國 立 交 通 大 學

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碩 士 論 文

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摘要

隨著科技的進步，人們能以更自然的方式與系統互動，像是能夠揮動控制器來打棒球，或是直接用手拖曳旋轉螢幕上的物件。這些新的互動方式打破了過去只能用手指操作滑鼠鍵盤的使用經驗，讓使用者身體的其他部份也能夠參與互動，操作的行為也因此更貼近日常生活的習慣與動作。

在人機互動的領域，有許多相關雙手互動的研究，企圖藉由雙手的合作，讓使用更為方便、直覺、有效率。智慧型的手持裝置通常都具有許多感應器可供雙手操作，像是多點觸控螢幕、加速器感應...。人們也常常利用雙手來使用這些裝置，但目前的介面設計仍然十分缺乏雙手互動的考量。仍然以單手操作為主要的互動方式。在相關的研究中，關於手持裝置的雙手操作研究也十分少見。本研究的主要目的是針對這個議題，探討如何讓使用者能夠利用雙手與手持裝置互動。

本研究首先透過實際觀察同樣是雙手在空中進行任務的捏麵人。瞭解活動中雙手的分工，雙手各扮演的角色，雙手的手勢和治具(棍子)的使用方式。治具在操作和檢視人偶上，提供了捏麵人師父很大的幫助。藉由這些發現，在手持裝置上，本研究提出了五項設計準則與三個設計模式，並製作三個設計原型以進行後續的使用者評估。

基於使用者的評估，最後本研究提出了四項設計模式：(1) 透過治具操作立體物件。(2)雙手移位物件。(3)雙手放置物件。(4)傾斜裝置以翻頁。

本研究所提出的設計模式包涵了雙手互動介面中合適的雙手合作模式、介面隱喻與注意事項。並詳細描述了其可解決的問題、相對應的解決方法與範例。提供了手持裝置介面設計師具體且有彈性的設計建議。

關鍵字：雙手互動、手持裝置、介面設計

ABSTRACT

With the development of technology, the interaction with interface has become natural just like the interaction with real objects in daily life. The involvement of body in the interaction is also increased. In contrast with past interface that only consist of mouse, keyboard, or joystick, these natural interface give better experience to users.

In Human-Computer Interaction, many researchers and designers have presented manifold bimanual interactions in different platforms. But in mobile device interface, there is a lack of bimanual interaction in general functions although people usually use the mobile device with two hands, and the related research is also seldom. The aim of this thesis is to explore which kinds of interaction design are suited to the bimanual interaction in mobile device.

Through an exploratory study of a traditional Chinese handicraft – pinching dough dolls, the various perspectives of bimanual interactions, including cooperation, roles of each hand, and the usage of the jig, were investigated. Based on the findings, design guidelines for building natural bimanual interactions in mobile devices are developed, and related design patterns are presented to demonstrate the practical applications of guidelines. To evaluate the usability and acceptance, three different prototypes were built and tested in real context.

Finally, this thesis developed three design guidelines: (1) Pattern 1 3D Manipulation with Jig. (2) Pattern 2 Bimanual Relocation of Object. (3) Pattern 3 Bimanual Object-Placing. (4) Pattern 4 Tilting to flip the page with touching to use tools.

The design patterns include the appropriate bimanual cooperation, usage of metaphors, and the concerns for building bimanual interaction in mobile devices. They describe the application of design guidelines, including what kinds of problem that designers face, how to solve, and the examples of solutions. This study provides designer concrete and elastic suggestions and improves current mobile device interaction design.

Key Words: Bimanual Interaction, Mobile Device, Interface Design

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在應藝所是我求學過程中最愉快的時光，能夠認識這麼多好同學，有三年來總是一起修同樣的課，作同樣 project 的完美夥伴周神（希望還有在做夥伴的機會）。無償提供口試前住宿，幫我排解一切煩惱的廚友溫神。在論文上給我許多建議，多才多藝又貼心的可薰學姐。一起口試，在畢業前幫我補上臨門一腳的菁妏。帶領我進入應藝所，在論文中有感謝我的屁股。還有同是鄧老子弟兵，相互砥礪的佳志、陳姵、佳欣。

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TABLE CONTENT

FIGURE CONTENT

1. INTRODUCTION

In human daily activities, two hands nimbly cooperate with each other when people interact with objects. The hand's movements and gestures are manifold. In Human-Computer Interaction (HCI), the benefit of bimanual interaction has been studied in past research. Although the interaction in mobile device typically involves both hands and people have ability to use both hands to operate the mobile device, the interface restricts the collaboration of two hands. This thesis is concerned with investigating design guidelines of bimanual interaction in mobile device through exploratory study of human's daily activities.

