Prototyping New Interaction Style

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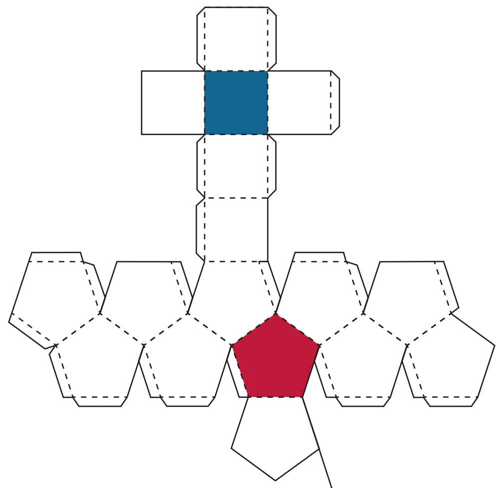

PROTOTYPING New Interaction Style

- a case study on designing deformable mobile devices

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Master of Arts Thesis

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2012

Acknowledgement

This thesis would not have been possible without the guidance and support of my supervisor, Embodied Interaction Lab Manager Jussi Mikkonen, who has made tremendous effort in every stage of the project execution, especially in prototyping and designing the user test. All the three games and interviewing questions for user test were designed and implemented by him. I want to show my greatest gratitude to Jussi. Additionally, I would like to thank Teemu Ahmaniemi, Merja Haveri, and Johan Kildal, from Nokia Research Center, who actively participate and support in the project.

Moreover, I would like to thank professors from Industrial and Strategic Design department who opened my mind and made design tangible to me, especially Peter McGrory and Turkka Keinonen. Equally important, researchers from Embodied Design Research Group, particularly Salu Ylirisku who is leading the group, have inspired me passion in design research. I'm proud of once being part of it.

Thank you, all my friends (Facebook friends also count) and people I know for revealing the meaning and values of life to me. Thank you for making the world a more beautiful place by doing good.

Finally my gratitude goes to my family for supporting me in any possible ways without a reason. Special thanks to my wife who has been invaluable to me.

Abstract

This is a project-based thesis work initiated by Nokia Research Center. The goal of this project is to investigate deformable user interfaces (DUIs) on mobile devices. Following background studies and identification of the research questions, various design methodologies were developed to encounter the new interaction style. An explorative experiment was designed to study the role of form in DUI design. The purpose is to find insights from people's instinct and tactile sense and to study dimensional properties on flexible materials. Another workshop was arranged so that experts in design and engineering experienced a whole design process for bridging form factors and applications with interaction. During the workshop, the context which is the detaching of touch interface users with the immediate environment was studied. Through these two activities, a set of design cues for deformable mobile devices was thus derived.

The method of research through design has been the backbone of this thesis work. Numerous prototypes were implemented as physical representation of the hypotheses in each stage. At last, a working prototype was constructed. Consisting of a flexible mobile device and an information system, the prototype enables deformable interaction with information distributed in the space. A set of user test was conducted accordingly. Through these design activities, the role of form factors in mobile DUIs was examined. Moreover, it can be concluded that physical deformation in DUIs results in more engaging experiences than touch interfaces.

keywords: deformable user interfaces, interactive prototyping, research through design, interaction design, mobile interaction, organic user interfaces

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Introduction I

Chapter I

This project-based thesis work focuses on exploring deformable interaction under mobile context. In this thesis, the design approach, process, outcome, and findings of the project will be illustrated. Starting with introducing the project, this chapter depicts the framing of the thesis by presenting the approach and process. Although the work is based on the execution of the project, only relevant materials which manifest the design methodology are presented in the thesis.

1.1 about the project

As technology advances, more and more possibilities have been opened to the realm of interaction design. Initiated by Nokia Research Center (Nokia Research Center n.d.), this project intends to develop new interaction styles based on flexibility. While touch screen, which merges input and output interfaces together, appears to be the major trend on mobile devices, there are other sensors embedded on devices as well to grasp users' motion in the space, such as gyroscopes (Pustka and Klinker 2008) and acceleration meters (Lantz and Murray-Smith 2004). With the help of these sensors, the hand held device might be able to understand the underlying context more by detecting the movement of the device and analyzing the collected data. Its corresponding response can thus be more intimate to users' need. Another benefit from these technologies is new interaction styles that are enabled. Users are able to utilize their skills of manipulating physical objects in the space to interact with digital contents. The game console Nintendo

Wii is an example (Wii Official Site at Nintendo n.d.). The realm of human-computer interaction is no longer a simple case of pressing buttons for cursors moving in four directions, up, down, left and right.

The purpose of this project is to explore the possibilities in building mobile interfaces based on flexibility. With flexibility, an object could be deformed in various manners, such as folding, bending, twisting, stretching, etc. The main idea is to understand how people manipulate a mobile device when its deformation is utilized as an interaction style. Pressing a button on a device can be defined as interaction enabled by deforming a button. However, the intention of the project is to explore how the deformation can be applied on the entire device. For example, by applying force on both ends of a device, one can make a flat device present in a curved state which then triggers a software action on the system. Different system responses can thus be developed based on various gestures.

There are several requirements that frame the project. The major concerns are listed below:

a. **Understand the corresponding form factors that mediate the new interaction style.**

   Through the execution of the project, it should be understood what the form factors are that manifest the subject's deformability, as well as the role of form factors in deformable user interface design.

b. **Consider real use cases under the constraints of minimized display and one-hand using situation.**

   The outcome should also present what the scenarios are when people could use deformation as an interaction style. There are two constraints presented, to minimize the display required and to consider one hand using situation. There have been several prototypes built for deformable user interfaces which will be presented in the next chapter as background review. In most cases, the deformation in these concepts acquired users to perform with two hands. However, for practical consideration, it could be more desirable for users if the deformation could be performed with only one hand. The other constraint is derived accordingly. That is, the device has to be small enough so that it fits one-hand use cases. Therefore, the size of the display is limited as well.

c. **Build a working prototype that manifests the characteristic of deformation as a new interaction style.**

   The building of a working prototype is required so that various interaction cases under different context can be tested. Users should be able to perform different gestures on the prototype and the system should respond accordingly.

1.2 the approach and the process

In order to explore in the new interaction paradigm, and also for the reason that prototyping is required in this project, research through design method is applied. With design artifacts as the outcome, design practices take place along the research process (Gaver 2012; Zimmerman, Forlizzi, and Evenson 2007).

Various prototypes are designed to facilitate the representation of the situation which addresses the research topic. The design of the prototypes is different than that in a product design process. Instead of seeking the optimal solution to a product, the prototypes built in research through design process aim to answer the research questions. The derived knowledge accordingly is to be used to construct a new theory or a framework (Frens 2006).

The process of the thesis can be found in Figure 1.1. The work can be divided into two parts, background study and design. In the background study, related works and the derivation of the research questions are presented (chapter 2). From this part, a holistic view of the design space can be obtained. The second part demonstrates a research through design process for developing a new interaction style. This part involves mainly the exploration experiment, co-design workshop, and prototyping as three different stages. The first design action is Form Exploration Experiment in which physical form was dissected according to the dimensions (chapter 3). It was an explorative process to understand human instincts on flexible materials with dimensional characteristics presented in different forms. From the experiment, the elements that construct deformable user interfaces could be found through the explorative manner. In the second stage, co-design workshop, experts in design and engineering were brought together to experience the whole design process in one day (chapter 4). By working in teams, the participants first understood the context and then developed their concepts. During the workshop, prototyping was utilized as a tool to fertilize team work. From the above two design actions, design cues for a flexible mobile device could be derived

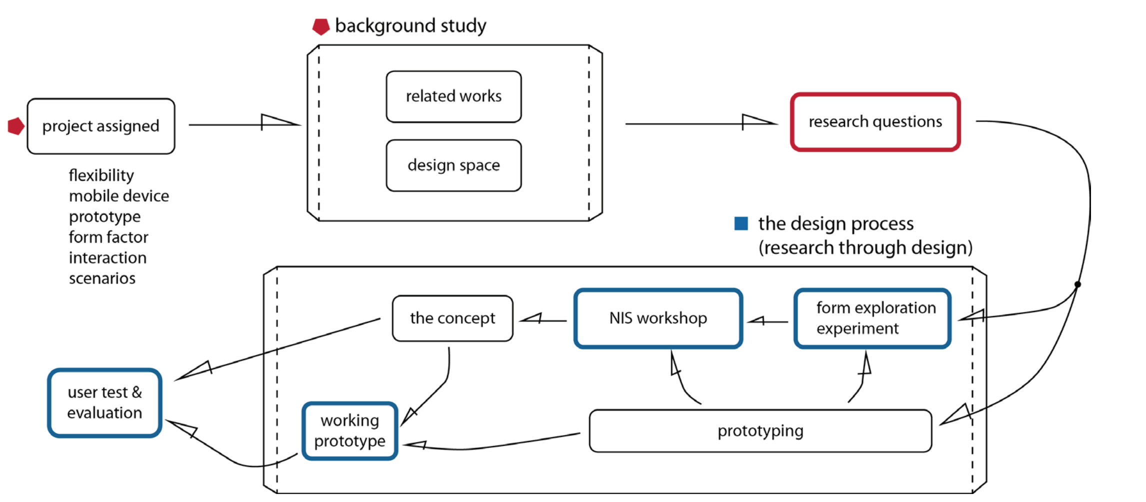


Figure 1.1 The Process

(chapter 5). Based on these findings, the design process entered its third stage in which a concept was generated and a prototype was built accordingly (chapter 6). The prototype was then used as a medium for users to practice the new interaction style. At last, a user test was conducted and the collected data was analyzed, which forms the last part of the thesis (chapter 7).

Background and Research Questions 2

Chapter 2

To start, the terminology of interaction and interface should be clarified. In accordance with the intervention of computers into people's life, Bill Moggridge proposed a new design discipline "*dedicated to creating imaginative and attractive solutions in a virtual world*" which is named as "interaction design"(Moggridge, 2007). Since then, many different understanding of the new design discipline have evolved. For example, as Jonas Lowgren mentioned in encyclopedia of interaction design, "*Interaction design is about shaping digital things for people's use.* (Lowgren, 2008)" Another framing of the new design discipline can be found from (Cooper, Reimann, Cronin, & Cooper, 2007) in which interaction design is defined as "*the practice of designing interactive digital products, environments, systems, and services.*" Likewise, interface design is another design discipline closely related to interaction design. In this thesis, the definitions of interaction and interface are adopted from (Frens, 2006). In his research of rich interaction, it is stated that interaction is an intangible property of products, and it only presents while interacting. Meanwhile, interface provides a linkage between users and the interactive product's functionality. Therefore, interaction is a relation between a product and its user and is mediated by interface. "*To design for interaction is to design the form properties of a product that comprises the interface.*"

In the following, background knowledge is constructed by surveying related works and investigating the design space. Research questions are derived accordingly through the background study. First, some examples utilizing deformation as an interaction style are presented. Since these works fall in the category of deformable user interfaces (DUIs), it would be beneficial to investigate the design space for this thesis work by examining the role of DUI among various interface styles. In the last, discussions regarding current major interface, touch screen, will be presented. From these discussions, the research questions of this work are derived.

2.1 related works

Various examples of mobile interaction design based on deformation are introduced in the section. Most of the works presented involves topics of flexible mobile device design, deformable user interaction, as well as prototyping.

The earliest example of utilizing deformation as an interaction style might be Murakami et al.'s work "DO-IT. (Murakami, Hayashi, Oikawa, & Nakajima, 1995)." DO-IT is an interactive system in which a deformable cube serves as an input tool for 3D shape manipulation. By performing various gestures on the cube, users can modify the shape of a virtual objective which is shown on a separate computer display. In bridging natural hand gestures with applications on mobile devices, Harrison et al.'s work is equally important (Harrison, Fishkin, Gujar, Mochon, & Want, 1998). In their research, several prototypes were built to present the situations of flipping pages and navigation within a book or document. The idea of developing metaphoric gestures from real situation could be also applied in the design of flexible interaction.

Lee et al. conducted a study in understanding gestures developed based on deformable displays.(Lee et al., 2010) In this work, preferable gestures and the associated computer commands were identified. The research methodology adopted was by asking the users to invent and execute gestures with flexible materials in hand when various commands were given. In this research, three different materials representing three levels of flexibility were chosen as the medium. It can be found that when the material presents more freedom from deformation, the invented gestures are more consistent among users, as well as the intuitiveness perceived. However, the authors also argued that too many gestures would cause confusion. Another similar research, PaperPhone, was based on the technology of flexible display and electrophoretic ink (Lahey, Girouard, Burleson, & Vertegaal, 2011). A working prototype was built to evaluate the effectiveness of various bend gestures. By recognizing various bending gestures, the prototype was able to make different software actions. The research methodology also started from asking users to define gestures for individual tasks. Through which, the preference of bending gestures was identified on the prototype. Both of these researches were mediated by prototypes in the form of thin rectangle sheet. Therefore, similar paper-like gestures were derived.

Gummi (Schwesig, Poupyrev, & Mori, 2004) is a flexible computer on which both bending gesture recognition and 2D finger positioning are implemented in the interaction design. A working prototype was built with a rigid display on top of the device, whereas a flexible part was installed beneath the display. In addition to the bending gesture, the flexible part was able to recognize the position of the fingertip underneath. That way, the occlusion of the display by fingers can be avoided. By combining bending gesture and 2D touch sensing of the fingers, Gummi was able to function various tasks with its specially designed GUI. According to the position of the fingertip underneath, the focus of interest on the display can be determined. The corresponding actions such as selection or zooming can be triggered by bending gesture. By showing only relevant information and distorting visual information, the design of the GUI was able to cope with the small screen size issue. Gummi manifested an example in which new interaction style fosters a novel concept of manipulating digital information.

In TWEND, Herkenrath et al. developed a prototype that recognizes bending and twisting gestures (Herkenrath, Karrer, & Borchers, 2008). TWEND was built in thick rectangular form and was designed for two-hand use cases. The prototype was connected with an external computer and an independent display. Although there were 18 gestures able to be identified on the prototype, they fall in only three categories which were bending at one of the edges, bending along the axes, and bending in waveforms. The resolution of the hand gestures appeared to be limited.

From above examples, it can be found that the developed gestures were strongly associated to the form factors of the prototype. With thin structure of the form, paper-like deformation was found through users' invention. When the form factor thickened, the possible gestures shrunk to merely bending and twisting. Notably, all these examples presented rectangular forms.

The following work might be the most relevant to this thesis work. Kildal et al. presented a model named Kinetic DUI-RP which stands for research prototype(Kildal, Paasovaara, & Aaltonen, 2012). The form factors of Kinetic DUI-RP resembled current touch smartphone in both dimension and shape. Rigid material was chosen for both long ends while flexible material comprised the middle body of the device. The rigid parts functioned as handle for users to deform the prototype with two hands. Their research focused on the factors that affect the performance of the interaction, such as optimal force required and its accuracy issues. A set of initial design guidelines derived from the study around DUI-RP was presented in the work as well. An interesting argument was that the effort in the development of DUIs was not to replace other interaction methods. Instead, an optimal interaction experience might be achieved by constructing an environment that implants various interaction styles and allows each of them to be performed in their best condition.

This thesis work might distinguish itself from the related works with the underlying context as well as the perspectives of form factor. Although a set of design guideline was presented in the study of DUI-RP, it might not be suitable for objects in different forms, especially when the manipulation is in one-hand case. Moreover, the related works mentioned above all presented the prototypes in rectangular form. It is worthwhile to conduct more studies on how form factors would affect the deformable interaction. Therefore, this thesis work distinguishes itself by conducting the study under the conditions of one-hand using and non-predetermined form factors.

2.2 organic, deformable, and tangible user interfaces

As can be seen from the previous section, the design of the digital world has come to an era where computers are no longer sitting in a specific space and in a specific physical form. The method to interact with "computers" has also evolved away from mice and keyboards. Organic user interfaces (OUIs) is among the major trends. Holman D. et al. argued that the rigid planar form of the display affects the interaction design and has limited the usability of computers. Organic user interfaces were thus proposed. (Holman & Vertegaal, 2008) In OUI design, the interaction is built on organic shape and deformation so that the interaction corresponds to the content and its purpose. As Kildal J. et al commented, DUIs can be regarded as a subset of OUIs for it focuses on the manipulation of deformable materials by hands. In their research, various motivations of using DUIs have been discovered, such as enhanced user experiences, good use of spatial mapping of actions, intuitiveness of the interaction, etc. (Kildal et al., 2012).

Speak of OUIs, what cannot be left out is tangible user interfaces (TUIs). Although tangibility is one of the major benefits that both TUIs and OUIs provide, there is slight difference between these two interaction paradigms. As illustrated in (Ullmer & Ishii, 2000), TUI was defined as interfaces that "*give physical form to digital information, employing physical artifacts both as representations and controls for computational media.*" The argument was based on the fact that people's skills in manipulating and sensing the physical space are not employed in the interaction with digital information.(Ishii, 2008a) While TUIs focus on the physical representation of digital information, OUIs focus on the physical form of the intermediate media and its manipulation. However, the separation does not make TUI design and OUI design conflict with each other. In fact, in (Ishii, 2008b), Ishii H. presented Urp, one of their tangible interaction works in MIT Tangible Media Group("Tangible Media Group," n.d.), and commented that its downside was the lack of the deformability on the tangible media. He and his group thus designed the second generation of TUI as organic TUI in which the tangible objects could change their forms. Several examples were presented in the paper as well. The foreseen future is a seamlessly integrated interface bridging our natural ability with digital information.

2.3 touch interfaces on mobile devices

Touch screen has been applied on various mobile devices especially on smart phones. There are numerous advantages that contribute to its success. However, it also has various drawbacks such as the occlusion of the fingers, and the lack of tactile feedback. Various studies have been conducted on this issue. For example, Levesque et al. commented that current touch screen devices are all flat and it's difficult to distinguish for they all sense like a piece of plastic or glass (Levesque et al., 2011). They tried to enhance touch interaction by applying programmable friction on touch screens so that its physical realism can be achieved. Other studies also confirmed that tactile feedback has a positive impact on visual buttons on touch screens (Koskinen, Kaaresoja, & Laitinen, 2008). Various technologies have evolved for enhancing haptic feedback on touch screens("Senseg," n.d., "Technology :: Tactus Technology," n.d.). All the efforts strive to enhance tactile feeling in touch interaction so that the interaction does not rely solely on visual sense.

Another phenomenon that can be observed in people's behavior is the immersion in the virtual world through smartphones. With internet connection, smartphones provide users with continuous access to social networks, webpages, entertainment, all the information available in the digital world. Due to the fact that graphical user interfaces is the dominating interface on touch devices, visual contact is constantly required in the interaction. Therefore, it can be seen almost in everywhere, at any time, that people immerse themselves in the tiny screen. It is not rare that people update their personal status on social network while already surrounded by friends. Moreover, at least one study has conducted in understanding smartphone users' behavior. Oulasvirta et al. concluded that it has become a habit that people briefly, repeatedly inspecting incoming message, and notifications from internet through the device(Oulasvirta, Rattenbury, Ma, & Raita, 2012).

From the discussion above, it could be observed that the usage of smartphone is increasing, and it requires much visual attention through touch interfaces. This observation leads to one of the thesis research questions which will be illustrated in the following section.

2.4 the research questions

From the background study, the research questions of this thesis work are derived as follows:

a. **How do form factors affect the DUI interaction from design's point of view?**

   As mentioned in the previous section, most related works are based on a predetermined form, rectangle. Since this interaction paradigm is based on physical deformation of a medium, its form factors could be a crucial part in the interaction. In this thesis work, the role of the form factor in DUIs is to be considered.

b. **How do DUIs enable users to engage with the immediate environment?**

   Touch interfaces have been the dominating interface on mobile devices which occupy modern people's life more and more. Its lack of tactile feedback and heavy vision acquirement could result in isolating users from the immediate environment. The solution to this issue might be derived from DUI design.

The first research question explores the role of form factors in DUI design, while the second investigates DUI applications by bringing the context into the research process. Throughout the thesis work, form factors and applications could be bridged with interaction in DUIs. To answer the first question, an experiment was designed to explore form factors in flexible state (chapter 3). The second question was answered by conducting a workshop in which participants practiced deformable interactions (chapter 4). The answers to these questions were discovered by conducting research through design. Various prototypes were designed and examined through the research process (chapter 6 and chapter 7).

