frequency that is feasible (with regard to the device capabilities and the user's ability to recognize it). Having a larger number of motors and generating a distributed vibration pattern has the highest complexity in terms of time and space (Fig. 1).

To explore the design options in detail, a series of experiments were conducted. We created a prototype with multiple vibration actuators in the form factor of a current mobile phone matching dimensions as well as weight and report on two studies. In our work, we investigate ways to increase the options for tactile output to provide a richer and more personalized user experience.

3 Related work

If we look at previous research, it is widely recognized that haptic interaction offers another channel to provide output to users as they may be in a context where they have to multiplex their cognitive attention between the device and context, and that performance can be improved in interactions with mobile phones and handhelds.

Brewster *et al.* [4] investigated the use of vibrotactile feedback for touch screen keyboards on PDAs to simulate the physical button presses. They found out that with tactile feedback users made fewer errors, and corrected more of the errors they made. They also designed a tactile progress bar indicating the progress of a download and found out that users performed better with tactile progress bars than standard visual ones [4]. Brown and Kaaresoja developed a set of distinguishable vibrotactile messages by using Tactons (tactile icons) to customize alerts for incoming calls, SMS, and MMS [5]. Poupyrev *et al.* [7] embedded a TouchEngine – a thin miniature low-power tactile actuator – in a PDA and conducted user studies that demonstrated 22% faster task completion when the handheld's tilting interface is enhanced with tactile feedback.

One example that uses different sequences in buzzing is the VibeTonz[2] technology developed by Immersion for enhancing ringtones and games in mobile phones. Other examples integrate vibration with sound, such as with Motorola's Audio-Haptic approach, which enhances ringtones with haptic effects using a multifunction transducer [13]. Williamson *et al.* [11] designed a system for mobile phones called *Shoogle*, which implements different real-world metaphors that reveal information about the state of the phone. For example, using *Shoogle*, users can determine the content of their SMS inboxes by shaking their phones, which activates vibration feedback.

All these approaches show that there are clear opportunities and advantages for using tactile output. The aforementioned projects focus on a single vibration actuator and look at the design space that is given by changing the intensity of the vibration. A more complex example is described by Chang *et al.* [6] who designed a tactile communication device called *ComTouch*. The device is designed to augment remote voice communication with touch, to enrich interpersonal communication by enriching voice with a tactile channel. In this case, tactile patterns and timings are immediately taken from the user and do not need to be generated. In [12], a tangible communication system using connected roles is described. The author demonstrates that having such a channel could improve the user experience in remote collaboration setting.

Haptic output has already been successfully applied in other areas. Tan *et al.* [8] combined the input from pressure sensors mounted on the seat of an office chair with tactile actuators embedded in the back of the seat to create an input device with haptic feedback. They also integrated the system into a driving simulator to determine when the driver intended to change lanes and alerted the driver with vibrotactile pulses about danger based on observed traffic patterns. This is an example of how haptic feedback can communicate information with low cognitive overhead, and this

[2] Immersion ViboTonz system, http://www.immersion.com/mobility/

motivated us to further investigate the design space of mobile devices. In the domain of wearable computing, there have been projects, such as [9] and [10] that suggest using vibrotactile output for communicating information discreetly without disturbing others. Similar to our approach, multiple actuators were used. However, the authors required the actuators to be at a specific position on the body (e.g. around the waist or in the hands).

Our motivation to further investigate multi-tactile output for mobile devices is based on the results of existing systems using single or multiple actuators mounted to specific places on the body. For our investigation we designed and implemented a prototype mobile phone with actuators as descried in the next section.

4 Prototype for Rich Tactile Output

We decided to develop a prototype that allowed us to create rich, tactile output in a device equivalent in size and shape to a typical mobile phone. As current mobile phones are highly integrated and tightly packed, we chose to use a dummy phone and concentrate on the vibration output functionality, see Fig. 2. A dummy phone is a plastic mobile phone with the same dimensions as a real one without any functionality and electronic boards inside. With this prototype, we set out to explore the impact of multi-tactile output on the user experience.