1.1 Background

With the development of technology such as multi-touch screen and motion sensing technology, people could interact with interface naturally just like the interaction with real objects in daily life. People swing the controller to hit the baseball on the screen like swinging real baseball bat while playing games with Wii. Kinect™ of Microsoft allows player's whole body to be the controller. SixthSense (Mistry & Maes, 2009) lets user use natural hand gestures to interact with the information. In iPhone, people could scroll the contact list directly by finger instead of a scrollbar and the acceleration of the list would depend on how fast the finger moves. In these designs, the manipulation is natural, and the feedback is predictable.

These interaction styles are built on users' pre-existing knowledge of the physical world. They make people achieve their goals more easily (Jacob et al., 2008). Over the last few decades, researchers have developed many different methods to apply pre-existing knowledge to interface design. The desktop metaphor that consists of folder, file, trash can and etc are derived from the office environment (Agarawala & Balakrishnan, 2006).The gesture interfaces apply the hand's motion of communication to be the input modalities (Alpern & Minardo, 2003). Hinckley et al. (2010) have applied the bimanual interaction while people painting in physical world to develop a painting system.

When people interact with these natural interfaces, their body involves more than the "window, icon, menu, and pointing device" (WIMP) interface. The physical actions of body could facilitate the cognitive development through repetitive actions as known as motor memory (Klemmer, Hartmann, & Takayama, 2006). This kind of memory could help people distinguish different functions by differentiations in actions and appearance (Djajadiningrat, Wensveen, Frens, & Overbeeke, 2004).

Through the meaningful actions, users have stronger expression of each function. In addition, Klemmer et al. (2006) also showed the errors that can be reduced since physical behaviors are highly related to commitment and risks.

Hands are the nimblest parts of human body. They could cooperate to do complicated tasks such as writing, painting, and sculpting. In Human-Computer Interaction (HCI), many researchers have studied the bimanual interaction in virtual environment. Bier, Stone, Pier, and Buxton (1993) developed Toolglass widget that allows user to use both hands to control the tools in drawing task. It could reduce steps, cursor motions, and errors. Russell et al. (2005) demonstrated that performing a compound task, painting, with two hands is faster than one hand. These researches showed people not only nimbly use two hands in physical world but also collaborate well in virtual environment.

1.2 Motivation

The interaction of mobile devices typically involves two hands. Current smart phones are equipped with many sensors for bimanual interaction such as multi-touch screen and accelerometer. People have the ability to interact with them with two hands, for example, they use both hands to drive a car, shoot an arrow, or play labyrinth while playing games. But especially in general functions, the interfaces are still only designed for single hand. We believe that the bimanual interaction has potential in mobile device interface design. This thesis could support the designer to built bimanual interaction in mobile device.

The studies of bimanual interaction in mobile devices are seldom. Edge and Blackwell (2009) have investigated bimanual painting system with augmented reality in mobile phone. They allow user painting in 2D and 3D environment. Taylor and Bove (2009) have developed "The Graspables"; it is a box that could sense how user grasp it and provide corresponding function such as phone and camera. The aspects of bimanual interaction in mobile device need to be understood deeply and widely such as the cooperation of two hands, the input modality, and the usage of metaphors.

In order to develop natural interfaces, researchers would study the aspects of physical activity and physical interaction. Kruger, Carpendale, Scott, & Greenberg (2003) observed how people orient puzzle on table and brought up some implications on tabletop. Fitzmaurice, Balakrishnan, Kurtenbach, and Buxton (1999) conducted an exploratory study about supporting artwork orientation. They studied how people draw in physical world to develop a rotating UI in painting software. But in recent mobile device interaction study, this kind of study is seldom. The majority of researchers provided a concept design directly, and then demonstrated evaluation from user testing. (Bartlett, 2000; Wigdor, & Balakrishnan, 2003; Crossan, & Murray-Smith, 2004) The aspects of physical world are also an important issue while building mobile device interface.

To sum up, people deal with many tasks with both hands no matter in physical or virtual world. Although the sensor techniques in mobile devices have developed maturely, present mobile device interfaces seldom allow users use it with two hands. The results of this thesis would help designers develop bimanual interaction in mobile devices. In order to design a suitable and user-center interface, the exploratory study of human's daily activity could be also contributory in mobile device interaction design. We focus on this method and make this area more complete.