3 User Study through Form Exploration Experiment

Chapter 3

An experiment was conducted in order to study the form factors of a flexible mobile device. Traditional design methods focus on human's cognitive skills despite the fact that other senses are as important as visual skills (Koskinen, 2011). Unlike the method in which users invented gestures to associate with given commands (Herkenrath, Karrer, & Borchers, 2008; Lahey, Girouard, Burleson, & Vertegaal, 2011; Schwesig, Poupyrev, & Mori, 2004), a more explorative manner was adopted in this work.

The purpose was to find insights from people's instinct and tactile sense on flexible materials by observing participants' action and response. Shape preference and possible gestures on flexible materials were examined, which became the design hint for the next prototype. In this experiment, four different models were presented to the participants. They were asked to play with and manipulate the models with the presence of stimulus.

3.1 the hypotheses

The experiment was designed to verify the following two hypotheses.

The first hypothesis is that different dimension induces different methods for interaction. For example, one-dimensional object can only be bent, although in every direction (Figure 3.1). Two-dimensional

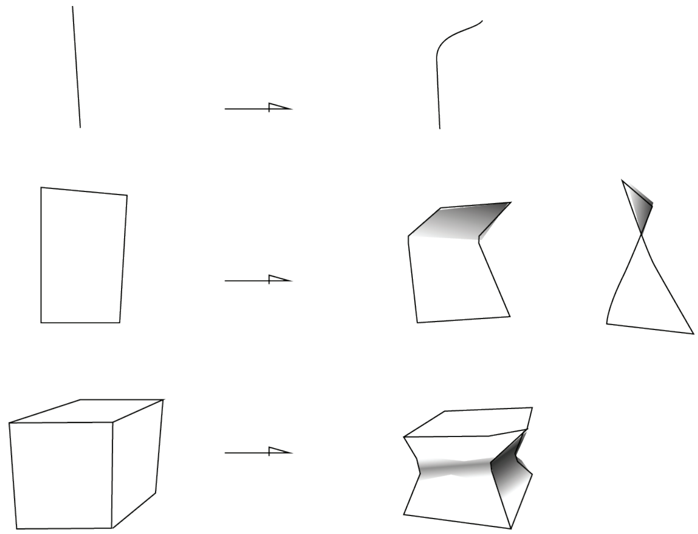


Figure 3.1 Examples of deformation in different dimensions

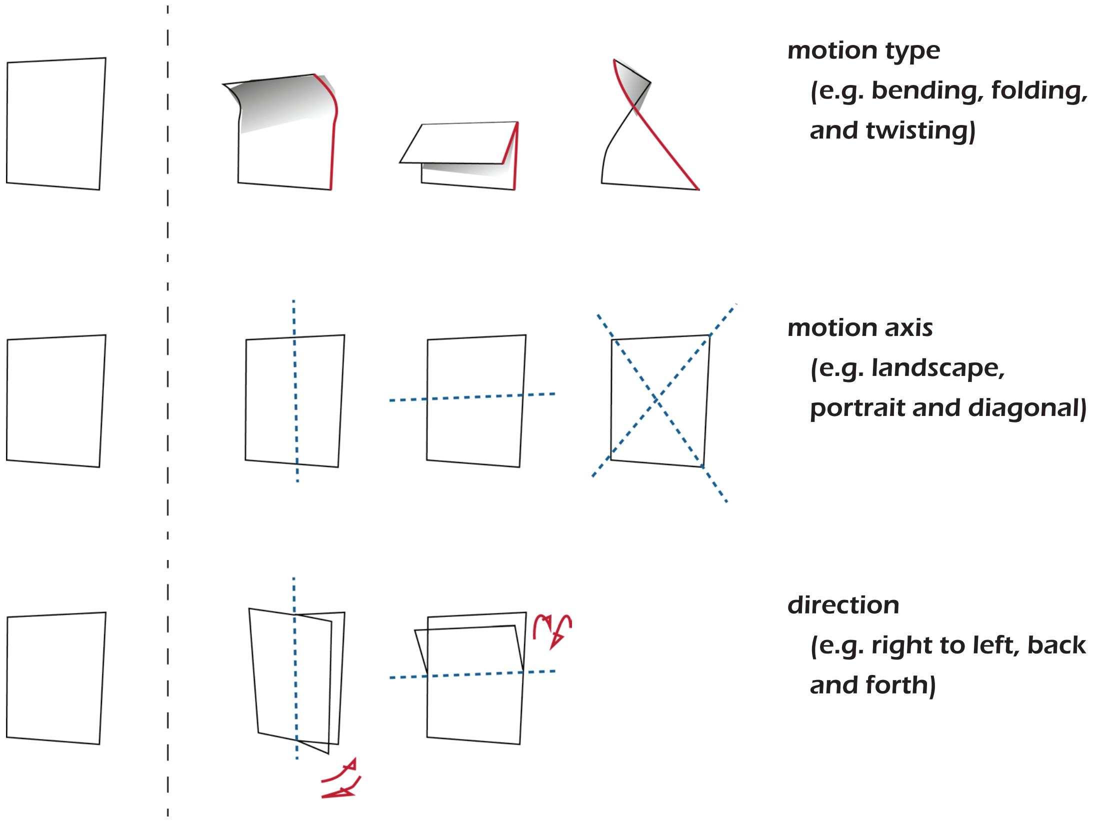


Figure 3.2 Deforming gestures classified by motion type, axis and direction of the action.

objects can be twisted and folded. As for three-dimensional objects, they can be squeezed. In the experiment, it was expected that similar gestures can be found under the same dimensional category. Namely, bending from one-dimensional models; bending, folding and twisting from two-dimensional models; and squeezing from three-dimensional models. Moreover, the corresponding possible gestures on different dimensional objects will be collected.

The proposal of this hypothesis was due to the fact that deforming gestures can be classified by the motion type, axis and direction of the action (See Figure 3.2) (Lee et al., 2010). By dissecting deformable forms in different dimensions, researchers could understand the relationship between physical elements and deduced gestures.

The second hypothesis is that human search for physical traits on the object that could trigger the interaction. By physical traits, it means a difference in shape, form, or material that can be distinguished from the background. For example, the margin of a piece of plan paper distinguishes itself from the other part of the paper. On the contrary, a single spot on the piece of paper is hard to be identified because there is no difference between it and other spots. The action of seeking for traits might not be a conscious process, which could imply that the traits identified in the experiment could be considered as elements for building intuitive interface.

This hypothesis was due to the attempt of reducing the demand of display on the mobile device. Tactile information could become more important when there is no visual information provided on the device.

3.2 the test

3.2.1 the materials

model prototypes

Four models were built and function as a medium in the experiment (Figure 3.3). In order to achieve flexibility, thick black cloth and sponge were chosen as raw material. Starting from the left to the right in the figure, the first model is in cylindrical shape with the intention to manifest one-dimensional characteristics. The second model is in oval shape with plan flat body. The third is basically a rectangular pillow in which sponge is stuffed in the middle. These two models mainly manifest two-dimensional characteristics. The last one is a ball which presents three-dimensional characteristics. Although, in practical, all the models are three-dimensional objects, the intention was to embed different spatial properties into the models so that the interaction in different dimensions can be studied.

There were two main concerns in the designing of the models. First, the prototypes were made from the same material and they presented similar volume. Second, there was no obvious functional capability

Figure 3.3 Four model prototypes

both in visual and tactile manner provided on the device. For example, there was neither screen indicating output capability nor buttons indicating input method. That way the participants may not be distracted by visually recognizable function-specific characteristics.

the video

The purpose of the video is to provide content for users to imagine possible interaction while the models are in their hands. That way contextual interaction could be generated accordingly. There are four scenes designed in this video, each with different purposes.

The first scene consists of geometric objects (Figure 3.4). First, a cross appears and disappears in the center of the screen. This could give a hint of aiming interaction. Although the participants might misunderstand the model in hand as a remote controller, this could also be an intimate start for encouraging users to interact with the content. Second, geometric objects change their size and move linearly, followed by balls bouncing toward the users. The idea behind the setting is to provide a neutral content without specific meaning so that users' reaction on stimuli can be observed.

In the second scene, the camera was set steady in the middle of a street (Figure 3.5). There were people walking across the street and trams approaching and leaving. Compared with the previous scene, the steady street view gives users solid connection between their personal experiences with the scene. In addition, informative signs were added into the scene. For example, people crossing the street were marked with triangle, and the number and direction of the tram were marked on top of the tram when it

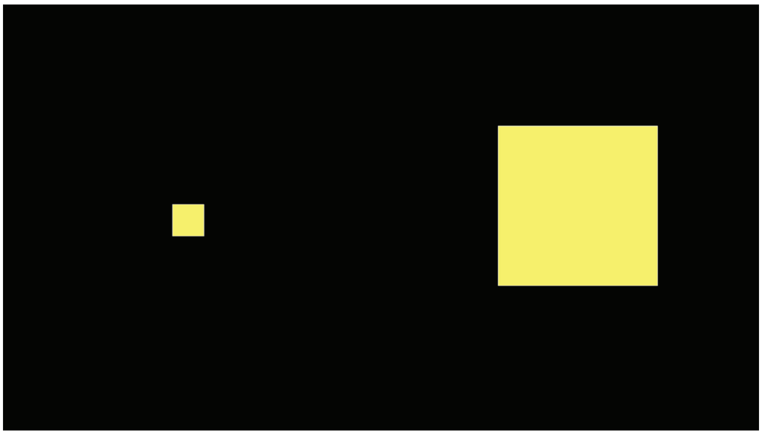


Figure 3.4 A screenshot of Scene One.

Figure 3.5 A screenshot of Scene Two.

was approaching. The signs could give participants hints that there is extra information available in the environment. Note that at this scene, users were asked to imagine themselves on the street in the city.

The third scene is a first-person point of view navigation scene. The scene was also taken in the city. However, unlike the previous steady scene, this scene was taken with a moving camera. There were panning and forward-moving of the camera indicating navigation situation.

The last scene was taken from the bottom of a transparent jar with water pouring in (Figure 3.6). This setting generates abstract and unpredictable movement of bubbles and water flow. Similar to the first scene, the setting provides neutral content without specific meaning, while the linearity and predictability were removed.

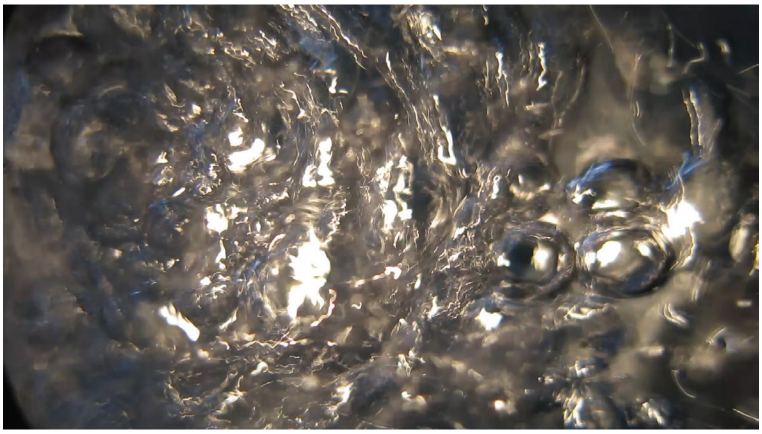


Figure 3.6 A screenshot of Scene Four.

The intention of the four scenes is to, first, show the interaction affordance in the video content. Then gradually bridge the content with users' personal experience yet stimulate users' imagination. Finally the last scene pushes users to an extreme case where there is no direct mapping of practical experience with the content. That way the least constraint is presented and most imagination could be possible.

Most researchers believe that people are imaginary but they need to be ignited (Koskinen, 2011). In order to stimulate participants' imagination, tricks were added in the video. For example, in the last scene where water was poured from above, the sound of toilet flushing was edited into the clip. Also, game-like marks were added in order to make the process less serious. A detailed sequence of the video can be found in Appendix A.

3.2.2 the procedure

The procedure can be divided into four steps:

1. **explanation of the experiment**

   The purpose and the procedure of the experiment were explained to the participants so that they understood the scope and tasks.

2. **participants look at the models and describe their perception without touching**

   Before touching the models, participants were asked to inspect visually all the four models on the table and describe possible deformation on the models.

3. **participants touch and describe their perception without looking at the models**

   Participants closed their eyes and played with the models in hand. They were asked to describe their perception. (See Figure 3.7)

4. **participants watch, imagine, act and react with the presence of the video**

   The video was played on a large display in front of the participants. They were asked to watch the video and imagine that there was real interaction created between the content and the model in hand. Their task was to use imagination to interact with the content via the model in hand as a medium. Meanwhile, users were asked to think out loud, which means they verbally describe their thinking and action.

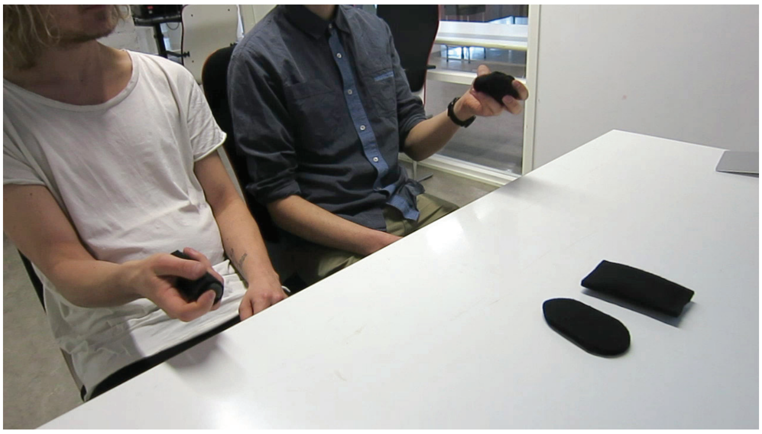


Figure 3.7 Participants physically examined the models without looking.

The reason why steps two and three were designed in this manner is to examine how people perceive and understand an artifact's ability through different senses. In Norbert Streitz's study, he explained macro affordance as physical shape and form factor of an object, while micro affordance is addressed as tactile characteristic of the object's surface (Streitz, 2001). In step two, users were able to see the whole model and described their visual perception of it. In this way the perceived macro affordance was revealed. After, they could touch and play with the model but with eyes closed. Users in this stage understood the models by hands exploring every part of the models. The purpose here was to examine the instinct through tactile sense. With a physical object in hands, they were also asked to try to deform the models. At this moment, micro affordance was perceived and action was manifested accordingly. Furthermore, in order to gain direct design hint for the next prototype, a question was given to the users: "*Imagine you are initiating a command through a button, a trigger, or a gesture, where or how is it?*" With eyes still closed, users were asked to manipulate the model and describe the corresponding gesture to trigger an interaction.

The instructor intervened in the process actively. Instead of being a fly on the wall, the instructor constantly encouraged participants to imagine and describe their thoughts clearly, especially when participants appeared confused. Participants were told that there is no judgment of good or bad, right or wrong in the experiment for its exploratory purpose. The instructor encouraged them to act by asking questions or assigning specific tasks, such as, "*how do you find out the route information of the tram?*" or "*please make a phone call with your friend.*"

3.3 result

3.3.1 discoveries from the test

Generally, the findings fit into three different layers, form, gesture, and application. On the layer of forms, different properties of macro and micro affordance could be revealed. On the layer of gestures, the characteristics that could bridge fundamental functions were identified. As for the layer of applications, physical actions were linked to practical intentions.

on the layer of forms

Discoveries that fit onto the layer of forms manifest different characteristics that are close related to the composition of the model. The first notable finding is the different perceptions of macro and micro affordance. As mentioned above in the procedure section, participants first examined the models by looking without touching. It can be found that most descriptions were related to the major characteristic of the shape while minor characteristics were neglected. For example, before the model was touched, the description on the rectangular pillow usually fell on the fact that it has certain volume in the middle which is squeezable. However, when the model was held in hand, the corners were discovered and participants were able to manipulate the model in more ways than previously described (See Figure 3.8).

The different perceptions between macro and micro affordance lead to the second finding. That is, people recognize physical characteristics such as edges or corners on the models as triggers to perform an action. Due to practical limitations in prototyping, the models were not perfectly shaped in the generic forms as described. For instance, the ball which indicates 3D form factor is not a perfect sphere. It was made of sponge wrapped with pieces of cloth, and hot glue was used to attach each parts. Therefore, even though it is not so visible from surface, there are edges and stiff bumps underneath (See Figure 3.9). When the question "*where is the button?*" was given to the participants, some of the participants considered these physical traits, a bump or edges on the body, as buttons and practically manipulate them in the test. Consequently, this could infer that these physical characteristics afford to be identified as a "button" or a "trigger" to initiate an action. One of the participant replied: "*It feels like there's some bumps… like sticking out, and there is a small concave, but all in all here is one bigger hard material or part that I can*

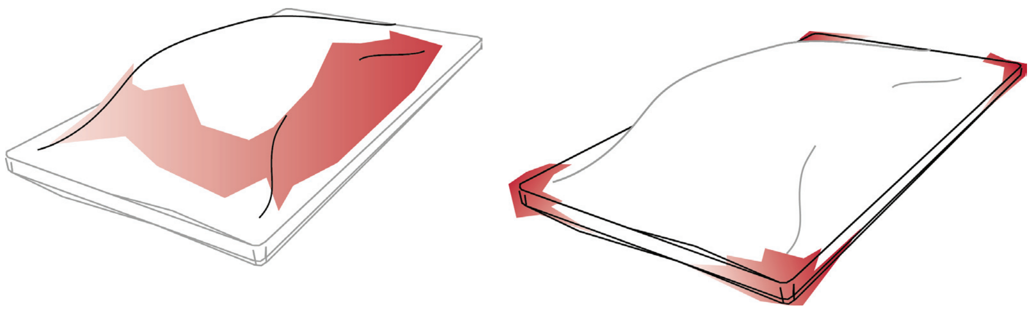


Figure 3.8 On the left, major characteristic of the shape catches the eye as macro affordance. On the right, more detailed characteristics are discovered through tactile sense.

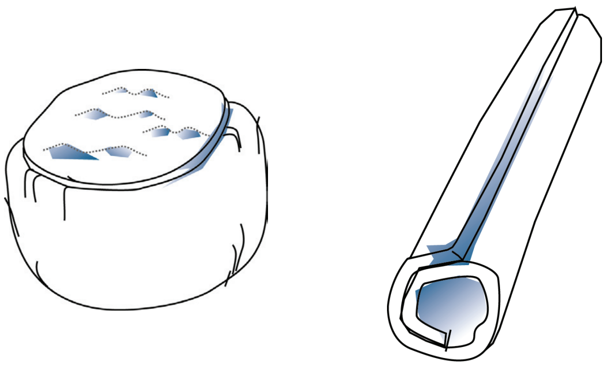


Figure 3.9 More detailed illustration of the models depicting subtle characteristics. On the left, the ball is not a perfect sphere. Instead, there are edges and invisible bumps underneath the surface. On the right, the cylinder has edges, and the middle part is softer than the outfit.

squeeze the whole thing like this... or then it feels like I can take the edges of this hard session and interact it with multiple directions." If affordance is sufficiently provided, without seeing an object, one can still perform an action by identifying its physical traits through tactile sense.