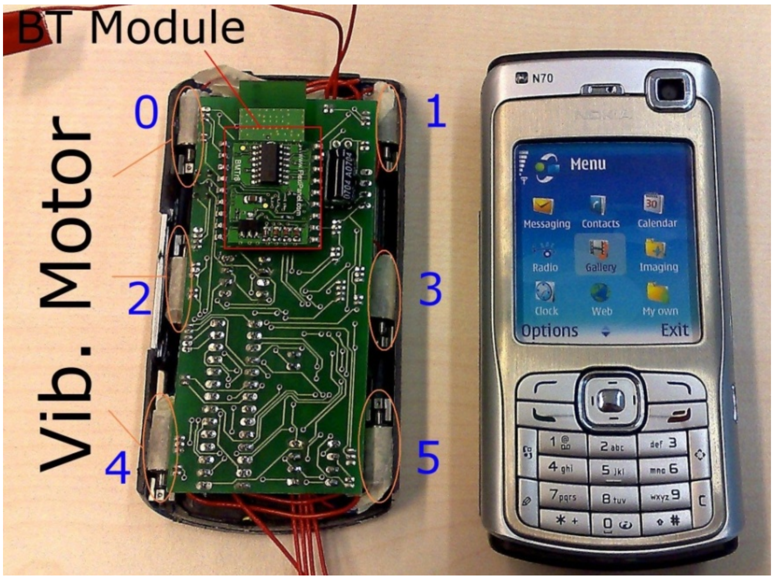

Fig. 2. Six vibration motors integrated in a dummy mobile phone, placed to maximize the distance between them. The motors can be controlled using a Bluetooth connection.

For the prototype, we designed a printed circuit board with one microcontroller (MCU), six controllable vibration motors and one Bluetooth module. The Bluetooth module was chosen so that the microcontroller, and hence the vibration motors, could be remotely controlled over a Bluetooth connection using another phone or a PC. We took a Nokia N-70 dummy phone, removed all its internal parts and integrated our multi-vibration system. Therefore, the resulting prototype looks and feels just like a real Nokia N70 mobile phone without any phone functionality. The N-70 Nokia mobile phone's physical specifications are:

- Volume: 95.9 cm^3
- Weight: 126 g
- Length: 108.8 mm
- Width (max): 53 mm
- Thickness (max): 24 mm

The actuators are standard vibration motors that are used in mobile phones to generate vibration alert. Four motors are located at the four corners of the phone, and two more in the center of the phone (see Fig. 2). Within the device, the actuators are located close to the back cover. The location of the actuators was chosen to maximize the distance between them. Using the prototype, we can therefore generate vibration pulses on the body of the mobile phone in six different areas and with varying intensity. During our experiments, we used a Bluetooth connection to control the vibration sequences of the motors.

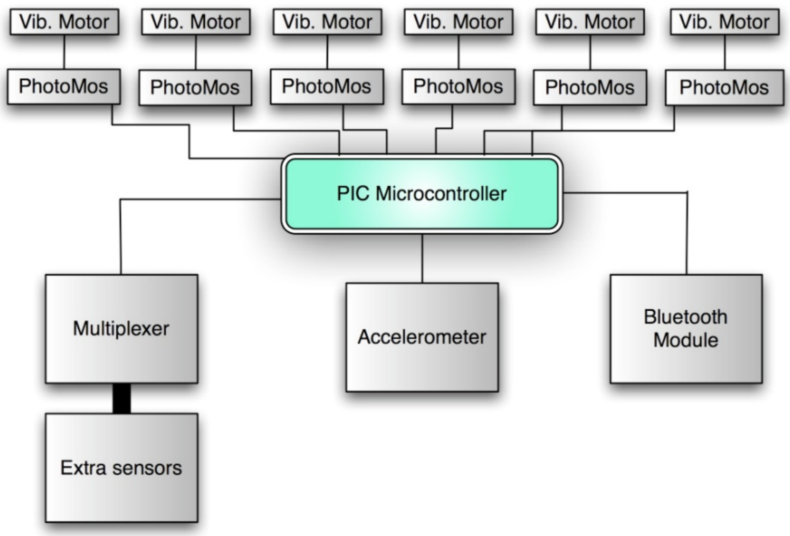

Fig. 3. PCB Architecture: a PIC microcontroller is responsible controlling all modules. Six motors are connected to the PIC via PhotoMos. A Bluetooth module is used to establish the connection to the PIC and send/receive data.

The microcontroller unit (a PIC18F2550) runs at 20MHz, and each motor is controlled using a PhotoMOS switch connected to the microcontroller. After a Bluetooth connection is established, the vibration intensity of all six motors can be controlled independently with no perceivable delay. The intensity is controlled using pulse-width modulation (30%-100%). The software running on the microcontroller receives commands that specify which motors should be switched on with what intensity over the Bluetooth connection. A Java-based application was implemented to run on another mobile phone and generate these commands. Using the prototype, we can generate vibration pulses on the body of the mobile phone in six different areas and can control duration and intensity. The architecture of the board is shown in Fig. 3.