1.3 Objectives

The main purpose of this thesis is to develop guideline for mobile device interface that allow bimanual collaboration. We explored what should be concerned when people use both hands to interact with mobile devices from daily human's actions first. From the observation of bimanual actions in daily life, we could define the collaboration patterns and roles of each hand. This pre-existing knowledge could help us address some implication of mobile device interaction design in future.

In sum, the goals of this thesis and the related issues are listed as follows

1. **Realize how two hands cooperate with each other in human's daily activity.**

   To this end, the following issues were posed:

   (1) Which kind of activity is appropriate?

   (2) The context of the activity.

   (3) Patterns of bimanual collaboration.

   (4) The roles of each hand in the activity.

2. **Develop guideline of bimanual collaboration for mobile device.**

   To this end, we should concern:

   (1) How to apply the knowledge of bimanual collaboration into mobile device interface?

   (2) Which kind of task in mobile device is appropriate?

   (3) How users feel about these new interaction styles?

1.4 Thesis Structure

We have organized the rest of this paper in the following way: Chapter 2, literature review, describe the theoretical foundation of bimanual action, the frame of activity analysis we adopt, the strategy of designing an intuitive interaction and the introduction of design pattern. Chapter 3, methodology, presents the research structure and the methods of each research activities. Chapter 4, the observation data of activity is analyzed and interpreted. Chapter 5, this study develope the design patterns for mobile device and presents the method of development. Chapter 6, the method of user evaluation is described. Results of user evaluation are analyzed and used to modify the guidelines. We wrap up this thesis in Chapter 7 with conclusions based on our findings and with a discussion and future vision that are based on the implications of our findings.

2. LETERATURE REVIEW

This part on literature review started with related works in HCI and a theoretical foundation of bimanual collaboration in Section 2.1. Section 2.2 described methods and theory that used to study human's activity. In Section 2.3, we confirm the scope of our implication for gesture design, and introduce methods of developing gesture interface. In Section 2.4, the study of metaphor help us know how to build a familiar system to user. Section 2.5 introduced the usage of design pattern in HCI and how design patterns help designers to solve problems.

2.1 Bimanual Action

2.1.1 Related Works in HCI

Bimanual interfaces allow user to use both hands to complete tasks in computer. The bimanual actions could be asymmetric and symmetric. Asymmetric bimanual interaction means two hand play different roles in activities. Many researchers developed different ways of interaction in different platform (Table 2.1). In mouse-based environment, Buxton and Myers (1986) distributed positioning/scaling and navigation/selection tasks to two hands and two devices. They found that users perform positioning and scaling sub-tasks simultaneously. In navigation/selection task, two-handed manipulation significantly outperformed one-handed no mater novices or experts.

Yee (2004) implemented a painting application supporting pen and touch input in tablet. Users use left hand to move canvas and right hand to draw. Through informal study, users feel comfortable with the bimanual interaction when the non-dominant hand play the simple action. Chen, Koike, Nakanishi, Oka, and Sato (2002) assigned different roles to each hand. Users used right hand to draw and to manipulate objects and used left hand to select functions on the menu.

Edge and Blackwell (2009) developed a framework to investigate the relationship between control and representation. They used painting metaphor and presented four kinds of bimanual interaction with augmented reality techniques. Users hold different devices with each hand. Dominant hand drew in the space. Non-dominant hand controlled the virtual canvas on the screen.

Table 2.1 Past asymmetric bimanual interaction study

Reference	Tasks (Dominant hand / Non-dominant hand)	Controllers	Device
Buxton and Myers (1986)	■ Scaling/positioning ■ Selection/ navigation	■ 2 physical controllers	PC
Chen et al. (2002)	■ Draw & object manipulation/ selection of functions	■ 2 virtual tools	Surface Computer
Yee (2004)	■ Draw/Moving Canvas & Selecting tools ■ Positioning object / Moving and scrolling windows	■ Pen & touch	Tablet
Edge and Blackwell d (2009)	■ Draw / Moving Canvas	■ 2 mobile devices ■ 1 mobile device with camera	Mobile phone

In contrast, symmetric bimanual interaction is that each hand is assigned same role. For example, zoom function in iPhone allows users stretching the display with two fingers of each hand. Casalta, Guiard, and Beaudouin-Lafon (1999) provided a symmetric rectangle editing task. They let two hands position two opposite corner of rectangle. They found symmetric way resulted in better performance than asymmetric way.

In above studies, there are two main kinds of bimanual interaction. The first kind is that two hands control different physical or virtual objects and functions separately, for example, one hand draws and the other hand move canvas. The second kind is to distribute subtasks of a task or a function to two hands, for example, one hand selects the function and the other hand executes. In the rest of this study, we will focus on these two kinds of collaboration in the exploratory study and investigate more kinds of division of labor.