The third finding is related to dimension and orientation. The extension of the shape in a relative long dimension gives hints of direction of pointing, deforming, and stretching (See Figure 3.10). For example, once participants held the cylinder in hand, they immediately used its one end to point at targets. It was also observed on other shapes whose one dimension is longer than the others. People tended to use the longer dimension to point a target, and where the thumb rests was expected to present a button.

on the layer of gestures

Through the experiment, the first hypothesis is accepted. It can be observed that different patterns of

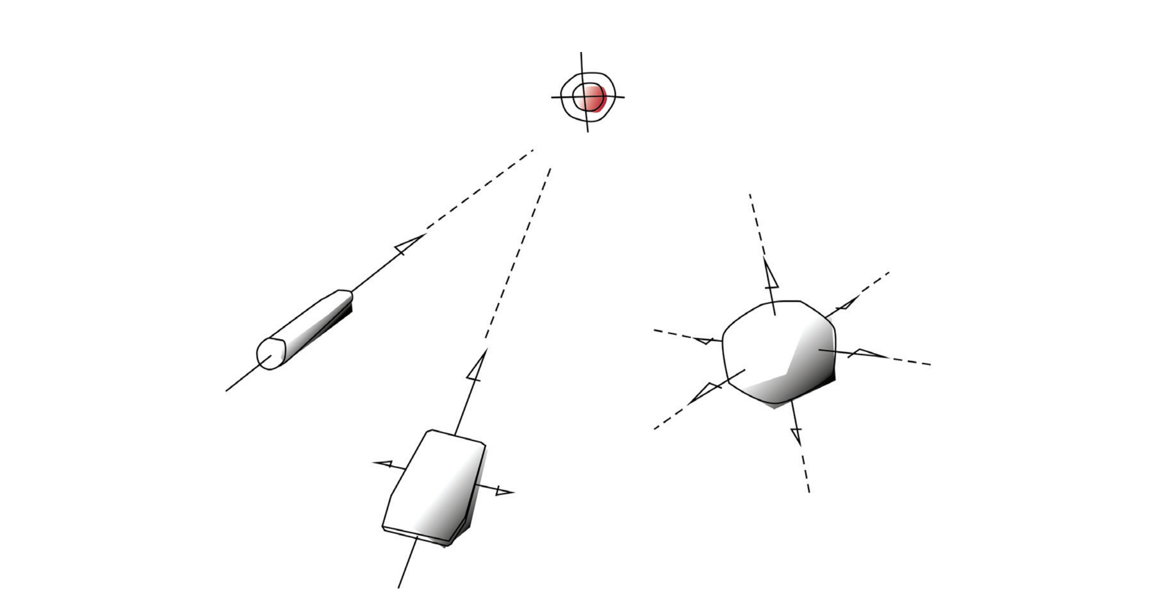


Figure 3.10 The relationship between orientation and directing.

deforming based on different characteristics of dimensions were revealed on these models. In general, on the 1D cylinder, there was mostly bending gesture. On the 2D rectangular pillow and oval flat piece, there were bending, folding, and twisting gestures. As for the 3D ball, squeezing was the major gesture observed. There were some special cases, such as twisting the cylinder. In this case, it was because there was a certain volume on the cylinder which allowed it to manifest not only 1D characteristic, as well as its form factor affiliated a cylindrical handle. Another special case was the squeezing gesture observed on the rectangular pillow. Considering the oval flat piece which also manifests 2D characteristics, squeezing gesture was not so obvious. In fact, the pillow manifested not only 2D but also 3D characteristics due to its volume in the middle. Therefore, almost all the gestures were observed on it. The findings of the linkage between gestures and dimensions can be considered when developing new form factors.

The second finding is that the models are considered as a medium between the body and the environment. With a model in hand, participants considered themselves capable of reaching objects. As mentioned in the previous section, on the layer of forms, the extension of the shape in one certain dimension gives hints of pointing and deforming. Correspondingly, on the layer of gesture, the extension is regarded as also the extension of users' body. A certain target becomes accessible through the conceptual extension of the body. Interestingly, although the ball provides most degree of freedom, there is no specific characteristic indicating the orientation (See Figure 3.10). Most people stretched out their arms further instead, which indicated the intuitiveness of the stretch-point-follow (or direct) action.

Another interesting finding is that flat surface indicates touch screen-style interaction. In some cases, participants placed their thumb or index finger on the flat part of the models. When trying to interact with the content, they maneuvered their fingers on the flat area even though there is no indication of the existence of a touch screen. People were already well-trained to use touch screen interface. A display was also expected by most participants.

Unsurprisingly, it can also be observed that the usage of thumb and index finger was the heaviest among the others in the interaction. These two fingers appeared to have higher resolution to execute more delicate tasks. In fact, Chang et al. identified in their research of vibrotactile communication device that index finger is observed to be the finger used to position the mobile phone (Chang, O'Modhrain, Jacob, Gunther, & Ishii, 2002).

One thing that should be kept in mind is that there was not only hand gestures presented, but also movement in larger scale as waving the arms or even moving the whole body.

on the layer of applications

In order to interact with the contents provided in the video, participants invented gestures and their corresponding applications. For example, there was pointing, following, and squeezing or pressing gestures for following moving objects and modifying. There was placing the model in horizontal position to simulate navigation as in video games, as well as placing the model in vertical position to scan the scenery. Also, there was pointing, squeezing, and pulling back to fetch information from a certain object. Moreover, squeezing/releasing indicated open/close, on/off, or other action pairs that reverses each other. These applications were collected by participants' verbal description while acting.

There were two interesting points identified. First, the imagined applications were quite independent. Different participants had different perspectives as well as their imagined use cases. With the same scene, one might be interested in fetching static information, such as discounts in a shop, while another tried to physically contact a person walking on the street. Second, similar gestures were used throughout a variety of situations, which means the same action or gesture creates different meaning to the participants under different conditions. This leads to the limitation on the interaction which will be elaborated more in the next section.

3.3.2 design hints and limitation

Design hints for the prototype in the next stage can be derived from the findings. They could be used as guidelines in order to achieve intuitive interaction on flexible materials. In addition to design hints, limitations were also revealed. The limitations could be regarded as not only problems to be fixed but also where the possibilities reside.

design hints

The design hints are general guidelines for developing the next prototypes.

a. provide "buttons"

Although there was no button implemented on the models, users tried to locate one and press it when action was needed, which indicates that humans are well trained and familiar to trigger action via a button. Once the button is identified, a direct channel could be built between users and the desired action. By providing buttons, the model could enable users to initiate actions as well as notifies its users of its capability. Here, the button does not refer to merely traditional button that has only two states, on and off. Unlike visual icons on touch displays, a button here refers to any mechanism or physical characteristics, such as a bump, that can be identified as being able to trigger an action.

b. provide both macro and micro affordance

From the experiment, the gap between macro and micro affordance was observed. In order to provide intuitive interaction, the model should provide both macro and micro affordance. Note that they do not contradict each other but complement. By considering both, designers could be able to deliver an easily understandable interface.

c. provide orientation

Point and direct is certainly an intuitive interaction. Even if the model in hand did not provide orientation as in the case of the sphere model, people used their body, such as stretching out the arm, to accomplish the action. Therefore, providing orientation on the model suffices the basic expectation.

e. provide tactile feedback

Since the models did not have display, participants concentrated more on the tactile senses perceived on the models. From many cases, people stated that they expected tactile feedback from the model.

the limitations

From the experiment, limitations on flexible interaction are also observed.

a. there were not many gestures

During the experiment, there were not many gestures invented by users. This does not mean there cannot be many gestures, but too complex gestures will cause confusion, which is contrary to the purpose of being intuitive. However, if the deformable interaction could be used as supplement to other interaction, the possibilities will be expended. This fact is also argued in various research works such as (Herkenrath et al., 2008), (Zigelbaum, Kumpf, Vazquez, & Ishii, 2008) and especially (Lee et al., 2010).

b. interaction depends on the context

Following the previous limitation, it can be found that in most cases, although the content in the video was constantly changing, similar gestures had been used repeatedly. For example, folding was used to acquire information from the tram, to open the door, and to initiate communication with people. The intention varied while the gesture remained the same. In order to achieve intuitive interaction, context awareness must be considered.

4 New Interaction Style Workshop

Chapter 4

As illustrated in chapter 2, there are two research questions to be answered through the research process. The preliminary answers to the first research question have been derived from previous explorative experiment. The connection between form factors and interaction was studied and design hints were derived. In the second stage of the research through design process, a workshop was arranged to answer the second research question. That is, “how do DUIs enable users to engage with the immediate environment?”

In this workshop, the participants experienced an interaction design process in one day. The tasks assigned for the participants were in the following order: understanding the subject and issues, discussing about the solutions, creating concepts and scenarios, and building prototypes. At last, prototypes were utilized as a means to practice the interaction. The scope of the workshop therefore covered form factor, interaction, and applications.

Toward the next design stage, generating concept and building functioning prototype, two paths were merged in this workshop. The first path started directly from participants’ experience and synergy generated within the group, followed by quick mock-up building, and, at last, the practicing of created scenarios with the prototypes in the field. Second, based on previous studies and the explorative experiment, several concepts regarding the form factors were generated and prototyped through 3D printing. These prototypes were brought to the workshop and given to the participants before practicing in the field. These two paths were diverse in the beginning but merged in the workshop.

4.1 the purpose

There are several aspects that need to be considered in designing new interaction style. First is the form factor that comprises the interface, which was already studied in the previous experiment. The second is the application case in which context is carried. The third is the interaction that bridges form factors and applications. The second and the third are still the missing pieces of the puzzle. For this reason, the purpose of the workshop is, first, to identify design hints for the interaction that bridges form factors and applications. And, the second, to gain insights of practical application cases that people might feel associated with DUIs under a certain context.

4.2 method

4.2.1 bridging form factors with applications

Three tasks targeting different aspects were designed: prototyping, generating scenarios, and playing in the field. To bridge form factors with applications, the content of each part was constructed first. The form factor of flexibility was explored by quick mock-up building, while application was imagined by understanding the context and discussion in the groups. Practical application cases were then presented as scenarios. Finally, the scenarios were practiced with the prototype in the field, from which, form factors and applications could be bridged by interaction. (See Figure 4.1)

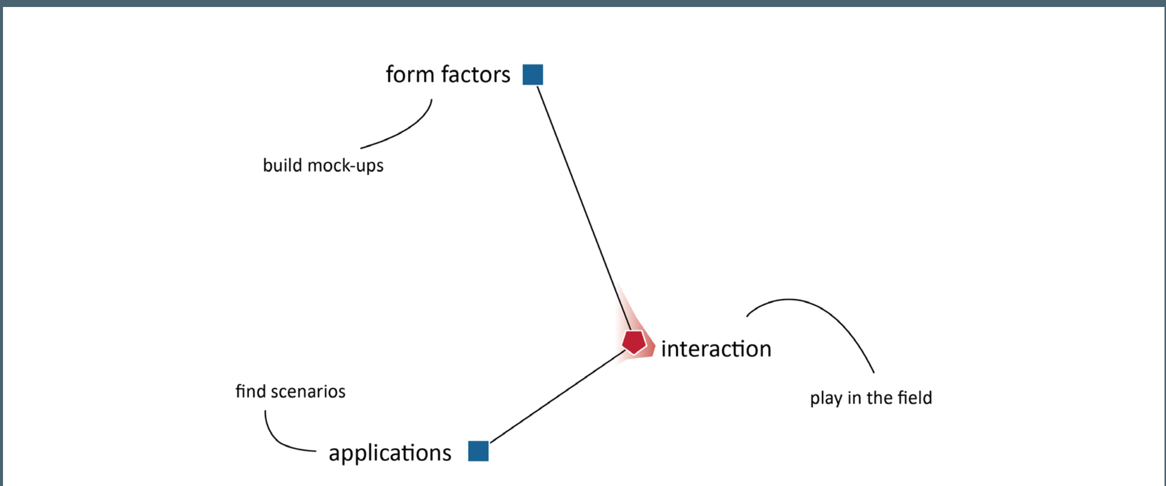


Figure 4.1 The form factors and applications are bridged by interaction.

4.2.2 the context

The context was derived from the intention of answering the research question: how do DUIs enable users to engage with the immediate environment? It is quite common that people immerse themselves in their phones even when walking on the street. As discussed in chapter 2, a flexible phone might provide interfaces that could avoid the phenomenon of detaching from the immediate environment. The tasks assigned to the participants in the field exploration session especially addressed this issue.

The derived context was then brought into the design of the tasks. In the brainstorming session, groups were told to investigate the detaching issue and imagine solutions based on DUIs. The tasks assigned in the field exploration session were related to the context as well. Since the immediate environment is perceived through our five senses, the groups were asked to imagine and practice how the DUI could mediate the perception of five senses via the prototypes.

As mobile devices have become one of the major communication channels between individuals, social aspect of the context was considered as well. One of the tasks was to ask people to practice communication between different prototypes. More detailed description of the tasks can be found in the following sessions.

4.3 the workshop

4.3.1 the preparation

the materials

One of the tasks designed in the workshop was to build quick mock-ups. Various flexible raw materials were provided, such as rubber, foam cushion, foam board, etc. (See Figure 4.2). In the field, a field kit which included notebook, pen, and camera phone were given to the teams. Instruction of the tasks in the field was attached to the notebook, and the teams were particularly asked to use camera phones to document their exercise in the field. After the workshop, the kits were collected back for data analysis.

the models

Four 3D printed prototypes were prepared. The design of the prototypes was based on derivation from previous studies and form exploration experiment. Each manifested different form factors and properties of flexibility. These prototypes were given to the teams along with the field kit before their practice in the field.

In the design of the four prototypes, various possibilities in form factors were considered. Numerous

Figure 4.2 Materials prepared for the workshop

Session	Duration
Introduction	20 mins
Ice breaking	10 mins
Warming up	25 mins
Brain storming + mock-up building	60 mins
Lunch	40 mins
Mid presentation	30 mins
Field exploration	60 mins
Prototype adjustment + summing up	15 mins
Final presentation	45 mins
Ending	15 mins

Table 4.1 The agenda of the workshop

deformable "buttons" were designed and arranged in different locations according to natural gestures, while the utilizing of different fingers was made possible. Both macro and micro affordance were considered, which was demonstrated through not only the shape but also the levels of flexibility in material. The models were designed so that different ways of holding was possible. Due to the non-disclosure agreement, the pictures of the models are not present in the thesis.

4.3.2 the procedure and tasks

The detailed agenda is depicted in table 4.1. The workshop started with introduction and ice breaking sessions. Basic information about the workshop and its purpose were presented in the introduction session. The participants did not know each other beforehand. Therefore, the ice breaking session provided an opportunity for each other to get acquainted. Tasks such as naming the team and designing the logo were assigned to inspire the team spirits.

Four teams were formed. Within each there were three to two participants with different proficiency. Following the introduction and ice breaking were the sessions illustrated in below.

I. WARMING UP

The subjects, flexibility and mobile devices, were presented to the teams in this session. Teams were given a short period of time to answer the following questions.

1. What are the benefits and limitations of flexible phone?
2. What else in your daily life do you want it to be flexible?
3. What does your phone mean to you?
4. Other than its ordinary functions, i.e. making a call, checking e-mail, navigation, etc., how do you utilize your phone's physicality?

II. BRAINSTORMING AND MOCK-UP BUILDING

The context was brought in at this session. The issue of immersing and staring at the phone was brought into discussion. Several questions were designed for this part.

1. What are the reasons causing the detaching from the immediate environment?
2. How can a flexible phone help with the situation?
3. What are the scenarios where flexible interaction can help engage with the environment?

The participants were asked to reflect on the questions individually before starting group brainstorming. That way, the perspectives could be diversified.

The teams were also asked to build quick mock-ups with the provided raw materials.

III. FIELD EXPLORATION

A 3D printed prototype along with a field kit was given to each team. Each kit had one notebook with instruction of the tasks and one camera phone which can be used for documenting the scenarios. Along with the prototype built by them, each team had at least two prototypes. They were asked to practice the following tasks with the prototypes.

1. Practice the scenarios presented in previous session in the field.
2. Capture color, sound, texture, smell, and taste of corners in the city.
3. Use one prototype to leave your trace (sound, smell, etc.) at some spot, send it to another member who is holding another prototype. Practice sending and receiving.
4. Discover your friends' trace.

IV. PROTOTYPE ADJUSTMENT AND SUMMARY

After returning from the field, teams were asked to modify the prototypes and summarize their findings. It was not to compare the two prototypes each team has but to improve the prototypes individually.

4.4 results and findings

4.4.1 the results

In the end of the workshop, six mock-ups were built. Each was associated with scenarios. As for the data collected, there were text and figures drawn on paper, notebooks, post-its and posters. There were also pictures and videos taken by teams via camera phones. The presentation of the teams was video recorded as well. With the help of mock-ups, acting appeared to be an inspiring and involving method in presenting interaction scenarios.

Due to the signed non-disclosure agreement, the concepts and the prototypes cannot be presented in the thesis. Nevertheless, the findings are demonstrated in the following section.

4.4.2 the findings

Data collected from the workshop were transcribed and analyzed. The findings from different stages can be illustrated in the following diagram (Figure 4.3).

I. FINDINGS FROM WARMING UP

Participants' attitude toward mobile phones was derived from the warming up tasks. Mobile phones provide easy access to internet where abundant digital activities take place constantly. In addition, mobile phones are regarded as an intimate personal item which represents users' memory particularly. For instance, in the phone, there are pictures taken from special moments and messages between friends. In both cases, the content of these activities can be accessed through the mobile device in hand. Despite the

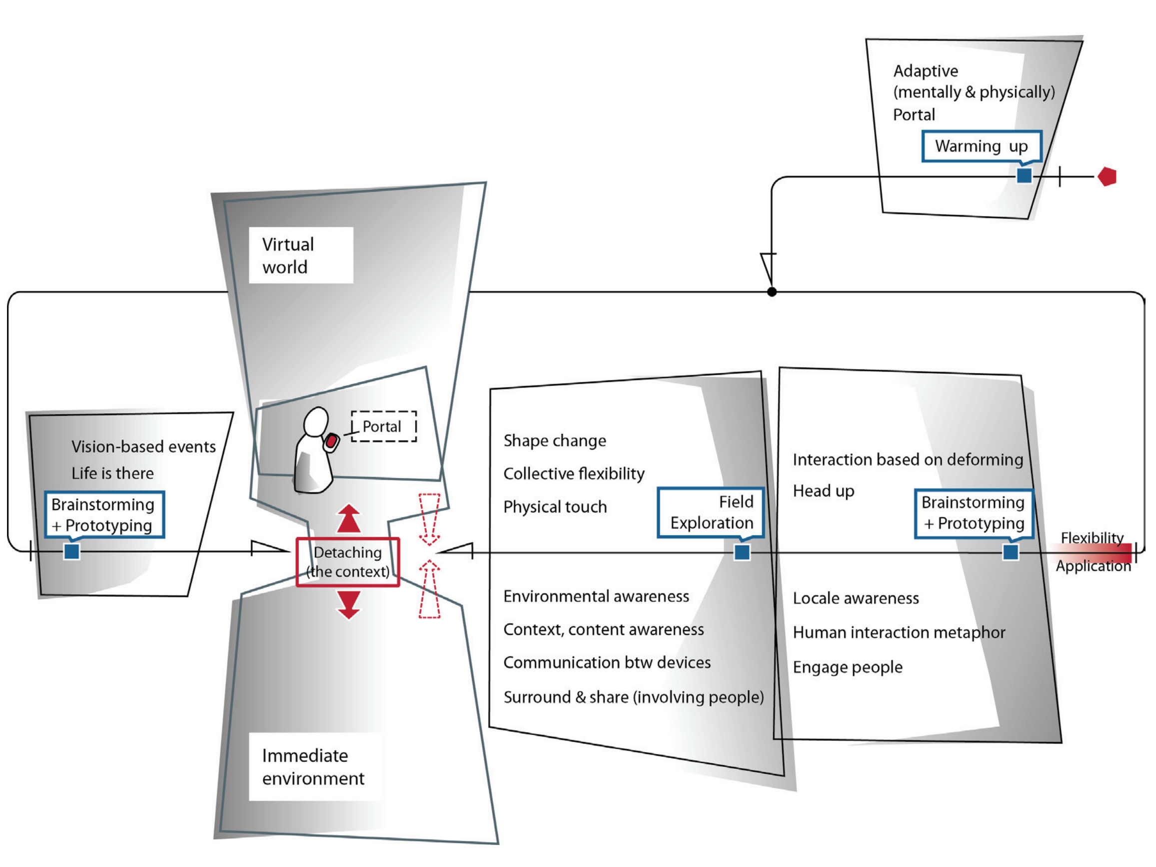


Figure 4.3 The map of findings from the workshop

internet accessibility, a mobile phone is still concerned as a social tool through which people can be easily connected. A mobile phone hence represents a portal to a virtual world.

As for the attitude toward flexibility, it can be deduced that the concept of flexibility is being able to adapt both physically and mentally. It is obviously that flexibility means the possibility of deforming physically in accordance with users' need. For example, a flexible device can be folded so that it is easier for storage. This physical property also affects people's mental state. For instance, in terms of flexibility, people mention robust which is connected with secure. Deforming according to body shape is linked with comfortable. Moreover, while hard is associated with cold, soft is connected with warm. Hence, flexibility also refers to adaption according to mental state.

II. FINDINGS FROM BRAINSTORMING AND MOCK-UP BUILDING

In the brainstorming session, the context was brought into discussion. It is the phenomenon that people tend to immerse themselves into the phone-connected virtual world in favor of the immediate environment. As derived from previous session, mobile phones function as a portal in this detaching context.

In order to answer the question: "*What are the reasons that cause the detaching?*" People pointed out that there are merely too many things happening in the virtual world. People want to stay connected to be aware of what's happening out there. There is also another digital identity for them to maintain. Another reason is that the interface on mobile phones is mostly vision-based which requires users to stare at the screen. When people's visual attention is concentrated on a tiny display on mobile phones, unconsciously people isolate themselves with the situated environment.