5 Experiments

To explore the design space in detail, we conducted two studies using the prototype. In the first study, we investigated how easy it is for users to identify individual actuators. The second study looked at the user experience provided by different vibration patterns and how easy it is to distinguish between them. In both cases we asked users to hold the device in their prefer hand. We also considered having a condition where users have the phone in a pocket; however, the variation in how people prefer to carry their phone would seemingly require a very large sample to make useful conclusions. If the phone is carried in a pocket or bag, the initial vibration is felt there. Then the users can seize the phone but do not necessarily have to take it out or even look at it as it was argued in [11]. Hence testing in the hand appears reasonable.

Study 1: Locating a specific actuator

In the first study, we asked the participants to tell the position of the vibration stimuli. This three-part study was conducted with 15 persons (5 females and 10 males), aged 21 to 30 with an average of 26 years.

In the first part, the users were asked if the vibration pulse was on the right or left side of the phone. In the second part, users were asked if the stimulus was on the top, middle or bottom of the mobile phone. Finally, in the last part, users were asked the position of the pulse in two dimensions: top/middle/bottom (on the y-axis) and right/left (on the x-axis). In this part the stimulus was generated just with a single motor. For example the pulse could be addressed like top-right (if motor 1 was on) or middle-left (if motor 2 was on). The motors' configuration is shown in Fig. 2. Turning motors 1, 3, and 5 on, simultaneously generated the stimulus on the right side and motors 0, 2, and 4 generated the stimulus on the left side. The stimulus on top was generated by turning motors 0 and 1 on, in the middle by turning motors 2 and 3 on, and on the bottom by turning motors 4 and 5 on at the same time. The experiment was repeated 10 times (5 times each for the right and left sides) in the first part, 15 times (5 times each for the top, centre, and bottom) in the second part, and 30 times (5 times for each motor) in the last part. All the vibrations were triggered randomly and remotely. The duration of each stimulus was chosen to be 300ms.

The experiment showed that users could discriminate between left and right, as well as top and bottom, with a recognition rate of 75% on average. Participants showed a similar detection rate for actuators in the four corners (with an average rate of 73%). However, recognition for the actuators in the middle of the device (as a group or individually) was significantly lower. One reason could be the lack of enough space between the motors in the middle and motors in top and bottom of the phone although in our design the motors were located with maximum distance from each other.

Therefore, the overall recognition rate of locating the vibration of a single actuator was only 36%. In Fig. 4, an overview of the results is given. The results indicate that it is preferable to place actuators for vibration in the corners of the device. One point that was not taken into account here in processing the result and drawing conclusions were potential differences between holding the phone in the right and left hand (in our survey, 80% of the participants were right-handed and held it in their preferred hand). As shown in Fig. 4, recognition rates between actuators on the right and left side are close. On the other hand, the results also depend on the motors' configuration which we will consider and test in future work.

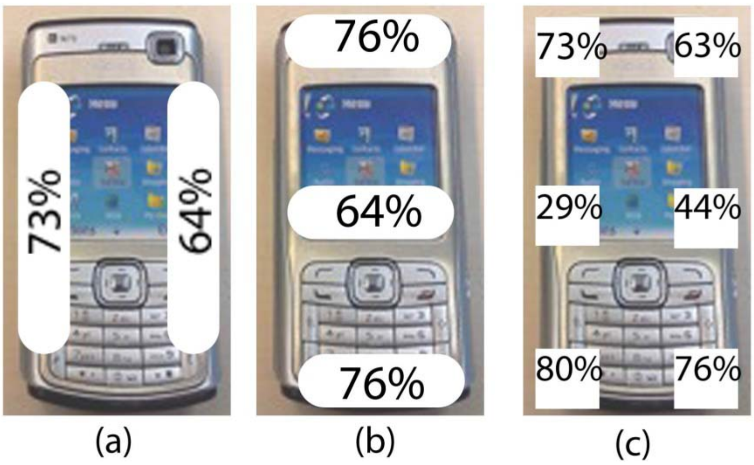

Fig. 4. The results show that users could better locate the active actuators in the corners than in the middle of the device.

Study 2: Discriminating between vibration patterns

In the second study, three vibration patterns were defined and the focus was on how well the participants can distinguish between these patterns. The main difference between the patterns is the number of motors that are switched on in a particular point in time. The first pattern called "*Circular*" meant that in each moment one motor was on, the second one was "*Top-Down*" with two motors on, and the last pattern was "*Right-Left*" with three motors on at the same time. To generate the patterns, each set of motors (1, 2, or 3 motors, depending on the pattern) was switched on for 300ms and then followed by the next set.