Besides, the metaphors used in aforementioned studies are mostly desktop or painting desk. The environment and objects that user interacts with is 2D. There should be more kinds of metaphor could be applied in mobile device.

2.1.2 Theoretical Foundation - Kinematic Chain Theory

In the above studies about bimanual actions, Kinematic Chain theory (Guiard, 1987) is the theoretical foundation. They have studied bimanual actions like handwriting, violin playing, sewing and others. There are three main characteristics of the KC model as follow.

1. Spatial Reference: The non-dominant hand provides a spatial frame of reference for the dominant hand's action. Non-dominant hand often plays a postural role in keeping objects which dominant hand performs actions on steady.
2. Spatial Scale: The dominant hand could do finer movements than the non-dominant.
3. Temporal: The dominant hand would do the manipulative action after non-dominant. Non-dominant would fix the objects which dominant hand performs actions in place first.

Guiard considered hand as an abstract motor. Motors change the position of object from reference position (RP) to variable position (VP). The collaboration of hands could be described as the assembly of tow motors. There are three kinds of assembly (Figure 2.1):

1. Orthogonal assembly: Two motors (hands) act on the same objects and separately control two dimensions of its motion that are orthogonal to one another. The output of each motor is independent. This kind of bimanual action is asymmetric.
2. Parallel assembly: Two motors act the same dimension of motion. For example, when people lift weight, they raise both hands in the same direction. The reference position and variable position are the same in this assembly. This kind of bimanual action is symmetric.
3. Serial assembly: Two motors act on the same dimension(s) of motion, and the output from one motor serves as the input of the other.

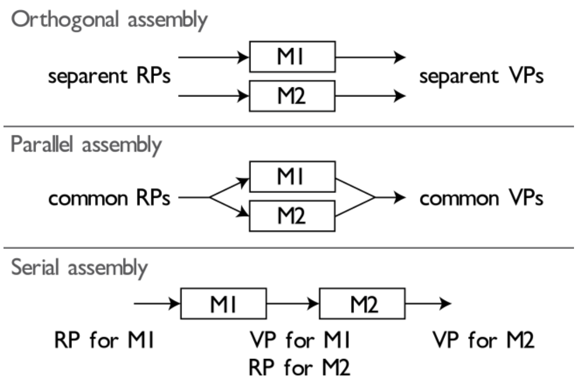


Figure 2.1 Three kinds of assembly. From "Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model," by Y. Guiard, 1987, *Journal of motor behavior*, 19(4)

The kinematic chain theory provided a clear definition of bimanual collaboration. In this study, the descriptions of the bimanual interaction in the exploratory study are based on this structure.

2.2 Study of Human's Activity

People take many actions in daily activities, such as to complete a task, or to finish a job (Nardi,1996). Actions have different meaning in different activities. It's important to realize why people take particular action through study of the activity they did. This section focused on the research method of human's activity and the theoretical foundation.

2.2.1 Research method

Observation is one of methods used to study human's activities. It is widely used in human-centered design. Researchers observe people in-field or in laboratory by shadowing, contextual inquiry, recording, and etc. For example, IDEO used observation in the early stage of design. Their designers observe real people in a real-life situation to explore the need and problem of users and the context where users are. (Kelley, Littman, and Peters, 2001) They also ask users to record their self by probe, diary, and etc. In past study, researchers have demonstrated implications of interface design based on observations of human's activities, in order to make the interface more natural to users (Fitzmaurice et al, 1999; Kruger et al., 2003; Terrenghi, Kirk, Sellen, & Izadi, 2007).

2.2.2 Analysis Method

Beyer & Hohzblatt (1998) developed contextual inquiry to understand human's activities. Researchers not only observe human's work in their work space but also conversation to them to get the past experience. Then they used affinity diagram to analysis the data. All the statements would be wrote down and categorized. And Beyer & Hohzblatt (1998) also developed work models to analysis human's work or activity. Work models consist of five models:

- Flow model – This model describe the communication between the members in an activities. It is used to understand the coordination, strategy, roles, and information structure.
- Sequence model – This model describe the steps used to complete a work. It is used to understand the triggers, intents, hesitations and errors during these steps.
- Artifact model – This model present all artifacts used for working. It focuses on the structure, information content, annotations, and presentation of artifacts.

- Cultural model – This model shows the influence that affect people. It focuses on the policies and organizational influence.
- Physical model – This model depicts the environment where people work. It focuses on the organization, division, and movement in the environment.