Another aspect of the brainstorming session was to introduce flexibility into this context and create scenarios in which possible applications can be identified. The questions raised in this session were how flexibility can help with the situation and what the scenarios are. One example of the findings in this case was to enable head up, from which the visual attention can be released from the tiny display to the environment. Interaction based on deforming could be utilized to replace the vision-based interface so that head up is possible.

As for the applications, participants' interests were generally in locale awareness, engaging people, and bringing human social interaction into the DUI design. People expected mobile device to be able to understand the locale in order to assist their daily life, which is consistent with where the current trend is leading to. Moreover, engaging people in the surrounding was considered as a method to tackle the issue of detaching with the environment. If the people surrounded can be involved, social interaction takes place between individuals. That way the status of being isolated could no longer persist. Furthermore, interaction design might benefit from taking human social interaction into account. For instance, when people smoke, the natural interaction of borrowing the light creates a minimum distance between two individuals. As can be seen from above examples, human was considered as a factor that could entice a person back in the immediate environment.

III. FINDINGS FROM FIELD EXPLORATION

Following the brainstorming and mock-up building session was to bring prototypes to the field and practice scenarios. In addition to practicing the scenarios generated by the teams, tasks such as capturing the perception from human's five senses were given. The findings can be summarized as follows.

Considering flexibility, the findings are:

shape change

One of the major characteristics of flexible materials is deformability. The teams explored multiple ways of changing the mock-ups' shape and size to trigger a certain types of event. The gestures were no longer confined in pressing a button but deforming the entire device as action trigger. Furthermore, the possibility of switching operation modes by changing the shape was examined. Different shapes convey different information in terms of affordance. Therefore, different operation modes can be associated with different shapes (See Figure 4.4).

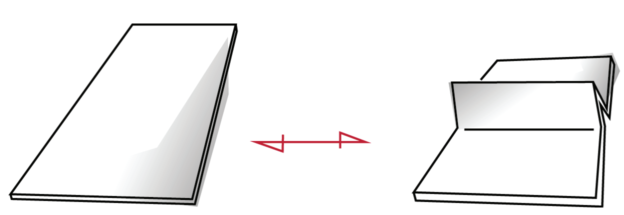


Figure 4.4 **Different shapes could be associated with different operation modes. (e.g. from left to right: standby mode, entertaining mode, and communicating mode)**

physical touch

In the tasks of capturing the five senses, the teams performed physical touch on all of the intangible substances. Namely, in the case of capturing the color of a vase, the prototype was bent to align with the curved surface of the vase. In the case of capturing the sound of a surface, the mock-up was placed on it and rubbed against the surface. While the substances to be captured were intangible, the way to capture with the tangible mediator was through physical touch (See Figure 4.5).

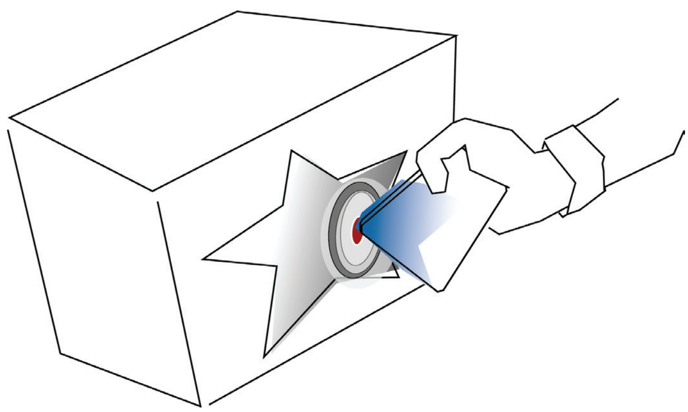


Figure 4.5 **Physical touch through the device as a mediator**

collective flexibility

Another interesting finding is collective flexibility. In this case, the concept of flexibility was expended from one single physical device to a flexible platform where multiple devices communicate with each other (See Figure 4.6). Flexibility on each device on this platform could form a piece of information. The synergy generated through the platform could result in a greater effect.

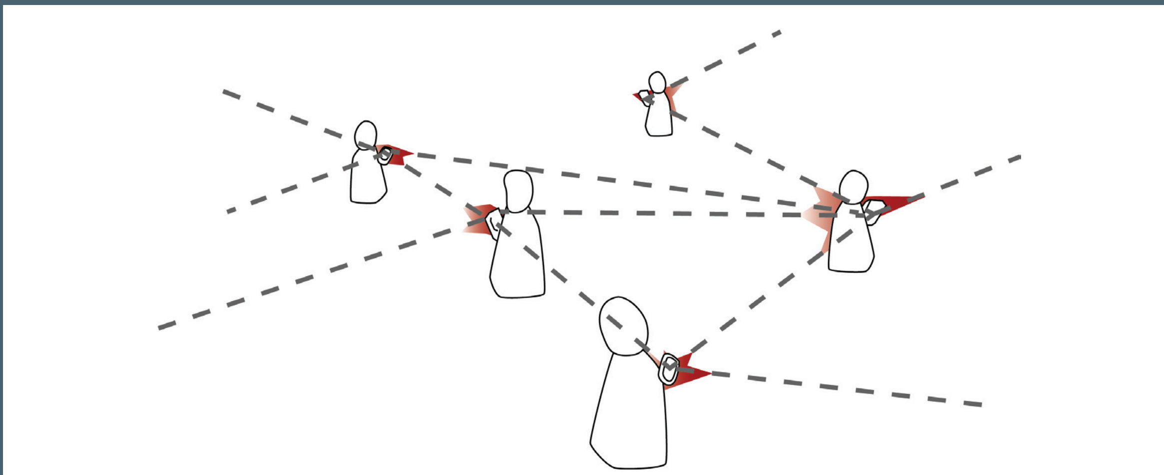


Figure 4.6 A platform where devices communicate with each other and information is presented in a form of collective flexibility

Considering applications, the findings are:

environmental awareness

People expected the device to understand the locale. The point was not only to know the location, but also to be able to provide relevant information associated with the specific locale.

context and content awareness

A mobile device was also expected to be able to understand the intention of the user. One practical example was to obtain traffic information by the mobile device. The device was expected to know who the user is, where the user wants to go, and reply with the timetable and number of the bus.

communication between devices

When devices can communicate with each other, the information is able to be shared. That way, social interaction is possible to be extended. Associated with the concept of collective flexibility, communication between devices enables shared information to be delivered in the form of flexibility. Each device manifests different level of flexibility according to the shared information.

surround and share

Teams also looked for possibilities in directly involving people to tackle the issue of detaching. A flexible device could be able to foster a situation where all the people can surround and share face to face. Engaging with the environment is not only about the physical objects in the space but also the people in the situation.

4.4.3 conclusion

Through the workshop, participants developed concepts based on their own experience and discussion within the teams. Starting with understanding the questions, developing concept, building mock-ups and practicing the scenarios, the teams were able to contribute magnificent findings and precious insights on this issue. As illustrated in Figure 4.3, the findings regarding application provides a basis for associating flexibility with practical application cases. Meanwhile, the findings regarding flexibility give hints on designing flexible interaction.

Answers to the research questions and solutions to the issue were proposed in the workshop. It was identified that there are merely too many activities happening on internet whose content requires visual contact with the display. Those applications have occupied most of the resources, which then caused the issue of detaching. The proposed solutions did not intend to eliminate, or avoid users to access those contents. Rather, the idea was to imagine how a DUI can be and what the requisite features that comprise an intuitive interface are. The features of the flexible device could help enable the release of visual attention from the device so that the issue of detaching can be eased. For example, one proposed approach was to share content in the space through DUIs so that the surrounding people could be involved in interacting with the distributed information. The ideas gathered from the workshop became great input for the further development of the prototype concept which is illustrated in chapter 6.

The findings presented above are not meant to be generalized to all people. Nevertheless, they provide abundant materials for developing concepts of DUI design. The design cues are derived accordingly, which is presented in the next chapter.

5 The Design Cues for a Flexible Mobile Device

Chapter 5

Previous works were distilled into design cues for a flexible device in this chapter. The two research questions were examined in form exploration experiment and new interaction style workshop respectively. In this chapter, the findings derived from the two design activities were concentrated into three categories: form factors, interaction, and application. The purpose of this chapter is to construct a solid foundation for the next design process, generating concept and building functioning prototype.

5.1 about form factors

By providing the following characteristic, a flexible mobile device could demonstrate the properties of flexibility. The characteristics not only provide affordance to give users the hint of its usage, but also are essential to enable new interactions that are not possible on ordinary touch screen mobile devices.

5.1.1 thin part enables bending and twisting

A flexible mobile device should consist of a thin part that enables bending and twisting gestures. It is not only for the practical physical reasons but also the affordance that a user perceives. Physically, bending and twisting type of deformation cannot be achieved on thick objects. Meanwhile, in terms of affordance, a thick object is also hard for users to perceive it as deformable regardless of its shape.

5.1.2 bulk part enables squeezing

In addition to bending and twisting, squeezing is another import gesture that is enabled by flexibility. However, squeezing is not achievable with thinness. On the contrary, it requires a certain volume on the body to be able to be accomplished. Thinness is associated more with crumpling while bulk is considered as squeezable. Therefore, in order to enable squeezing gesture on flexible mobile device, it should consist of a bulk part.

5.1.3 shape changing ability

A device which utilizes deformation as one of its main interface is expected to be able to change its shape as well. The shape changing ability consists of two perspectives. The first is to change the shape between different physical states, which is associated with operation mode switching. In other words, changing the shape of the device triggers the switching of its operation mode. The second perspective is self-deformation. The device changes its shape by itself. For instance, a device could inflate itself to indicate users of incoming messages. More examples of shape changing interfaces can be found in (Coelho & Zigelbaum, 2011; Rasmussen, Pedersen, Petersen, & Hornbæk, 2012).

There are other characteristics that are not so related to flexibility. However, they are worth to be considered in new interface design under mobile context.

5.1.4 elongated body for indicating orientation

From form exploration experiment, it can be identified that orientation is a crucial factor that affects how a device is held by users. A form without orientation confuses people at the first sight, and the confusion even persists when the device is picked up (See Figure 3.10). A device with elongated body provides clear orientation which also closely linked to the following property, pointing.

5.1.5 tip for enabling pointing

Point and follow is a natural and intuitive action when people interact with objects in the environment. In the form exploration experiment, most interaction started with pointing. If the target moves, users followed its movement. It can be clearly observed that users tried to understand where the form characteristic was that gave a hint of pointing on the model. An elongated body or rather sharp corner would be considered having this property. On the contrary, if the model has no significant sign of pointing, such as the 3D ball in the experiment, users looked for alternative characteristic to accomplish the action. For example, a rather flat surface on the ball was used to face the target in one of the cases.

5.1.6 flat surface enables installation of touch screen

People have been accustomed to touch screen style interaction. In fact, display is no doubt an important interface in mobile device design. From previous research, it can be found that DUIs can only be a supplement to the main interface. This could be due to the low resolution of hand gestures and the confusion that results from too many gestures. Therefore, by implementing a flat surface on mobile device, the expectation of users can be met. The combination of touch screen style interaction and DUIs could enable richer interaction. However, it does not mean only flat touch screen is proposed to be implemented on mobile devices especially nowadays flexible display has been possible. Before flexible display is widely applied on organic forms, flat surface would be more intimate to users.

5.1.7 button for thumb or fingers

For the same reason that display should be kept, buttons would be beneficial in mobile devices. Button is an intuitive interface to people for its simplicity and quick response, which could be a proper solution to simple tasks.

5.2 about interactions

Currently, touch screen has been the major interaction medium. Starting from track pad on laptops to personal digital assistants (PDA) and mobile phones, touch interface has emerged for decades. Users are well trained with touch screen style interaction. For interaction design on mobile devices, it is essential to investigate how touch screen style interaction is implemented on a system. From which, the metaphor applied in touch screen style interaction can be learnt and the pattern could be mapped onto flexible interaction. It is not to clone one interaction style onto another, but to approach with the essentials that people are already familiar with. In the following, the observation of touch screen style interaction is introduced, which will be followed by the design of flexible gestures.

5.2.1 touch style interaction

Dan Saffer defined patterns as "*a combination of a gesture plus a system response that can be repeated in a variety of situations across many devices.*" (Saffer, 2009) Major operating systems such as iOS from Apple Inc. and Android from Google("Gestures | Android Developers," n.d.) also have their corresponding gesture design guide lines for software developers. From the guidelines the general principle of metaphor could be found. In the following table, the relationship between some basic gestures and the system response is listed (Table 5.1).

When a user sees a target with an intention of selecting it, the user can accomplish his or her wishes by point and touch. Similar behavior is observed in form exploration experiment where users pointing at objects before initiating other actions. This is a direct mapping of realistic living experience with the manipulation of virtual digital content.

Another point that is worth to be further elaborated is the mapping of intangible digital content onto a 2D plane. On touch screen, objects are presented on a two dimensional plane. In the case of moving a virtual object on touch screen, users use their fingers to control the objects on this virtual plane. According to the movement of fingertips, the objects are displaced to another position, for instance, the action of arranging the placement of icons on the desktop of a smartphone. Moreover, the gestures of scroll, swipe, and pinch are in fact manipulating the virtual plane. For example, in the case of viewing a picture, the metaphor created on the interaction is based on the direct manipulation of the two dimensional picture. By scrolling, different parts of the picture can be displayed, which matches our living experience. It simply simulates the manipulation of a piece of picture on desktop.

Gesture	System response
tap/touch	open/activate/select
double tap/touch	zoom in or text selection
drag	move object
swipe	scroll
pinch open and close	zoom in and zoom out
long press	enter data selection mode

Table 5.1 Gesture and system response on touch interface

Similarly, the relationship between system response and flexible gestures could be derived as follows.

5.2.2 bending

The gesture is comprised of bending forward and backward. Per its simplicity and straightforwardness, the magnitude of bending can be associated with adjusting a value in two directions. Practical example could be adjusting the volume of music playing, the pointer on a navigation bar, or simply confirmation and denial.

Bending can also be further associated with hand gestures such as capturing and grabbing since the deformation could emulate the relative position of the thumb and the other fingers.

5.2.3 twisting

In addition to adjusting values as in bending gesture, twisting could also be associated with more complex actions in three dimensions. The gesture is comprised of the relative position of two independent sides moving in two opposite directions. Each side also has its relative position with the body. For example, a rectangular flexible piece can be described as the composition of a body and four sides, left, right, top and bottom. One of the twisting gestures can be the moving of only the left side, while the right side and the body base remain still. Another twisting gesture can be the moving of both the left and right side relative to the body base. The composition of the movement on each part can be associated with different system response.

Practical example can be as simple as moving forward or backward to the next page, which emulates the action of flipping a page of a physical book. Swapping of two different objects or spaces can also be associated with the twisting gesture.

5.2.4 squeezing

Squeezing can be associated with confirm or selection. In the form factor exploration experiment, it can be found very often that in addition to pointing and following, squeezing is involved in the action. In some cases, participants performed a series of action: point, follow and squeeze; or point, squeeze, and follow. The participants commented that they were selecting or choosing a target on the screen through squeezing. The extra gesture filled the gap when the intention of selection presents. Moreover, squeezing and releasing can be paired up to complete more complicated tasks. It is closely related to the drag-and-drop action. The duration and the magnitude of squeezing could be utilized as another parameter to determine an action on a system. For instance, by squeeze-and-hold, one can quiet down the phone and reject an unwanted call.

Gesture	System response
bend	*adjusting values, capturing and releasing*
twist	*adjusting value, flipping, swapping, navigation*
squeeze	*selection, confirm, stop*

Table 5.2 Gesture and system response on DUIs

Based on the observation in experiment and workshop, the gestures and system response is proposed as in the table above (Table 5.2). Compared with previous table which shows touchscreen style interaction, the metaphor illustrated in touchscreen style interaction is more on two dimensional control, while flexible interaction has its strength in manipulating contents in three dimensions. Three dimensional manipulation should be able to provide more degree of freedom than that in touch interface, which could open more opportunities in the metaphor of the three dimensional interaction.

The following point is not so related with flexibility. However, it provides a useful hint in the design of flexible interaction.

5.2.5 physical touch intermediated with the device

In the previous section, point-and-follow action was introduced. Another closely related action is physical touch. During new interaction style workshop, the participants were asked to use the device to capture perceptions based on the five senses. It can be observed that when capturing the five senses, the participants tended to physically touch the subject with the device. For example, when capturing the sound of a gravel path, the participants utilized the flat surface on the device and rubbed against the gravel path. The sound is generated and captured through the physical touch. Therefore, a strong linkage can be found between point-follow and point-touch. The device appeared to be considered as an extension of the body. Physical touch is an intuitive action with those reachable targets, while point and follow applies for those cannot be reached.

5.3 about applications

The following explains applications that could be enabled by DUIs.

5.3.1 reduce or augment visual contact

Although the purpose of introducing DUIs is not to replace vision based interaction, there are situations that visual interfaces do not fit better than other methods. Several examples can be given as following. One example is that, when the phone rings, the ringtone can be muted simply by flipping over the device if the user does not want to be disturbed ("Nokia: FlipSilent," n.d.). Another example is again when the phone rings, the volume of the ringtone decreases when the action of picking up the phone is detected ("HTC: Quiet ring on pickup," n.d.). Additionally, due to the fact that flexible material could arouse a sense of durability and robustness, radical actions could be explored. For instance, an alarm could be stopped by smashing the device. Vision based interfaces can of course accomplish the same tasks. However, users could benefit more from the interaction described. Similarly, flexible interaction could also benefit users under certain conditions.

Another reason to support the reducing of visual contact is derived from the fact that the detaching issue results from vision based interaction. By reducing the necessity of visual contact on the device, the visual attention can be released to the current immediate environment, which is one of the major benefits of DUIs.

5.3.2 continuous input

Currently, there are roughly two different input styles on mobile devices. The first is touch-screen style interaction whose basic gestures can be found in Table 5.1. The second one is accomplished by physical buttons. Both provide continuous and discrete input. Buttons provide discrete input, which means the system reacts on a single input pulse basis. Continuous input is accomplished by repetitive action, such as repeatedly pressing a button. Another option is to press the button and hold. However, this is achieved by translating the holding time period into the controlled parameter in favor of the action itself. Touch screen provides both discrete and continuous input. For example, discrete input is applied by taping on virtual button icons while continuous input is accomplished by swiping. In this case, excellent precision can be achieved with high level of visual attention.

As for flexibility which is to be introduced as a new communication channel between human and computer, it provides also both discrete and continuous input but on a continuous basis. The deformation can be interpreted as an impulse which triggers system behavior similar to a button. Continuous input can be achieved by measuring the magnitude of deformation or the length of deforming period. The new method of continuous input provides opportunities in mapping the action with applications.

5.3.3 three dimensional control

While touch screen style gestures are constrained on this two dimensional physical surface, flexible interaction provides opportunities in mapping three dimensional physical actions with digital contents. There are applications mapping 2D gesture on to 3D virtual space. For example, 123D Sculpt ("123D Sculpt for iPad on the iTunes App Store," n.d.) is a 3D modeling application on iPad. Users are able to create a 3D model by 2D gestures on the touch screen. When the gestures are performed in three dimensional space and can be measured, new applications could be possible. Flexible interaction can be further developed for manipulating objects in virtual 3D space.

5.3.4 shape and flexibility changing

As mentioned in previous section, shape changing can be divided into two categories depending on the initiator. The first category is reactive shape changing in which users change the shape in order to trigger different operation modes. For example, a flexible device consists of a flexible display. In ordinary operation mode, a picture of an object can be displayed on the flexible display which is flat. The other operation mode can be triggered by users who bend the device to a certain angle. In this mode, the display presents a curved surface. On which, different perspectives of the picture is displayed. Per it is a vase, the view of the vase from different angles can be seen from the curved display at the same time.

The second category is proactive shape changing in which the deformation is initiated by the device and the user reacts on that. When the whole body of the device is considered as an interface, its shape is a parameter of interaction. One example can be the notification of incoming digital content. The shape changes depending on the type of the content. Different shapes notify different types of incoming message. In addition to that, the shape can also represent the amount of the content. The more digital content it has, the greater the shape changes.

Similarly, the same applications could be implemented by utilizing the variation in flexibility. As an illustration, a flexible device could be soft in standby mode so that it is comfortable sitting in a user's pocket. When an incoming message presents, the notification could be informed by changing the material's property from soft to stiff which arouses user's attention.