This study was conducted with 7 users from the previous study and 6 new users (in total 4 female, age range 20-42, average age 27 years). At the beginning of the experiment, all patterns were played to the users and they asked to memorize them. Additionally we include random patterns to see whether the user could locate the predefined patterns. First we tested the recognition of each pattern separately against random patterns. During this phase in the experiment, users indicated if the played pattern was the pattern shown at the beginning or not. Each experiment was repeated 10 times (i.e. 5 times the predefined pattern and 5 times a random pattern, in random order). Overall users correctly identified the specified patterns and the random patterns with 80% accuracy for all three patterns.

In the next phase, we compared the detection of the patterns using all patterns in the experiment. Users had to indicate if the vibration stimuli constituted one of the predefined patterns or random vibration and potentially identify the pattern. In this part, each pattern appeared 5 times at random places in the sequence. Based on the results, the accuracy rate for the first pattern "*Circular*" was 82%, the second pattern "*Top-Down*" 51% and the last one "*Right-Left*" 68%. The results show that the recognition is independent of the number of active vibration actuators in one particular moment. This showed that different patterns could be defined as default in mobile phones and could be used as feedback or any other usage in mobile devices as users could understand and discriminate different patterns. For instance, most mobile phones have a feature that let users assign a specific ring-tone to a number or group of numbers in the contact list. Instead of that, they can use patterns and assign different patterns to different contact items.

Limitations

During the user studies, we could not explore the interaction with real mobile phones as these devices are tightly integrated and is hardly possible to integrate extra actuators without altering the form factor. Once integrated within a functional phone, we expect that there are interesting aspects with regard to multimodality (e.g. visual navigation relating to tactile output).

Although the user studies were conducted with a limited set of users, we see a clear trend that shows the potential of rich tactile output. In our experiment, we focused on situations where users have the device in their hand and the results only apply to these use cases. As we are aware that people often have their phones in pockets or bags, we are currently looking into experiments to assess how feasible rich tactile output is for such scenarios.

The generated sensations and the quality of the tactile output are strongly dependent on the actuators used. In our prototype, we used common actuators present in typical mobile phones to show that rich tactile output can be achieved with these components. Nevertheless, we expect that specifically designed output elements may even improve the user experience. Hence our results can be seen as a bottom-line from which to improve. Such improvements could be achieved on all dimensions introduced earlier.

The vibration stimuli created in a device are not exactly limited to the spot where they are created. These signals also pass through the shell of the phone depending on the material. Hence, stimuli from different motors may influence each other. Again, a more targeted design of the device covers may help to reduce ambiguities and create a better user experience.

6 Conclusion and Future Work

One of the main issues in user interface engineering is presenting clear and understandable feedback and output during the interaction with a system. Advances in technology made mobile devices ubiquitous and enabled users to employ them in many contexts. However, they often employ naive alerting policies that can transform them into nuisances as users of mobile devices are bombarded with alerts and notifications.

Rich tactile output creates new options for providing information to the user. Currently, this modality is used only in its very basic form. Analogous to the developments in ringtones, there is a potential for personalization in tactile notification. Using a customized prototype with multiple, independently-controllable vibrating actuators, we explored the effectiveness of multiple haptic output in a suite of experiments.

From our experiments we conclude that multiple actuators can be used to create a richer user experience and users are able to feel and recognize different forms of tactile output in a single handheld device. Users were able to understand stimuli generated with motors in different locations in a mobile phone while holding it in their hands. In particular, based on the motor's configuration, our research findings indicate that the corners of the handheld device provide the most effective places for mounting vibration actuators.

While testing dynamic actuation patterns with different durations, we found out that discriminating between vibration patterns is feasible for users. We consider this a new potential mechanism for providing tactile output and personalizing the mobile phone in parallel with audio ring-tones and offer a new dimension for a richer user experience.

The results of our study and the interviews carried out indicate that having several vibration elements in a handheld device is feasible and understandable and can be suggested to be used as an effective way to provide richer tactile feedback and output, improve the user interface, and offer a new dimension for a richer user experience. In our future work, we are investigating the use of multiple vibration output elements as a feedback mechanism also during visual interaction on mobile devices. In addition to the tests we have conducted, we look at the recognition rate of multi-tactile output on a mobile phone when it is in a pocket or bag attached to the body.

So far this research shows the potential tactile output for mobile devices. To explore it further, we suggest testing other configurations with different numbers of motors.

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