Building of Prototypes

6

Chapter 6

In this chapter, the role of prototyping in this project is introduced. Prototyping is considered as a means to explore, test and verify concepts under development. Koskinen et al. argued prototypes as "*physical hypothesis*" which have sufficient product qualities to draw conclusions from (Koskinen, 2011). In the following, prototypes built along the project development are introduced. How prototyping assists the developing of concepts and how the hypotheses were verified is illustrated in the first section, while the second part demonstrates the concept of the functioning prototype and its implementation.

6.1 the role of prototypes in this project

The role of prototyping can be examined from two different points of view. From practical point of view, prototyping is regarded as a means to explore, test and verify the ideas. With concrete representation of the idea, prototypes help not only designers to evaluate the ideas but also potential users to understand the idea and experience practical use cases. Intangible concepts are thus made tangible to both designers and users. On the other hand, from research point of view, prototyping plays an important role in the method of research through design. Designers design and build prototypes to help answer their research questions. The design is utilized as a medium to cause impact on the studying subject so that the reaction can be observed. This attitude toward prototyping accompanies the execution of the project. Corresponding to different purposes of each stage, various prototypes were built along the process.

After background research, form exploration experiment was designed. The first set of prototype, prototype v.0, featured the dimensional characteristics (See Figure 6.1). The purpose of prototype v.0 was to provide a concrete substance so that users' intuitive reaction on these basic form elements can be observed. Prototype v.0 was designed as building blocks in different dimensions and manifested both macro and micro affordance of form factors.

Figure 6.1 Prototype v.0

Based on the findings from the experiment, basic form factors were expanded, and another set of prototypes, Prototype v.0.1, was built to explore the deformation and hand gestures (See Figure 6.2). The materials chosen for Prototype v.0.1 were mainly foam board and polystyrene so that prototypes can be built in a quick and cheap way. Prototype v.0.1 consisted of more than thirty mock-ups which enable the exploration of the possibilities in deformation and form factors.

Figure 6.2 Prototype v.0.1

Extracted from Prototype v.0.1, a set of more concrete prototypes, prototype v.1.0, was built for new interaction style workshop where prototyping was involved heavily. Prototype v.1.0 was presented in the workshop and served as a means for participants to practice the interaction. It was based on the findings of previous prototypes, v.0.1. Instead of using quick mock-up materials, prototype v.1.0 was 3D printed so that they were more durable and ready for testing in the workshop. In addition to prototype v.1.0, participants built various prototypes as well during the workshop as described in previous chapters. The building of the prototypes makes intangible concept tangible, and discussions can be built around the prototypes. In a way, prototyping fosters discussion and ideation.

After the workshop, another set of prototype, Prototype v.1.1, was built (See Figure 6.3). The purpose was to further develop the prototypes built previously with the findings from workshop integrated. Moreover, it was to be ready for implementing electronic components so that functioning is possible. On Prototype v.1.1, practical consideration of hardware implementation was taken into account in the designing of the form.

Figure 6.3 Prototype v.1.1

A working prototype, Prototype v.2.0, was built after the planning of hardware was finished. Likewise, it was a 3D printed model. However, there were hardware implementation and software programming involved in the prototyping, which allowed various gestures performed and recognized on it. Similarly, it was tested and modified to suit the need for the incoming user test, which resulted in its later improved versions (See Figure 6.4).

The design of this working prototype was to implement a platform where various properties of flexibility can be presented so that the features could be tested with users. At this point, the prototype does not

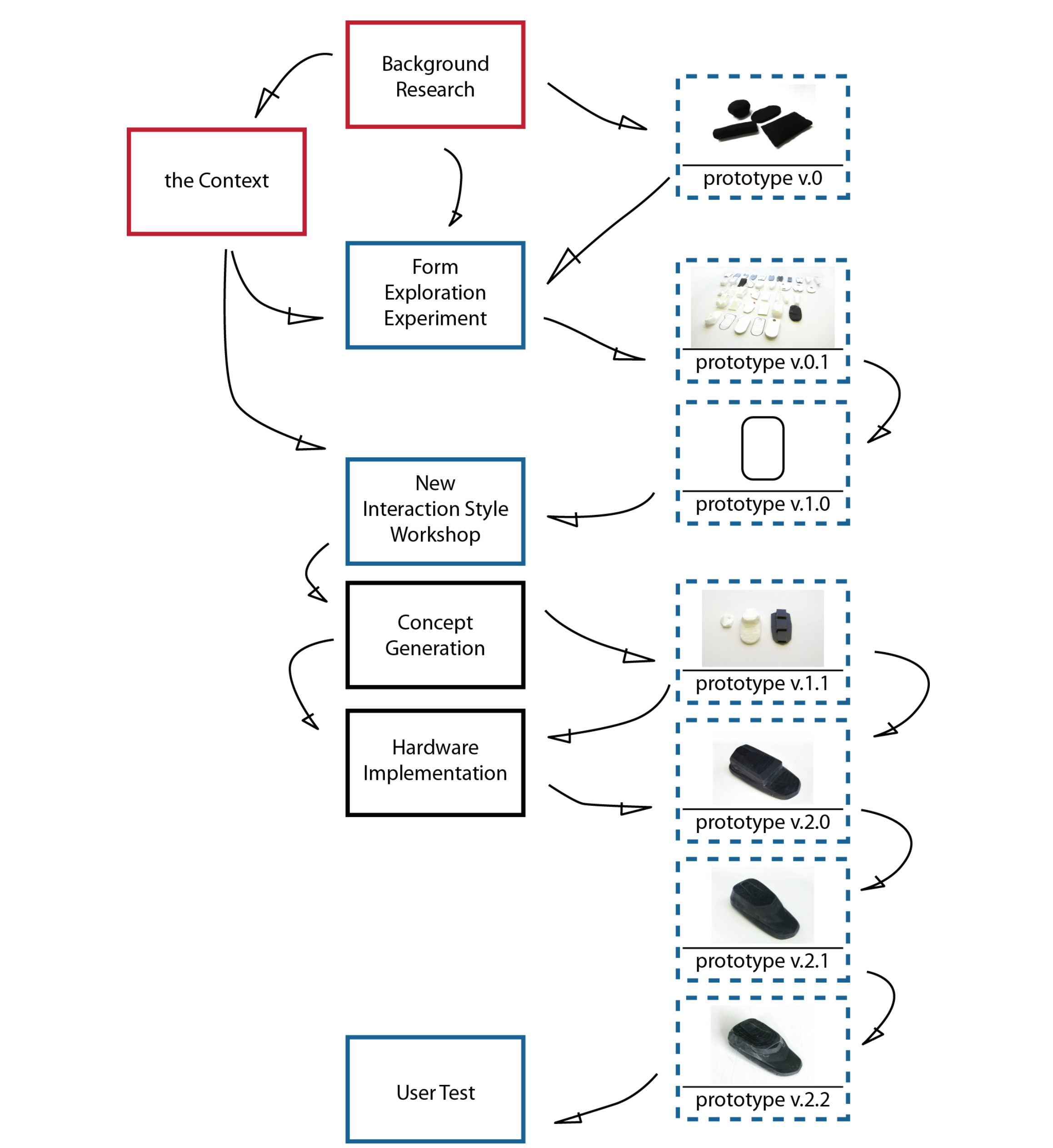


Figure 6.4 The role of prototyping in the project

refer to a single model. Rather, it is a platform which involves the mobile device model and the testing environment (See Figure 6.5). More detailed description of the platform and its implementation is demonstrated in the following section.

6.2 building of the working prototype

The design of the prototype does not intend to include as much functionality and features as possible; rather, it is to select relevant features so that flexible interaction can be examined on certain applications.

The concept of the prototype is described in the first section. In the second part, practical implementation of the prototype is introduced. The implemented prototype fulfills the purpose of utilizing flexibility as an interface.

6.2.1 the concept

The working prototype consists of a flexible mobile device and an information system which is in charge of processing digital data. A wireless communication channel is built in between so that commends and information can be exchanged between the device and the information system. It is also possible to allow more than one mobile device communicating with each other on this platform (See Figure 6.5).

The concept can be examined from three perspectives. Firstly, from the perspective of functionality, various flexible gestures can be performed on the device. Through the communication channel, the information system is able to respond to the recognized gestures. Secondly, from the perspective of

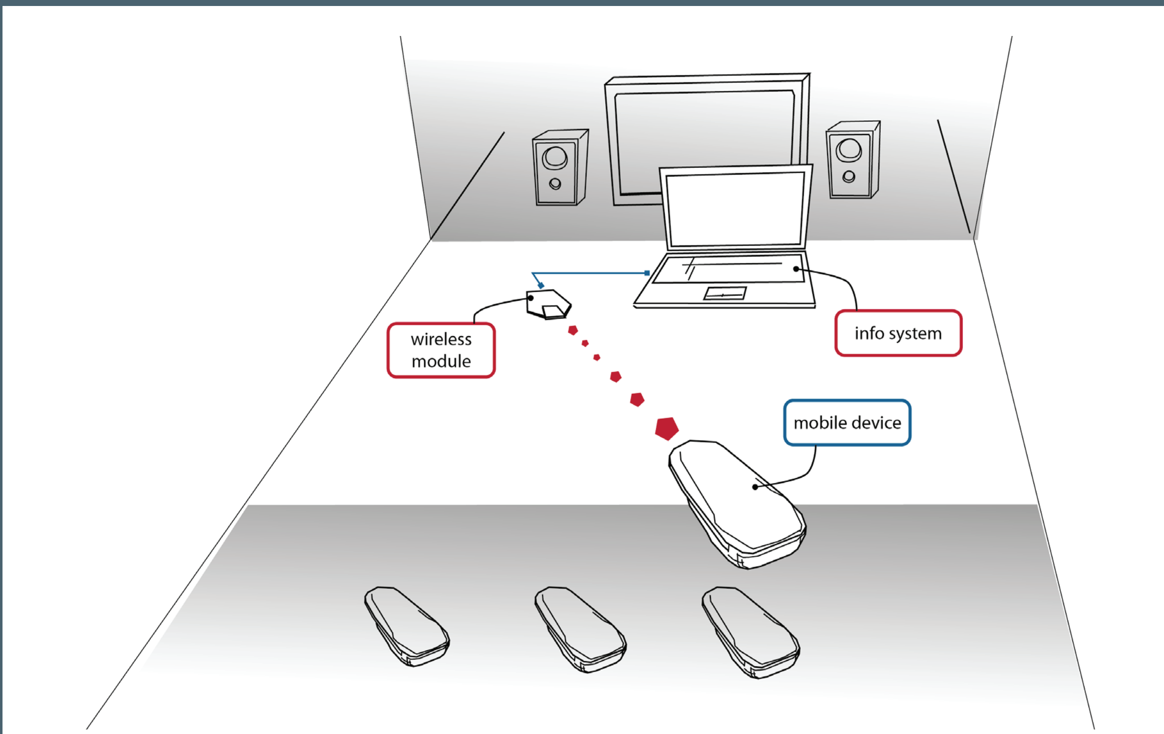


Figure 6.5 The environment of the prototype platform

form factors, most of the design cues are followed on the mobile model. It conveys affordance that manifests flexibility and mobile interaction. The last, from the perspective of applications, information is distributed into the space. There is no display implemented on the mobile model. Visual information is presented through the information system.

To further elaborate on the third point, the design of Gummi could be referenced (Schwesig, Poupyrev, & Mori, 2004). In Gummi, the authors identified the issue of small sized displays which confined the amount of information that can be presented to users. To solve the issue, the effort was put on its GUI design. Visual information was distorted on Gummi so that only the information users concerned was presented. Similarly, the concept of distributing information into the space strives to tackle the small sized display issue. The information system not only processes the data but also makes response by providing visual and audio feedback. The design of the platform avoids concentrating information onto one single device, which allows the releasing of visual attention back into the space.

The distributed information is also due to the project constraint which is to minimize display on the mobile device. Besides, not implementing a flexible display on the model is also due to the intention of minimizing the complexity of prototyping. The implementation of the concept is described in the following section.

6.2.2 the implementation

In the following, practical implementation of the prototype is demonstrated. It is divided into two parts, the elements of the platform and the features of the flexible mobile device.

the platform

The platform consists of two major parts, the mobile device and information system. The information system is completed with a laptop running Processing program ("Processing.org," n.d.). It functions as an interface for communicating with the mobile device, through which visual and audio feedback can be provided. The other part of the platform is a mobile device whose detailed features will be described in the next section. The device not only reacts directly on users' manipulation but also process commands sent from the Processing program. For example, when the device is squeezed by a user, a short pulse of vibration is immediately triggered as a tactile feedback. Moreover, the applied pressure on the device is reported to the program which makes reaction according to the level of force. In order to enable communication between the two endpoints, a bi-direction wireless channel is constructed between the device and the program. It is made possible by two XBee wireless modules ("XBee® ZB - Digi International," n.d.) implemented on both endpoints. On this platform, it is possible to increase the number of mobile devices, and the devices can communicate with each other as well. Figure 6.5 illustrates the relationship between the elements in the platform.

the flexible mobile device

There are two major concerns involved in the design of the mobile device. The first is the design cues presented in the previous chapter. Figure 6.6 lists various features that are realized in the form factor. Another consideration is practical requirement of the electronic components that enable the functionalities. Numerous sensors and microcontrollers are implemented so that gesture recognition can be realized. Detailed description of the components is listed in Table 6.2. Figure 6.7 also shows how the components are implemented inside the model.

The designed model is 3D printed in flexible material. Various gestures are able to be performed and recognized on the model. The gesture type and its deformation magnitude are transmitted to the laptop for further processing. Table 6.3 illustrates all the gestures that can be performed on the model.

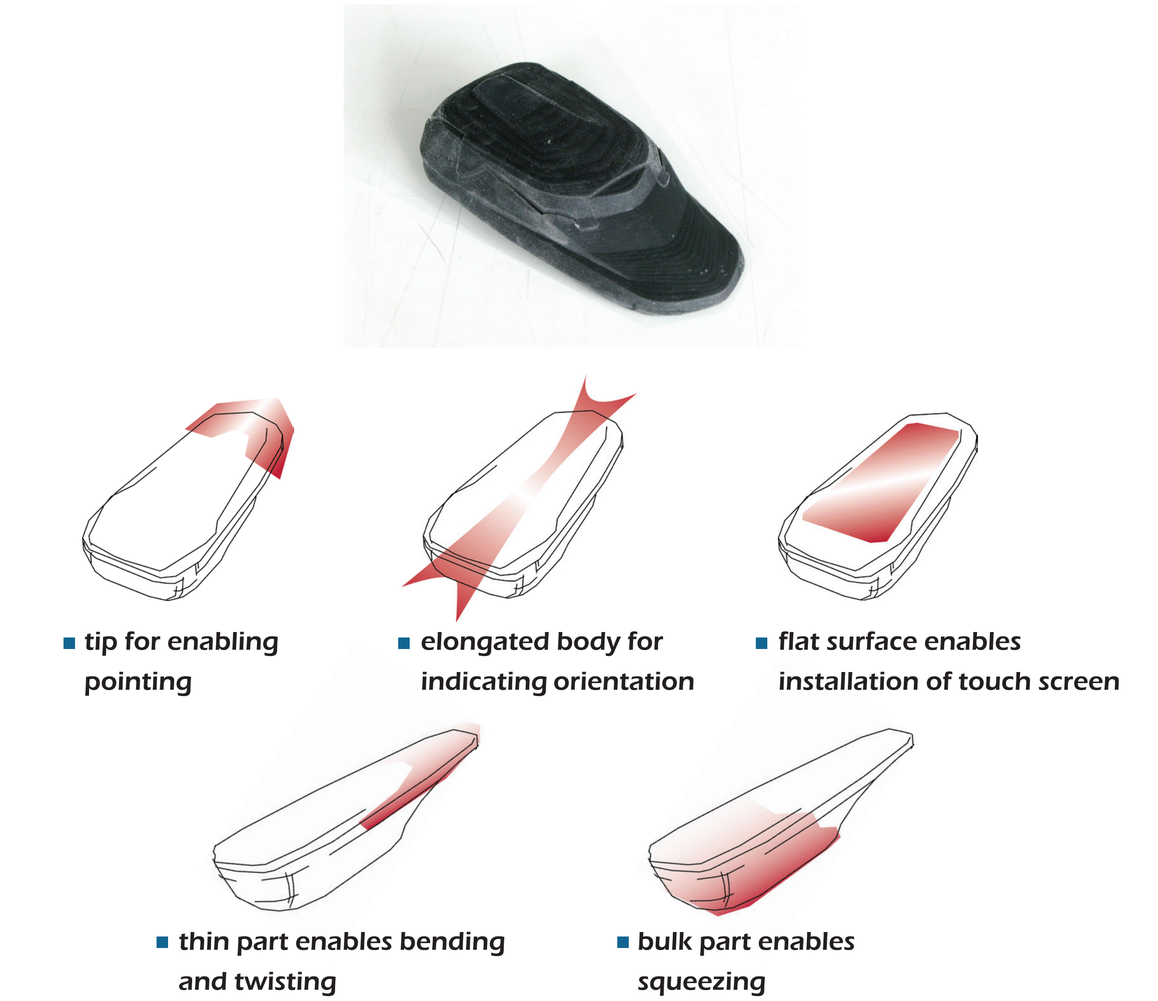


Figure 6.6 Form factors featuring the design cues in chapter 5.

Component	Function
Arduino Fio microcontroller board (*“Arduino - ArduinoBoardFio,” n.d.*)	microcontroller board which processes the commands and sensor signal
Xbee RF module (*“XBee® ZB - Digi International,” n.d.*)	radio frequency module which enables wireless communication between devices
flex sensor (*“Flex Sensor 2.2” - SparkFun Electronics,” n.d.*)	a flexible resistor whose value varies according to the degree of bending
force sensitive resistor (*“Force Sensitive Resistor 0.5” - SparkFun Electronics,” n.d.*)	a flexible resistance whose value varies according to the pressure applied
vibration motor (*“Vibration Motor - SparkFun Electronics,” n.d.*)	vibration generator which functions as haptic feedback
Battery (*“Polymer Lithium Ion Battery - 1000mAh - SparkFun Electronics,” n.d.*)	power source

Table 6.2 Electronic components used in the prototype and their corresponding functions.

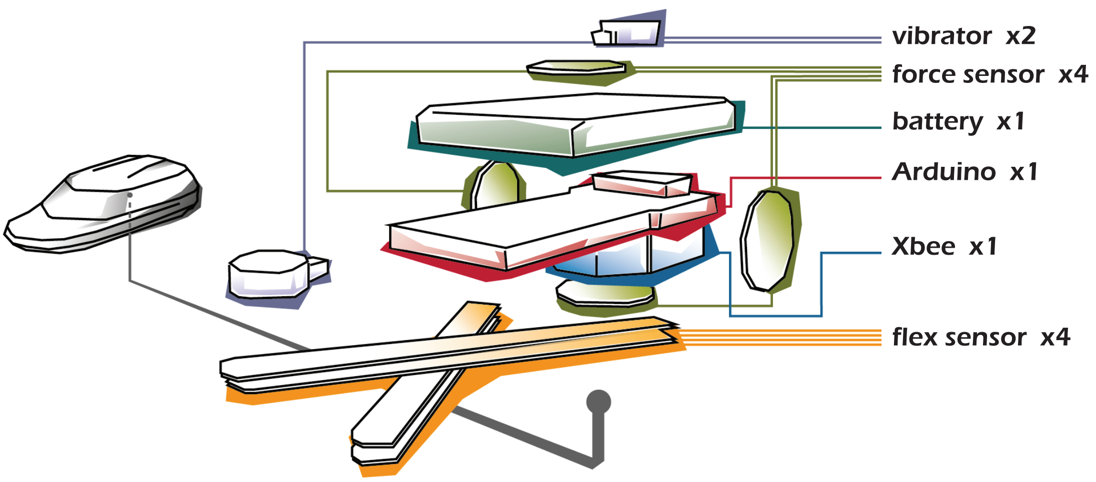


Figure 6.7 The implementation of the model and the components.

Bending UP

Bending DOWN

Bending Left UP

Bending Right UP

Bending Left DOWN

Bending Right DOWN

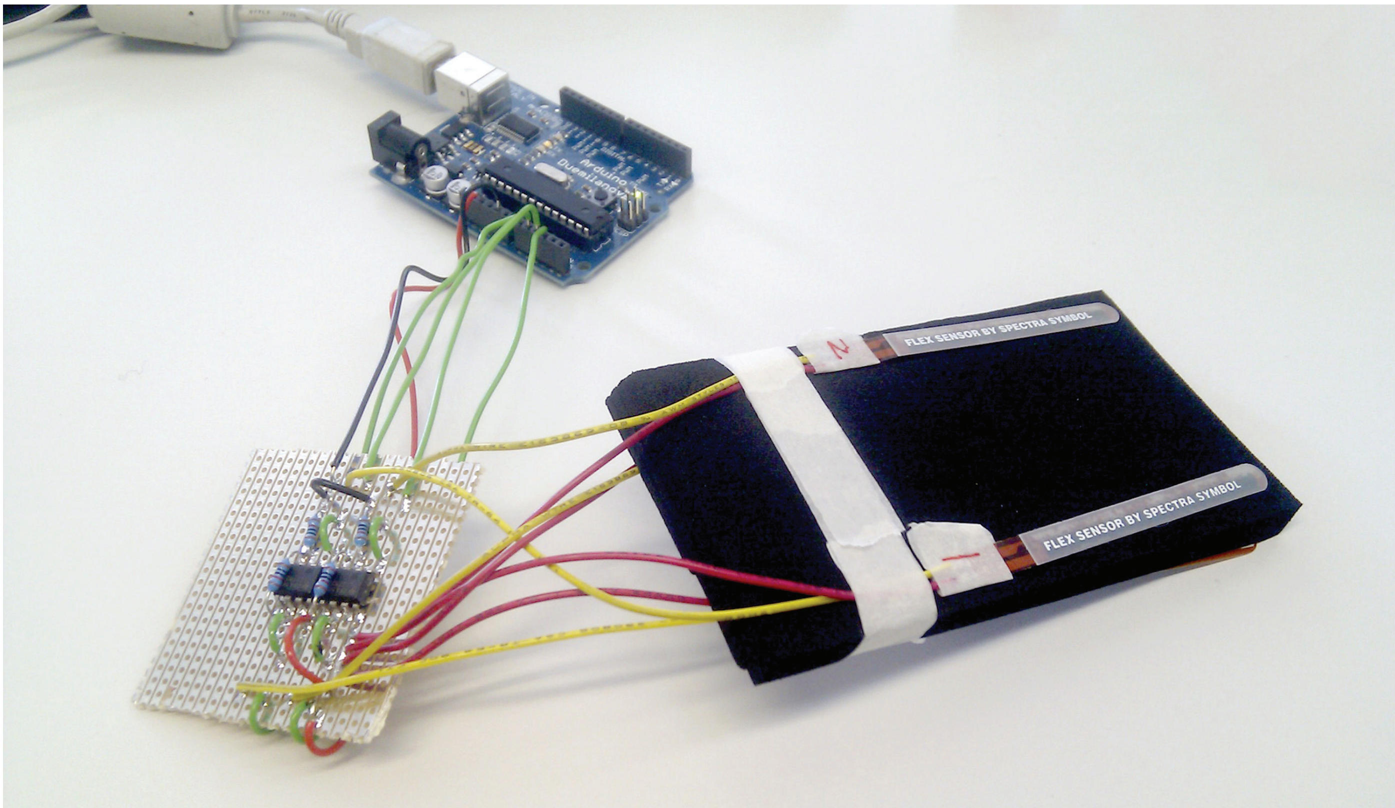
Twist CLOCKWISE

Twist COUNTERCLOCKWISE

Squeeze I

Squeeze II

Table 6.3 Recognizable gestures on the mobile model.



7 Evaluation of Mobile DUIs through User Tests

Chapter 7

A set of user test was designed to evaluate the concept of mobile DUIs in practical applications. The implemented prototype was thus the physical representation of the hypotheses for researchers to investigate into the research questions.

There were two categories in the test tasks. The first one was analog input in which users adjusted the values of variables by physically manipulating the mobile model. The second was gaming. Users played three different games where the context was brought into the physical deformation of the prototype. In order to understand the impact flexible interaction had, the same tests were done on touch screen devices for comparison.

7.1 the hypotheses

As deformable interaction is a relative new interaction style, two hypotheses are made accordingly.

a. **The interface built on deformation can be provided as a reliable means to control analog input.**

   One possibility of utilizing deformation for interfaces could be in the application of continuous analog input. The proposal of this hypothesis is to understand the validity of DUIs in analog input which could be expended to applications such as selection and adjustment.

b. DUIs could provide more engaging, involving, and interesting experience in interacting with digital contents.

DUIs require users to physically deform an object, which involves action in three dimensional spaces. Compared with action on touch interface, the involved action could enable more engaging experience.

The proposal of this hypothesis is that flexible interaction involves more body movement which opens more opportunities in enriching interacting experience.

7.2 design of the user test

Two categories of applications on mobile DUIs were designed. The first category was to examine the role of flexible interaction in inputting analog values. The result should present the reliability of flexible interaction in controlling analog values, which provides a solid ground for further application development. In the design of the second category, context was considered and introduced into the test cases. The chosen context was gamming. Three different games were designed for the tests.

In order to understand the impact flexible interaction has, the same tasks were done through touch screen style interaction. In addition to the implemented prototype platform, an Android touch screen phone was programmed so that the same tests could be performed on the phone ("Android," n.d.). After each task, Likert scale of agreement was used for User Engagement Scale (UE-Scale). The questions were based on (Levesque et al., 2011) and can be found in the following section.

After all the tasks were finished, there was an interview to finish the test. The interviewing questions included users' attitude toward and behaviors on their own phones. Moreover, the experience throughout the test on both the prototype and touch screen phone was examined. Interviewing questions are attached as Appendix C in the end of the book.

7.3 test cases and procedure

7.3.1 test cases

Analog control

In the first part of the evaluation, the controlling of analog input was simulated. Users were asked to control the position of a pointer to match a corresponding target along a slider. In each test, a target was assigned with a tolerance value as well. For example, with target value 25 and tolerance 2, a user must move the pointer into the range from 23 to 27. There were five different target values and four different tolerance ranges, which resulted in twenty different combinations. To complete the full series of the combination, a test case was repeated for twenty rounds. The selection method was dwelling, which means once the pointer remains its position within the tolerance range for a certain period, the selection is confirmed.

There were two test cases in this part. In the first test case, there is only one slider along with one target and one pointer. In the other test case, there were two sliders on left and right side of the display, respectively. Similarly, there were one target and one corresponding pointer on each slider. Both targets should be matched to complete a task. (See Figure 7.1)

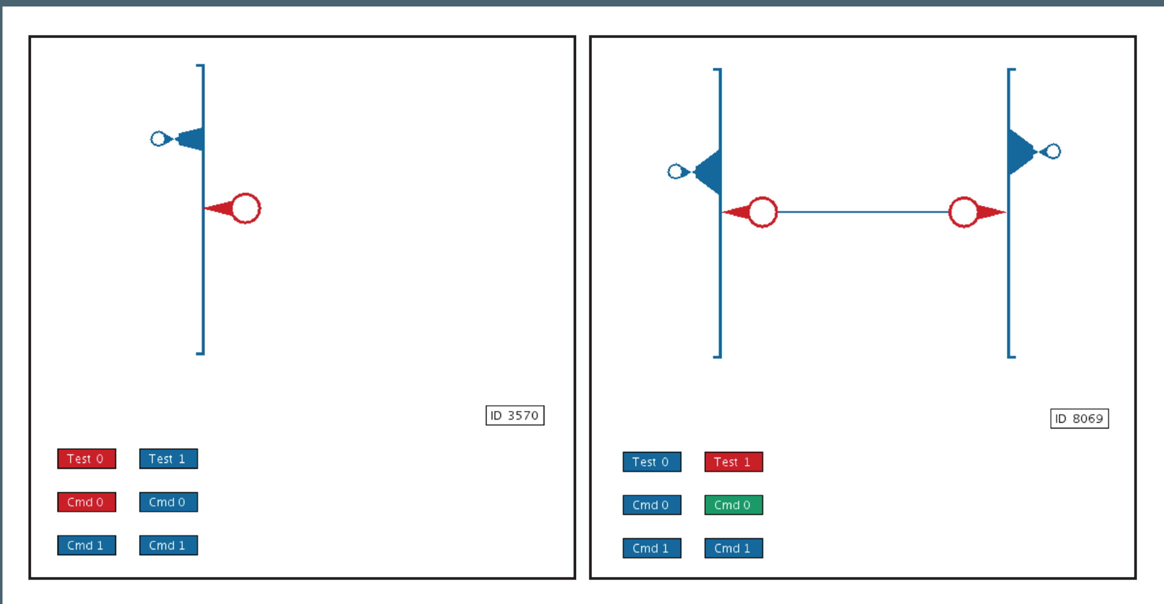
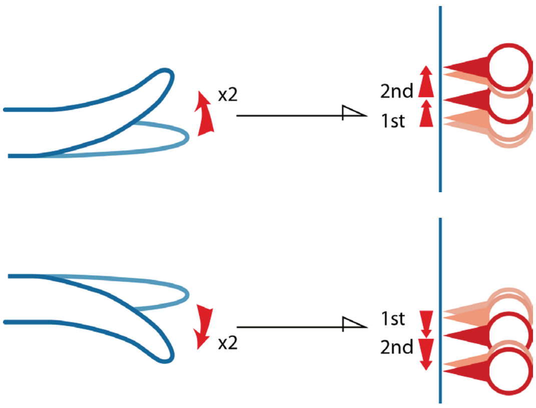
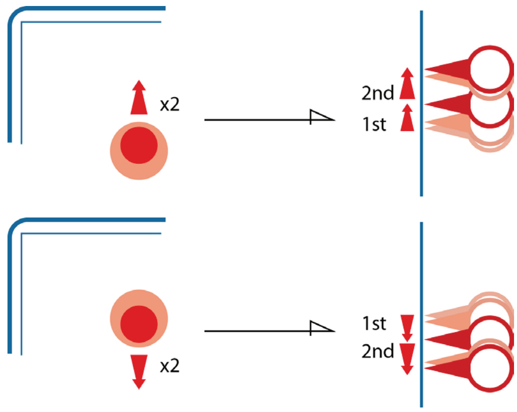


Figure 7.1 **The screenshot of the cases of one slider and two sliders. The pointers are shown in red while the targets are colored with blue.**

In these two test cases, two different methods of controlling the pointers were designed. The first was a derivative adjustment which allowed users to trigger the shift of pointer position incrementally. An incremental value was derived from user's gesture and added to the previous reference value. The action was similar to manipulating a button on which repetitive action was required to achieve a target value. For example, when the user performed "bend up" action, the pointer moved upward according to how hard the device was bent. The harder the device was bent, the larger the incremental value was. The updating speed was also faster accordingly. The pointer stopped moving when "bend up" gesture vanished.

The other method was an absolute adjustment. In this case, the degree of bending determined the position of the pointer. For example, when the user performed "bend up" action, the more the mobile model was bent, the further the pointer went upward. The position of the pointer reflected the degree of bending in real time. The pointer returned to its initial position when the "bend up" gesture vanished.

Derivative Adjustment

DUI	Touch Interface
	
The deformation triggers pointer's movement incrementally.	*Swipe Gesture on touch screen triggers a movement with inertia.*

Absolute Adjustment

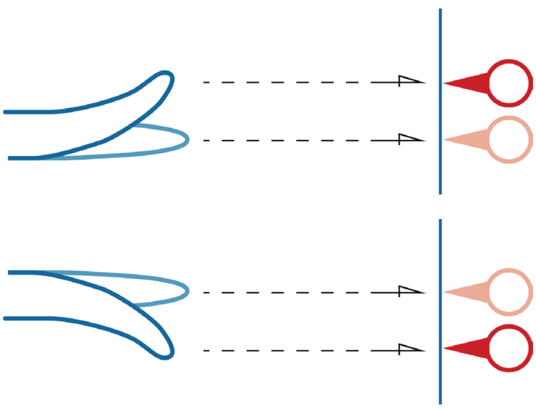
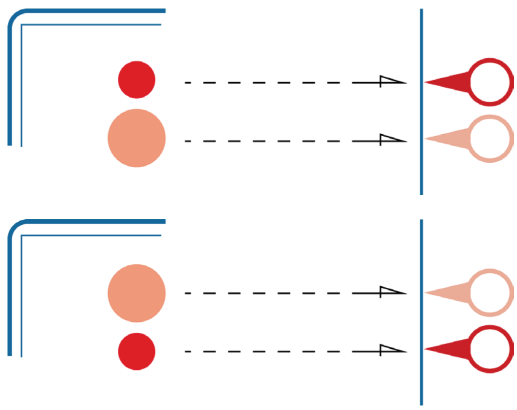
DUI	Touch Interface
	
The amount of deformation determines the pointer's position.	*The pointer's position reflects the exact position of the finger tip.*

Table 7.1 Illustration of controlling methods in different combinations.

The corresponding adjustment method was also implemented on touch screen device. In the case of derivative adjustment, users could perform "swipe" gesture which triggered a movement of the pointer with inertia. The pointer can also be adjusted by "drag" gesture. The movement was based on its previous position. In the case of absolute adjustment, the position of the pointer always reflected the exact position of the fingertip regardless of its previous position. That is, the pointer was always beneath the fingertip.

The adjustment method on both devices is listed in Table 7.1. With all the different variables, there are eight different combinations derived for the whole test set. The coded names of the tests are listed in Table 7.4.

Game

In the second part of the test cases, users were asked to play three different games.

The first game was Chopper game. In this game, users drove a helicopter through a tunnel. The constraint was that the helicopter should not hit the ceiling or the ground. In the space between the ceiling and ground, there were obstacles that a helicopter should dodge. The helicopter moved forward in an increasing speed which was determined by the program. Users controlled the altitude of the helicopter by manipulating the device in hand. (Figure 7.2)

The way to control the helicopter was similar to the absolute adjustment in the target-matching task. On the prototype, the degree of bending determined the position of the helicopter. The more the device was

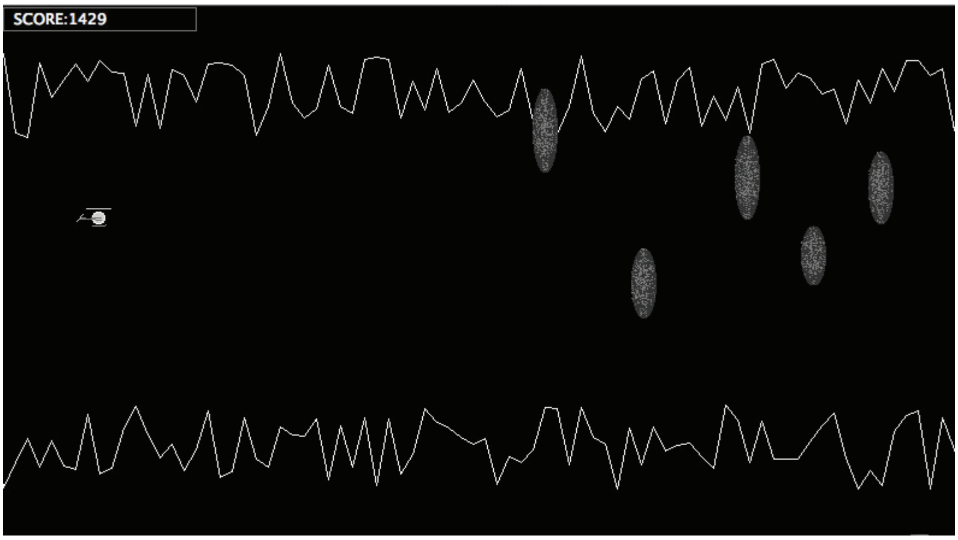


Figure 7.2 Screenshot of Chopper game

bent upward, the higher the helicopter went. The same effect applied to the other direction. When the bending gesture was released, the helicopter returned to the middle of the display. While on the touch screen device, the position of the helicopter always reflected the exact position of the fingertip.

The second game was Guiding game. In this game, users tried to guide a flock of birds whose motion was simulated according to Reynolds' distributed behavioral model (Reynolds, 1987). The flocks flew out from the bottom of the screen. Users were able to rotate the two guide bars illustrated by aligned dots to match the target square. In addition to that, the color of the birds and target should also be matched. After the birds flew away from the guiding range, the flocking pattern was formed and they were not controllable anymore. Therefore, a certain degree of uncertainty was added into the game. (Figure 7.3)

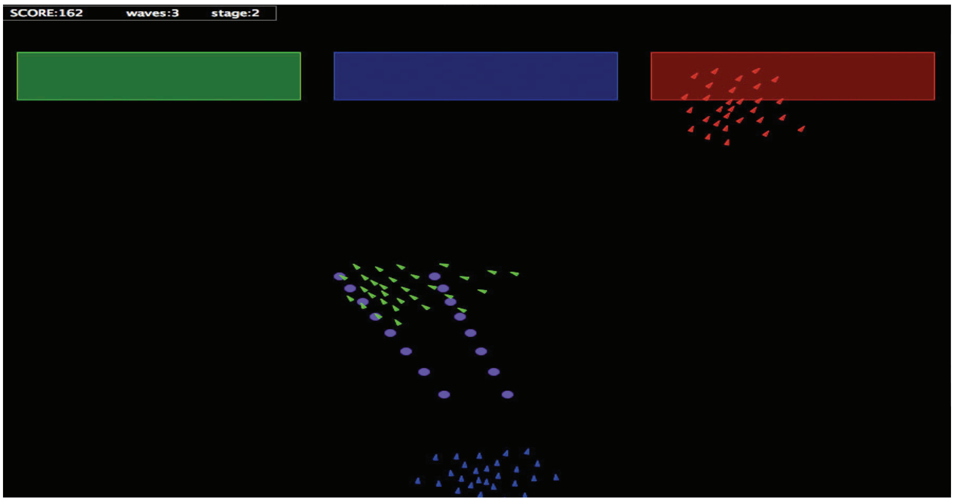


Figure 7.3 Screenshot of Guiding game

The way to control the guiding bars was similar to the absolute adjustment in the target-matching task. On the prototype, the degree of bending determined the rotation degree of the guiding bars. In addition to bending, users can also perform twisting gesture to control the guiding bars. On the touch screen device, the far end of the guiding bars always followed users' fingertip.

The third game was SpaceTunnel game. In this game, users navigated a spaceship. There were brown circles appeared randomly in the space. As time goes by, the circles enlarged and turned into blue, and eventually disappeared. The task for users was to drive the spaceship into the blue circles. (Figure 7.4)

The way to control the spaceship on the prototype was by performing different gestures on which the deformation of the prototype was mapped into the virtual space. When the user performed "bend up"

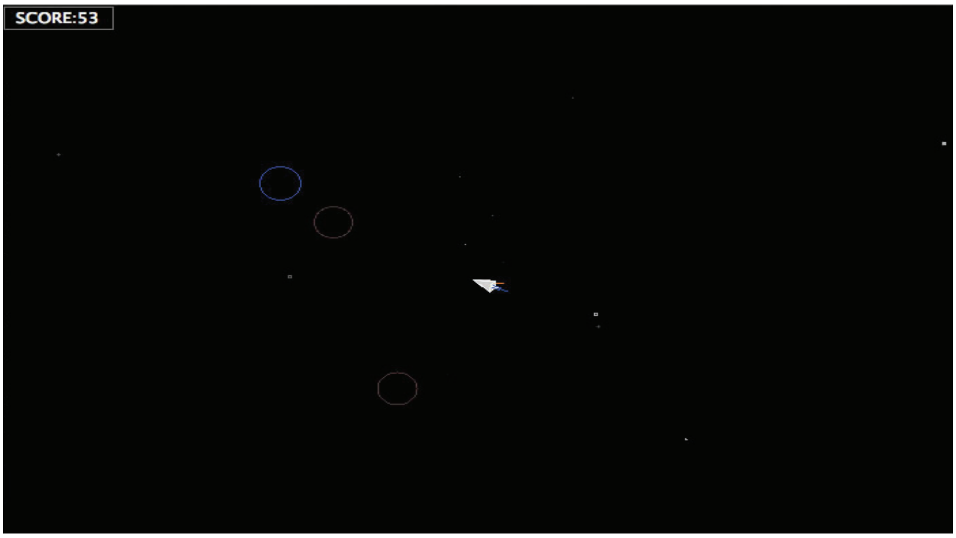


Figure 7.4 Screenshot of SpaceTunnel game

gesture, the spaceship went upward. When the user performed “bend down” gesture, the spaceship went downward. Turning to the left and right can be achieved by performing “twist clockwise” and “twist counterclockwise,” respectively. When only one side of the prototype was deformed, it was able to navigate the spaceship toward diagonal directions. For example, by bending only the right side of the prototype upward, the user can move the spaceship toward the top left corner of the screen.

The way to control the spaceship on the touch screen device was by touching different parts of the screen. The position of the fingertip relative to the center of the screen determined the movement of the spaceship. For example, if the fingertip was on the left side of the center point, the spaceship moved towards its left side regardless of the current position of the spaceship. If the fingertip was on the upper side of the center point, the spaceship moved upward. Users can stop the spaceship by touching the center of the screen. The distance between the touch point and the center determined the speed of moving. The closer to the center the fingertip touched, the slower the spaceship moved.

7.3.2 test procedure

The counter balanced sequences

In order to counter balance the effect of the test order, all the participants were tested with different test sequences. This way, a particular task would not appear simpler simply because it was always tested in the last when participants had learnt the skill. Two ways of controlling the pointers and two different numbers of sliders generated twenty four different test orders. The order of the gaming was also counter balanced. To further counter balanced the effect of testing order of flexible interaction and touch screen style interaction, the order was evenly distributed as well. The detailed test sequence can be found in Appendix B.

In target-matching tests, the test order of target-tolerance combination was fixed for all users. There are five targets and four tolerance range for each slider, which needed twenty rounds to finish all the possible combination. The sequence of the target value-tolerance range combination was pre-determined by Fisher-Yates shuffle method (Knuth, 1998). The same sequence was applied on all the participants. The test program was automated so that the test automatically continued to the next target-tolerance combination until twenty rounds were all finished.

Step	Session	Description
1	Introduction	Introducing of the test and consent form signing.
2	Analog input	Users perform the task of matching targets. The task is determined by the counter-balance table.
3	UE-scale	Five sentences are provided for users to evaluate the previous task.
Repeat step 2-3 until all the tasks are performed on both DUI and touch interface.		
4	Gaming	Users play the game according to the counter-balance table.
5	UE-scale	Ten sentences are provided for users to evaluate the previous task.
Repeat step 4-5 until all the games are played on both DUI and touch interface.		
6	Interviewing	Free comment and interviewing.

Table 7.2 The test schedule

Test procedure

The test procedure is as follows. First, the analog control was tested. According to the test sequence table (See Appendix B), each participant followed different order of tests. In each test, a sequenced task of twenty target-tolerance combination was performed. After each test, five sentences were presented to the user. In order to apply Likert scale, each sentence was rated from one to five. The test was repeated until all the tests were done on both the prototype and the touch screen device.

Second, users were asked to play the three games. Similarly, the playing order was different between each participant to counter balance the ordering effect. As in previous test, Likert scale was applied to evaluate the experience. In the UE-Scale, ten sentences were presented to the participants after each gaming. While a 5-point Likert scale was used in previous tests, a 7-point Likert scale was used in gaming for the UE-Scale. Scaling from one to seven, the participants were asked to rate each sentence.

In both parts, users were allowed to use only one hand to manipulate the device. Gaming session was followed by an interview whose questions are listed in Appendix C.

Detailed schedule of the test is listed in Table 7.2.

7.4 test results and analysis

Twenty four participants joined the test, from which twenty one valid data sets were collected. Among the twelve females and nine males, the average age was 26.7.

The reasons for ditching those three data sets are explained as follows. Two of them resulted from miss touch of the command button during the analog input test on touch interface. In addition to the sliders, the command buttons were displayed at the same time on the screen. The two participants touched the button accidently during the test, which switched the program into another test mode and made the collected data invalid. The other fallacious data set was collected from the very first participant who took extra amount of test rounds than other participants. The data set was considered as invalid as well.

7.4.1 statistical results

There are three sets of data can be analyzed statistically. The first set is the performance of analog input. For each task and each user, the following data was recorded: time required to enter the tolerance range, time required to confirm the selection, and counts of cross over the target range. With these data, the performance on DUI and touch screen interface can be evaluated and compared. The second set is the UE Scale from analog input tasks, while the third set is that from gaming. The UE Scale helps understand the perception and experience during the tests.

Performance analysis on analog input test

The following three pairs of figures depict the preliminary analysis result of analog input tests.

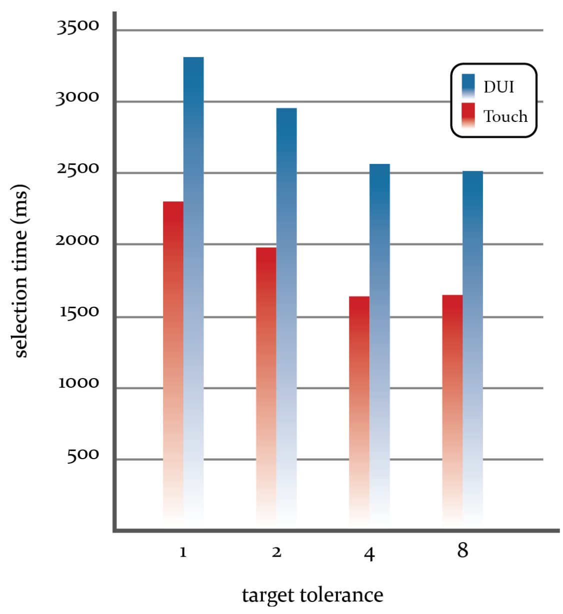


Figure 7.5a Performance comparison in one-slider case

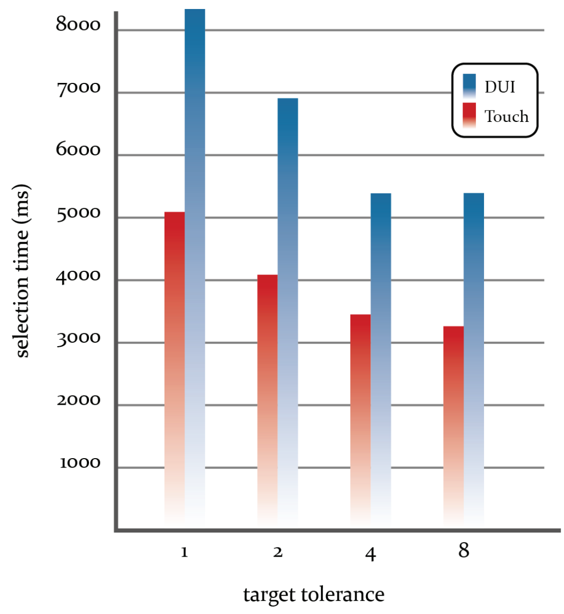


Figure 7.5b Performance comparison in two-slider case

Figure 7.5a and Figure 7.5b depict the performance comparison between DUI and touch interface for one and two slider cases, respectively. It can be found that in both cases, regardless of the adjustment method, less selection time was required on touch interface, which was nearly more than 20 percent faster than that on DUI. It can also be seen that the larger the target tolerance, the shorter the selection time as expected.

Figure 7.6a and Figure 7.6b depict the performance comparison in one slider case between the two different adjustment methods, absolute and derivative. Figure 7.6a illustrates the relation between selection time and target tolerance. It can be seen that, with the same tolerance, absolute adjustment was faster than derivative. On the other hand, Figure 7.6b depicts the relation between selection time and target distance. The signed target distance should be noticed since the targets were distributed on both sides of the initial pointer position. Minus target distance was derived from bending backward, while positive target distance was derived from bending forward. Due to the asymmetry form of the prototype, the behavior of bending forward and backward was not the same.

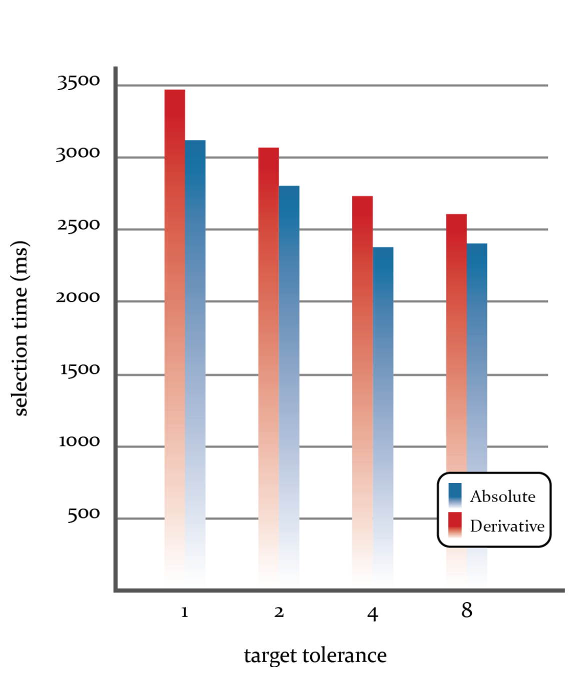


Figure 7.6a **Performance comparison in one-slider case showing the relation between selection time and target tolerance.**

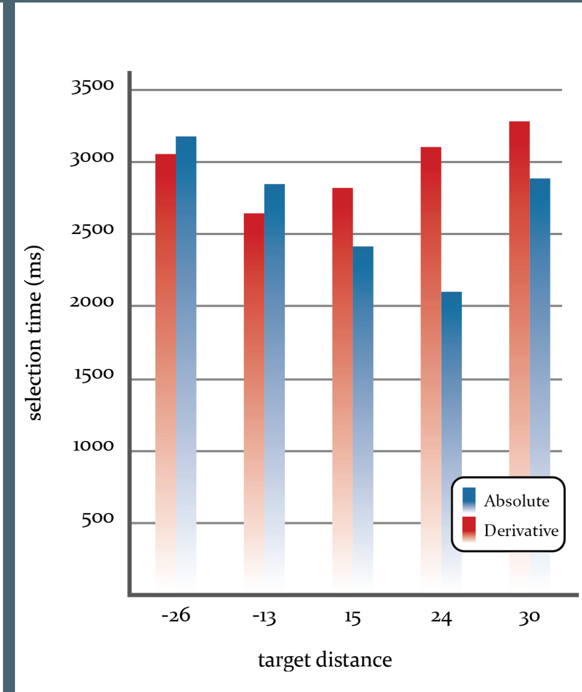


Figure 7.6b **Performance comparison in one-slider case showing the relation between selection time and target distance.**

Note that the minus sign in target distance indicates the direction of the target.

Another fact that can be observed from Figure 7.6b is that longer target distance does not necessarily require longer selection time when absolute adjustment method was applied. When target distance is 24, the selection time had the smallest value regardless of the fact that targets with distance 15 were closer to the initial position.

Figure 7.7a and Figure 7.7b illustrate the application of Fitts' law model on the collected data (Fitts, 1954). Index of difficulty was modeled as $\log_2(D/W+1)$, where D was the target distance and W was the width of the target. It can be seen that derivative adjustment yielded a more aligned result with Fitts' law model, while absolute adjustment had a poor fit.

The poor Fitts' fit of absolute adjustment might result from the fact that a shorter target distance did not necessarily induce less selection time, which can be observed from Figure 7.6b. In absolute adjustment condition, the angle of bending directly reflected the position of the pointer. To achieve a nearer target, only small bending degree was required. However, in the presence of resisting force, to bend and maintain a small degree might not be easier than a moderate degree. The metaphor of moving a heavy box on the ground might apply. A similar phenomenon can be found in Scott et al.'s research in which target selection was achieved by applying force on the prototype (Scott, Brown, & Molloy, 2009). In their

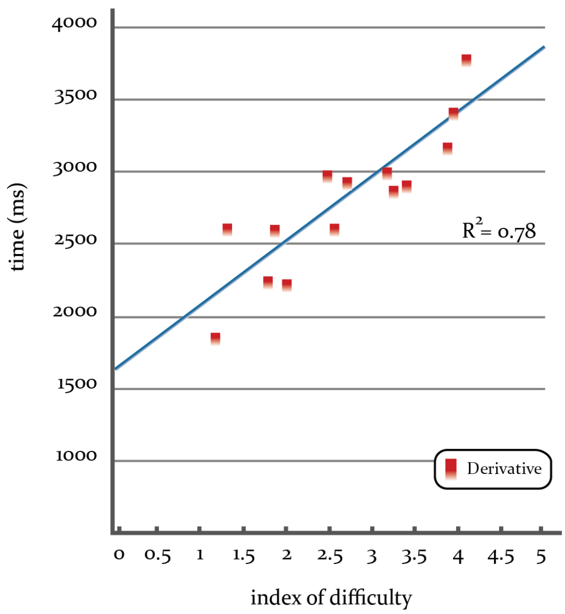


Figure 7.7a Fitts regression analysis of derivative adjustment in one-slider case.

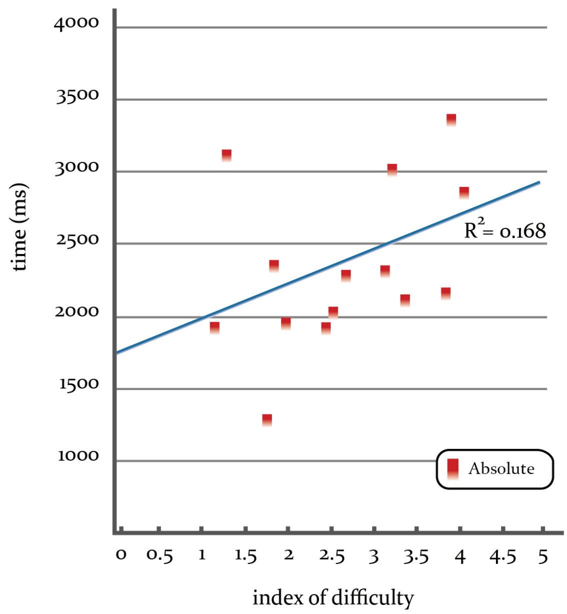


Figure 7.7b Fitts regression analysis of absolute adjustment in one-slider case.

research, the nearest target required the longest selection time in most cases. The authors argued that Fitts' model might not be appropriate for this kind of devices which acquire negligible limb motion.

UE Scale on analog input test

Table 7.3 illustrates the mean rating from the analog input test. A 5-point Likert scale was applied in the UE Scale. The description to the code name of the tests can be found in Table 7.4.

It can be found that:

a. In general, compared with touch interaction, the self-evaluated performance on DUI was poorer and required more concentration. In DUI, participants also needed to concentrate more, felt less confident and more frustrated. The only exception was the performance on ToCo which was scored slightly higher than that in AToCo. ToCo was also scaled as the least challenging one among all the flexible tasks since it required the least concentration, least frustrated, and most confident. This gave a hint that with simpler task, DUI might be able to compete with touch interface in applications that requires concentration and precision.

b. Even though with all the frustration and the feeling of poor performance, participants enjoyed interacting with DUI than with touch interface under all test cases.

UE-Scales / Technical Tests	T0C0	AT0C0	T0C1	AT0C1	T1C0	AT1C0	T1C1	AT1C1
I performed well	4,19 (0,7)	4,14 (1,0)	3,67 (0,8)	4,33 (1,0)	3,38 (0,7)	3,71 (0,7)	2,93 (1,1)	3,86 (0,7)
I needed to concentrate	3,33 (1,1)	2,86 (1,1)	3,69 (1,2)	2,86 (0,9)	4,05 (1,1)	3,29 (1,1)	4,38 (1,1)	3,26 (1,1)
I felt confident in my ability to hit the target	4,29 (0,8)	4,19 (0,9)	3,86 (0,9)	4,4 (0,9)	3,52 (0,7)	4,07 (0,7)	3,19 (1,0)	4,1 (0,8)
I felt frustrated	1,95 (0,9)	1,71 (0,8)	2,02 (1,0)	1,62 (1,1)	2,24 (1,0)	2,14 (0,9)	2,81 (1,2)	2,17 (1,1)
I enjoyed interacting with the device	3,48 (0,9)	3,14 (1,0)	3,55 (0,8)	3,1 (1,2)	3,76 (1,2)	2,95 (0,9)	3,43 (1,2)	3,02 (1,0)

Table 7.3 Mean (st. dev.) questionnaire responses, with 1 = strongly disagree, and 5 = strongly agree.

UE-Scales / Interface	DUI	Touch Interface
One slider, derivative adjustment	T0C0	AT0C0
One slider, absolute adjustment	T0C1	AT0C1
Two sliders, derivative adjustment	T1C0	AT1C0
Two sliders, absolute adjustment	T1C1	AT1C1

Table 7.4 The code names of all the test cases

Basically, for the target matching tasks which required more precision and concentration, participants confronted more challenges in DUI than touch interface. However, flexible interaction results in more enjoyable experience.

Table 7.5 illustrates the mean rating from the gaming test. A 7-point Likert scale was applied in the UE Scale.

UE-Scales	Chopper DUI	Chopper Touch Interface	Guiding DUI	Guiding Touch Interface	SpaceTunnel DUI	SpaceTunnel Touch Interface
UE1. I was absorbed in my interaction task.	5,57 (1,0)	5,24 (1,2)	5,33 (1,2)	4,62 (1,0)	5,33 (1,3)	5 (1,1)
UE2. I felt in control of my interactive experience.	4,76 (1,4)	5,1 (1,4)	3,86 (1,4)	3,24 (1,4)	3,05 (1,5)	2,48 (1,1)
UE3. I found this application confusing to use.	2,14 (1,1)	2,38 (1,4)	3,14 (1,6)	3,19 (1,4)	4,05 (1,7)	4,76 (1,5)
UE4. I liked the visual and tactile effects used in this application.	4,52 (1,4)	4,12 (1,2)	4,05 (1,1)	3,67 (1,5)	4,29 (1,2)	3,52 (1,3)
UE5. This application appealed to my visual and tactile senses.	4,38 (1,5)	4,02 (1,1)	3,95 (1,1)	3,48 (1,5)	4,19 (1,3)	3,76 (1,4)
UE6. I would recommend this application to my friends and family.	4,02 (1,7)	3,71 (1,4)	3,43 (1,4)	2,57 (1,8)	4 (1,2)	2,76 (1,4)
UE7. I would have continued to interact with this application out of curiosity.	5 (1,7)	4,24 (1,6)	4,48 (1,5)	3,48 (1,9)	5,05 (1,7)	3,57 (1,7)
UE8. I felt interested in my interaction task.	5,29 (1,1)	4,33 (1,3)	4,76 (1,2)	3,86 (1,6)	4,95 (1,5)	3,9 (1,5)
UE9. This interactive experience was fun.	5,4 (1,2)	4,57 (1,2)	4,81 (1,3)	3,67 (1,6)	4,71 (1,7)	3,71 (1,5)
UE10. I felt involved in this interaction task.	5,29 (1,1)	4,81 (1,2)	4,81 (1,3)	4 (1,3)	4,9 (1,6)	4,1 (1,4)

Table 7.5 Mean (st. dev.) for the user engagement scale, with1 = strongly disagree, and 7= strongly agree.

The data above implies that:

a. Compared with touch interaction, DUI brought more positive experience in the user engagement scales. Significant differences can be found especially in recommendation (UE6), curiosity (UE7), interest (UE8), fun (UE9), and involvement (UE10).

b. Among the games, participants felt more in controlled with DUI, except for Chopper game. However, if compare the performance of DUIs between the games, it can be found that Chopper game is the one that provides most control feeling among the games.

In general, participants felt more involving, engaging, and fun in flexible interaction. Moreover, under the gaming context, DUI could provide more control feeling than touch interface.

7.4.2 findings regarding the hypotheses

findings regarding the first hypothesis

The first hypothesis describes that the interface built on deformation can be provided as a reliable means to control analog input. For examining the validity of hypothesis, Fitts' law model was applied preliminarily to analyze the data collected in target-matching tasks. The result indicated that, in the case of one slider with derivative adjustment, the performance of DUI was most in line with Fitts' law. The time required for completing a task increased in accordance with the increasing index of difficulty. However, the validity of Fitts' law on absolute adjustment and two-target cases was questioned. More analyzing strategies should be applied to further examine the performance under each test case. Therefore, until more tests or analysis are completed, the first hypothesis is only conditionally accepted.

findings regarding the second hypothesis

The second hypothesis illustrates that flexible interaction provides more engaging, involving, and interesting experience in interacting with the contents. In the first part of the tests, analog input tasks, it can be found that flexible interaction was given slightly higher scores in scaling the enjoyment of the experience. (Question 5, Table 7.3) While the target-matching tasks appeared to be neutral, there was much contextual information provided in gaming. From the user engagement scale Table 7.5, it can be found that DUI succeeded touch interface in almost all the questions which investigated the engagement when experiencing with the interaction. Flexible interaction appeared to be more interesting, involving and fun than touch interaction, especially under the gaming context.

In addition to the statistical results, the same findings can also be found in interview responses. In terms of feedback, many participants commented that the sense of realism was enhanced: "*You need to physically deform a device which gives more feedback especially the resistance.*"; "*Force is required, which feels more like interacting.*"; "*feel like really controlling something.*" While mentioning touch interaction, several participants commented that it does not feel like interacting because there is only visual feedback.

Although the performance might not be superior to touch interaction, flexible interaction was more engaging and involving. Several participants commented that it was quite challenging, but they enjoyed. Other comments were like: "*Because it is challenging, it is fun especially in games.*"; "*It's more fun in games. I feel more involved.*" One participant explained: "*I feel more involved. My emotional feeling is enhanced. When I am frustrated, I feel more frustrated. When it is exciting, I feel more excited.*"

On the other hand, touch interaction provided higher performance especially in target-matching tasks, but distanced users from the manipulated content. Most participants complained on the fact that the thumb blocked the view. People had difficulty in seeing the target or pointer beneath the finger. The device was tilted to an angle so that the pointers beneath the fingertip were visible. One participant commented: "*I wish my fingers are transparent.*"

From both statistical result and interview responses, flexible interaction was considered more engaging, involving and interesting. Therefore, the second hypothesis can be considered as accepted.

7.4.3 other observations on flexible interaction

different mindset affects the interaction

There exist different mindsets among people, and the mindset affects the way people link visual information with their action. It seems so obvious and natural that bending "UP" should trigger the pointer to move "UP" in the target matching tasks as well as in other similar situations. However, it was observed during the test that some participants felt confused and kept moving the pointer toward the opposite direction. To move up the pointer, the participants bent down first. On seeing the pointer moving toward the unintended direction, they changed the gesture. This observed fact seemed mysterious and difficult to explain until one of the participants flipped over the prototype in the middle of the process and stated "*In game consoles, I always turn on the reverse control option.*" The participant was able to clearly explain how the visual information was interpreted. Although the visual elements were displayed along a vertical slider extending from bottom to top, the interpreted information in the participant's mind was a straight line stretching from "NEAR" to "FAR". Therefore, it seemed reasonable that in order to move the pointer to the "FAR" end which was close to the top of the slider, a user can bend the device "FORWARD" which was the same as "Bend DOWN" gesture. Similarly, to move the pointer toward the "NEAR" end which was at the bottom of the slider, one can pull the device "BACKWARD" which was the "Bend UP" gesture. This explained why there were some people keep moving the pointer in the wrong direction in the beginning of each test. It was the mismatch between the mindset and programmed prototype behavior that caused confusion.

As for those whose mindset matched with the programmed behavior, flexible interaction style appeared intuitive and natural for them. People were able to link the visual information with their action in a short time. One of the participants stated that once the skill was learnt, which did not take long, verbal instruction of the incoming tasks seemed unimportant. The participant was able to understand how to manipulate the device once the task was shown on the screen.

Matching gestures with 3D content is expected

One of the interesting finding is the possibility of mapping body movement in the space into three dimensional virtual space. Unlike touch screen style interaction in which users maneuver fingertips on a two dimensional flat surface, flexible interaction relies on the deformation of a physical medium in three dimensional space, the immediate environment. Since the presented tests were only two dimensional applications, there is still one degree of freedom that was not utilized. Confusion might be induced when the visual information in responding to users' action does not match with their expectation. There were participants expecting to have three dimensional control over the content when manipulating the prototype. One of the participants explained that it was a bit confusing when the deformation took place in three dimensional space but the visual element moved in only two dimensional plane.

Regardless of the fact that the spaceship in fact moved only on two dimensional plane, some participants felt more in control in SpaceTunnel game and stated that they felt like a real pilot of the spaceship. There were also participants suggested that the chopper game should be modified into a three dimensional version.

Flexible interaction enables multiple control

Through flexible interaction, it is possible to develop more applications in which users are able to control multiple variables at the same time. In the target-matching tests with two targets, most participants tried to match both targets simultaneously when they were testing with the prototype. In most cases, the participants eventually finished the tasks by matching the targets one by one. Even though the attempts appeared to be failed, they felt it's a challenging and fun experience. There were also participants who challenged themselves and managed to succeed in matching both targets at the same time. This observation gives a hint of the possibility to develop applications utilizing flexibility for multiple controls.

Under the one-hand constraint, the same condition was not possible when the interface was built on a touch screen. The task can only be done by using the thumb to control the two pointers individually. Otherwise it was not possible to hold the device.

opportunities in one hand use case

In the test, users were allowed to use only one hand. Several drawbacks in touch interaction can thus be identified, such as the occlusion of the finger. Using one hand to hold and manipulate touch screen in horizontal position was especially a hassle. The games in the tests were displayed in landscape orientation, which disturbed people with the one-hand constraint. Several participants rotated the phone and held it in up-straight position so that it was more comfortable at the expense of coordination of information. Another drawback on touch interaction was, when the screen was large, people might find difficulty in reaching the point from one corner to another in diagonal position.

7.5 conclusion and improvements for next prototype

Two hypotheses were raised and examined in this user test. Participants were able to complete the tasks of analog input with the proposed prototype. Also, flexible interaction provided more engaging, involving, and interesting experience in interacting with digital contents.

Touch screen style interaction and flexible interaction were compared in the tests. Touch interaction is definitely an intuitive interaction style for it is based on seeing and pointing. However, several issues, such as the lacking of feedback, distance from the manipulated content, and the detaching with the immediate environment, were raised accordingly. The presented prototype of DUI, on the other hand, enabled the distribution of information into the space. That way, it is possible to build an interface that allows people to engage with the immediate space. Another aspect worth noticing is the force required in deformation. The downside of the force is that it gets people tired, which might result in difficulty in coordinating visual feedback and physical force input. Kildal et al. have conducted several studies in testing stiffness of materials wishing to determine optimal force required for DUIs (Kildal, Paasovaara, & Aaltonen, 2012). The upside is that the force and the perceived resistance bring more interaction with tactile feedback. It makes people feel more like controlling.

Being a physical representation of the hypotheses, prototypes were used as a medium to be tested to verify the assumptions. The implementation of the working prototype and test cases followed some of the design cues proposed in chapter 5. Through the user test, those design cues were examined as well. For example, positive feedbacks were gathered for the design cues of continuous input and the mapping of three dimensional control, while design cues regarding form factors appeared to be moderate. Since not all the design cues proposed were implemented, much opportunity for the next prototype is left. There are several improvements could be made in its physical form, interaction, and applications.

form

The major downside of the prototype was in the stiffness of the mobile model. Many participants complained that the prototype was too stiff to deform especially when constant force was required. In the next prototype, the material should be carefully chosen so that the deformation does not require much effort.

Another improvement resides in the form factor. In order to switch between different gestures, many users had to change the way of holding. The position of holding changed whenever the switching of gestures was required. This is especially demanding when force is obligatory to deform a device. The next prototype should provide sufficient affordance and a comfortable support for holding the device so that more freedom is given to the fingers to perform different gestures.

interaction

Since there are different mindsets among people, it would be beneficial to enable the customization of the gestures for users. A training session can be introduced into the prototype so that the behavior of the prototype matches with each user. Before using the prototype for applications, the training session allows users to perform all the basic gestures which will then be learnt by the prototype. The customized prototype matches the mindset of the user and a more intuitive interaction can be possible.

Moreover, only part of the device was utilized in the interaction. All the gestures required only fingers to deform the front part of the device. In the next prototype, more gestures can be developed so that the whole device can be used as an interface.

application

Since users have expectation in interacting with 3D content, there will be many opportunities found in 3D applications. DUIs could be further developed so that a stronger linkage can be made between the deformation and digital content which is presented in a virtual 3D space. For example, DUIs can be implemented in applications of 3D modeling. Moreover, it could be a great opportunity to combine and merge the 3D virtual content into the immediate environment where the users situate. It is possible to further extend the experience in augmented reality through flexible interaction. Note that, the content presented does not confine in visual information only. There are still contents utilizing non-visual senses, such as sound and tactile, that can be implemented as feedback or information carrier. The presented prototype platform consisting of a mobile device and separated information system gives freedom in interacting with and distributing information into the immediate space.


ID 2922
Test 0
Test 1
Cmd 0
Cmd 0
Cmd 1
Cmd 1

Conclusion 8

Chapter 8

In this thesis work, research through design method was adopted, and various design cues were derived for DUI design on mobile devices. A working prototype was implemented and tested with users. The results indicated that form factors play an important role in DUI design. In addition, physical deformation in DUIs results in more engaging experiences than touch screen interfaces. The achievements are illustrated in the following figure (See Figure 8.1).

Novel design approaches were established for developing applications in the new interaction style. After the identification of the research questions, the first design activity was constructing an experiment for exploring the form factors on flexible materials. Design cues of form factors were derived for flexible mobile device accordingly. The second was a workshop in which experts in design and engineering experienced a design process in developing applications of DUIs. Various concepts targeting at the thesis research questions were derived, as well as the prototyping of the concepts. The two research questions were preliminary answered by the experiment and workshop respectively. The last was the design and implementation of the working prototype which was followed by a set of user test. The prototype was a platform consisting of a mobile model and an information system which allowed the distribution of information in the space. Through the user test, the answers to the research questions were revealed.

In addition to the improvement mentioned in chapter 7, future possibilities could be examined from a strategic point of view. The prototype is able to be programmed according to different purposes, which

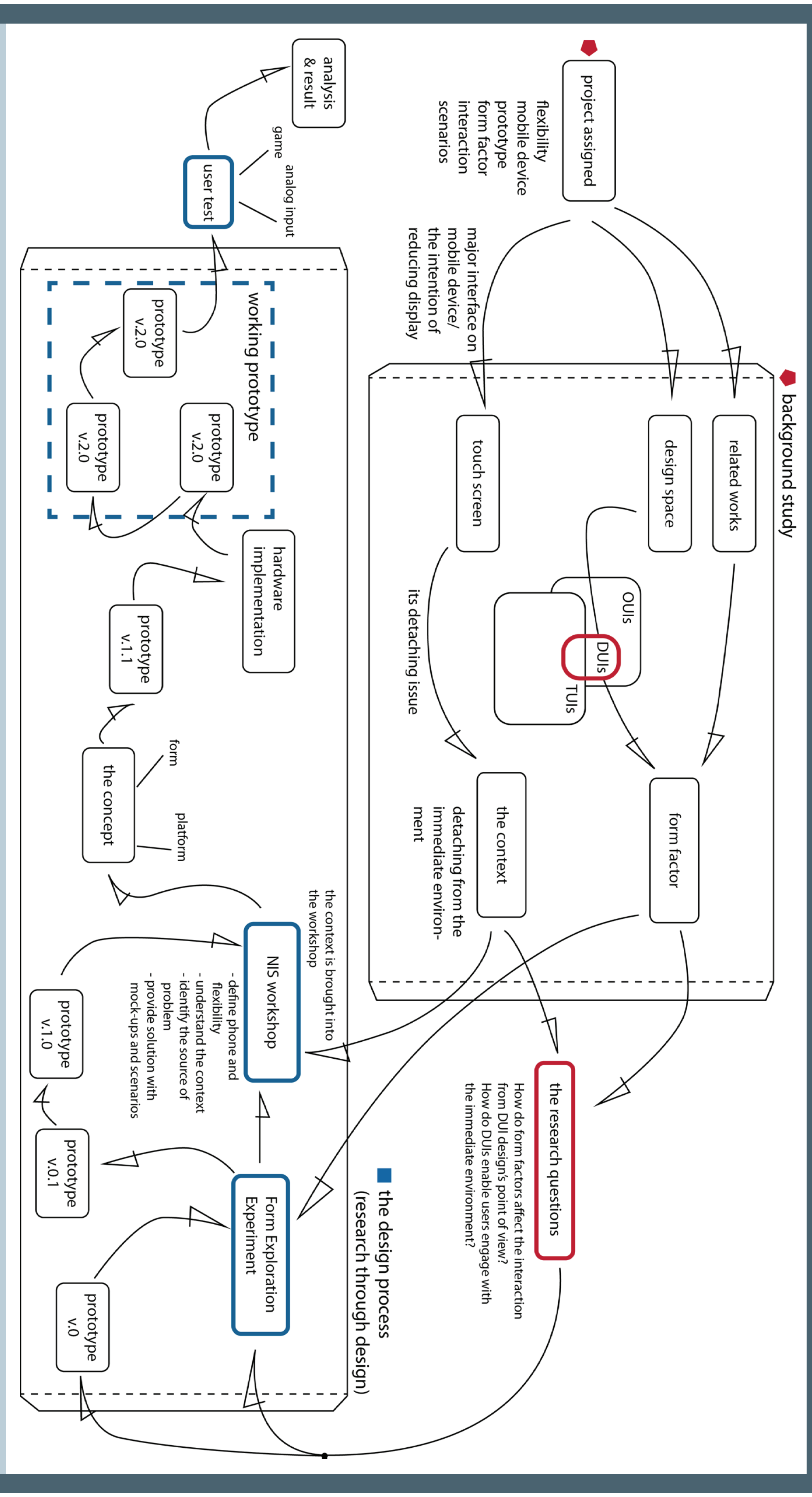


Figure 8.1 **The illustration of the thesis work**

means numerous applications can be built on the platform accordingly. For the purpose of engaging with the environment, the proposed platform has its advantage in distributed information and more engaging experience. However, to further encourage the engaging of the environment, it requires novel applications that are desirable to users, for example, location-aware applications dedicated for the immediate environment. These applications that are closely connected to the locale could provide a stage for DUIs to manifest its advantages. Users thus might be able to engage instead of detach with the space.

This work distinguishes itself from others by conducting a study without predetermined form factor as well as the focus on one-hand use cases, which is more intimate to practical conditions. Another point is that the prototype serves full mobility. There is no wire connected between the device and the computer servo. The benefit of this factor is that it allows more genuine mobile experience during user tests.

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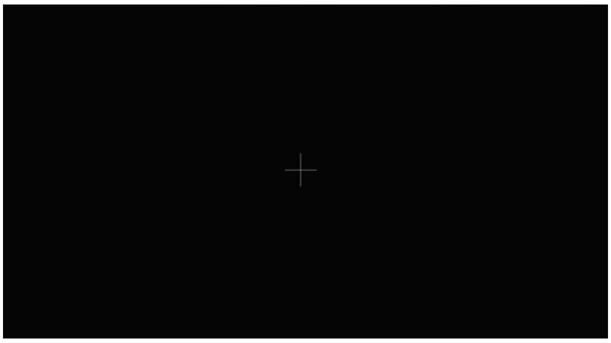
Appendices A

Appendix A: Movie Sequence

Screenshot	Description and duration
Scene 1. Geometric objects	
	A cross appears in the middle of the screen. 1.5 s
	Squares move and changes the sizes. 12.5 s
	Red balls bounce toward the users from far end. 9 s

Scene 2. Steady camera street view

Still street view. Information tags are attached on moving subjects.

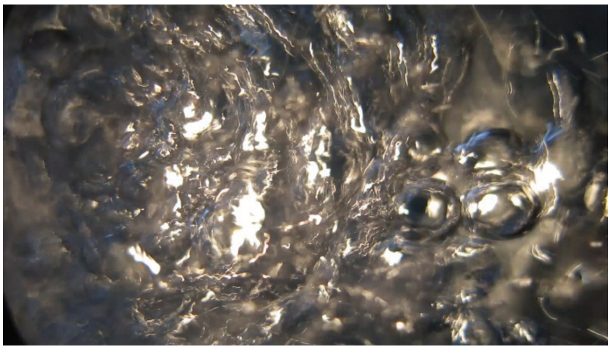
72 s

Scene 3. A first-person point of view navigation scene

First-person point of view, showing the view of a person walking on the street.

55 s

Scene 4. Abstract scene



Taken from the bottom of a jar with water poured in.

35 s

Appendix B: Test Sequence

	Analog Input				Game		
User1	A	B	C	D	CP	GD	SP
User2	A	B	D	C	CP	GD	SP
User3	A	C	B	D	SP	GD	CP
User4	A	C	D	B	SP	GD	CP
User5	A	D	B	C	CP	SP	GD
User6	A	D	C	B	CP	SP	GD
User7	B	C	A	D	SP	CP	GD
User8	B	C	D	A	SP	CP	GD
User9	B	A	C	D	GD	SP	CP
User10	B	A	D	C	GD	SP	CP
User11	B	D	A	C	GD	CP	SP
User12	B	D	C	A	GD	CP	SP
User13	C	A	B	D	CP	GD	SP
User14	C	A	D	B	CP	GD	SP
User15	C	B	A	D	SP	GD	CP
User16	C	B	D	A	SP	GD	CP
User17	C	D	A	B	CP	SP	GD
User18	C	D	B	A	CP	SP	GD
User19	D	A	B	C	SP	CP	GD
User20	D	A	C	B	SP	CP	GD
User21	D	B	A	C	GD	SP	CP
User22	D	B	C	A	GD	SP	CP
User23	D	C	A	B	GD	CP	SP
User24	D	C	B	A	GD	CP	SP
	A: T0C0, B:T0C1, C:T1C0, D:T1C1				CP: Chopper, GD: Guiding, SP: SpaceTunnel		

Note: Cells shaded in blue indicate that touch screen style interaction is test first, and then is the flexible interaction.

Appendix C: Interviewing Questions

1. Which kind of phone do you have?

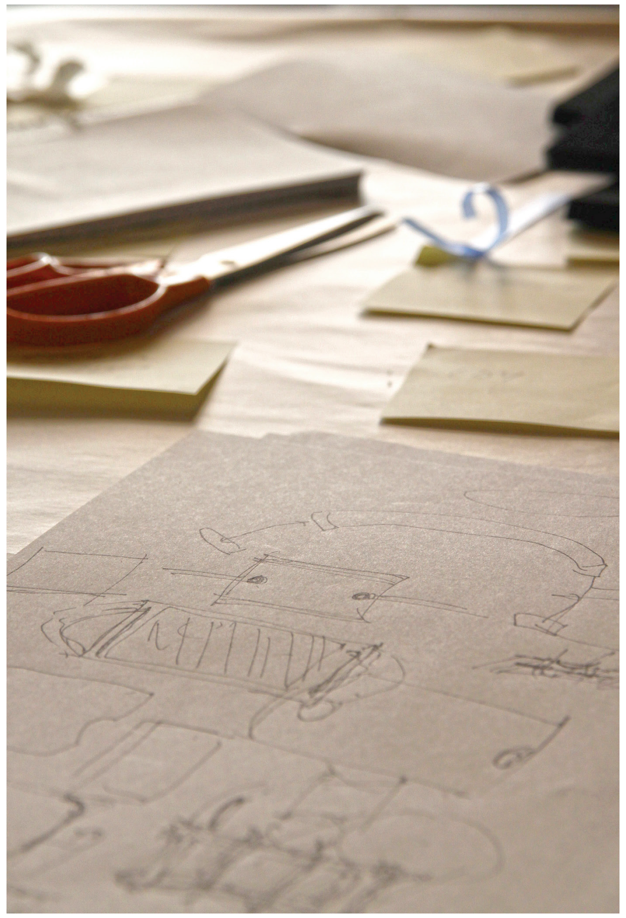
    a. Where do you use it?
    b. Do you carry it around all the time?
    c. Where do you usually keep it?
    d. How does it feel when carrying?
    e. How does it feel when using it?
    f. What do you mainly use it for?
    g. What is the most liked app?
    h. Do you share it with anyone?

2. Do you use it much to manage your life?

    a. What do you use the other applications for?
        i. Do you use it as a calendar?
        ii. Do you watch videos or listen to music?
        iii. Do you take photos with it?
        iv. Do you use it to share things with friends or family?
        v. Do you use it to keep to date with things? (news, social networks, email)
        vi. Do you use it to organise things with your friends or family?
        vii. Do you use it to do research or browse the web?
        viii. Do you use it for payments or shopping?
        ix. Do you use it for accessing places?
        x. Do you use it for controlling something at your home?
    b. Do you use it to play games?
        i. What kind of games?
        ii. How does the controls work with gaming?
        iii. How does the shape of the phone work with gaming?
        iv. Do you use it to play fast paced games?
        v. Do you use it to play slow paced games?
        vi. Do you play games that require you to shake or tilt the phone?

3. Compare touchscreen device and the deformable device.

   a. How did the touchscreen device work with sliders?
   b. What was the feel of the touchscreen device?
   c. How did the deformable device work with sliders?
   d. What was the feel of the deformable device?
   e. How did the devices work with games?
      i. Chopper game?
      ii. Guiding game?
      iii. Space tunnel game?
   f. How does the visual information and your interaction feel connected to each other, when using the touchscreen?
   g. How does the visual information and your interaction feel connected to each other, when using the deformable device?



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New Interaction Style

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