The activity theory is used to be the theoretical framework for describing the context of human activity in HCI field (Nardi,1996). According to this theory, user wants to achieve an objective in activity. And they could use the tools to achieve it. Objects and tools could be concrete or abstract. Tools, as mediations, are used to aid the object transiting into an objective. User could use to tools to manipulate and understand the object.

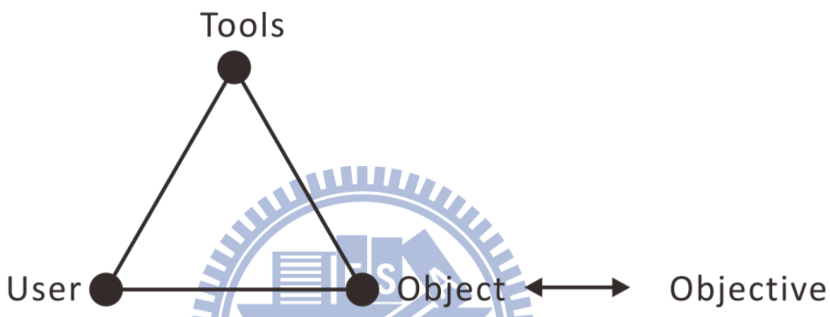


Figure 2.2 Relationship among four aspects of activity theory.

An activity consists of actions or chains of actions that related to each other by the same object and motivation. It can be defined in different levels: activity, action and operation which correlate to motivation, goal, and condition. Actions are planned consciously and have an immediate and defined goal. Actions can be broken in chains of operation. Operations are well-defined routine that address particular condition during the execution of action.

2.3 Gesture

In WIMP interface, the mental model of interaction with interface is only the fingers and eyes. But in daily life, people perform manifold gestures when they discourse with other people or interaction with objects. Gestures are defined as the "body movements" that use in communication with people (McNeill, 1992) and manipulation of objects (Fikkert, 2010). Users could interact with computer by using gesture because of the improvement of sensing technology. In HCI, the body movements consist of a motion of the hands, facial expressions, head movements, hand postures and whole body postures (Saffer, 2009).

2.3.1 Gesture Taxonomy in HCI

Generally, there are two main kinds of gesture; one is used to communicate with other people; the other is used to manipulate objects (Mulder, 1996). Kipp (2005) identified two classifications in daily communication gesture: non-communicative and communicative. According to the functions of gesture, Cadoz (1994) provided three classifications. Semiotic gestures are used to communicate meaningful information. Erogotic gestures are associated the human manipulation with artifacts. Epistemic gestures are exploratory motions that help human learn from physical world.

In HCI, Karam and Schraefel (2005) focused on the process of interacting instead of communication. He defined five classifications: deictic, manipulative, semaphoric, gesticulation and language.

- Deictic gesture: deictic gestures involve pointing to confirm the spatial or identity position of an object.
- Manipulative gesture: Quek et al. (2002) provided a definition of manipulative gesture as mapping the actual movements of the gesture hand/arm to the movements of the object in the interface. This type of gesture often requires the visual, force-feedback, or haptic feedback from the object being manipulated. User could interaction with physical objects to manipulate digital objects, such as rotate the doll's head to manipulate head in MRI interface. (Hinckley, Pausch, Proffitt, & Kassell, 1998)
- Semaphoric gesture: Quek et al. defined semaphoric gesture as "any gesturing system that employs a stylized dictionary of static or dynamic hand or arm gestures." For example, user used numeric gestures (one through five) for navigating the interface (Alpern & Minardo, 2003), and there are many mouse gesture plug-in in browser e.g., All-in-One Gestures.
- Gesticulation gesture: This is directly related to content of the speech. It is the most nature gesture.
- Language gestures: language gestures are used for sign languages. They consist of a series of individual signs or gestures that combine to form grammatical structures.

This study would focus on the manipulative gesture. The feedback and the relation between manipulation and virtual object are the important issues.

2.3.2 Gesture Interface Design

Same gesture has different interpretation in different context. When researchers build a gesture interface, they often used user-defined method to define the relationship between gestures and functions in past study (Bhandari & Lim, 2008). Researchers showed how each function works to participants; participants need to select or create gestures to achieve the function. In the procedure of user defined experiment, Nielsen, Storring, Moeslund, and Granum (2004) used scenario that the application implements in.

The general usability principles are important for the gesture interface design, such as learnablity, effectiveness, efficiency. In addition, Saffer (2009) provided the characteristics of good gestural interface in his book:

- Discoverable: Easy to know where could interact with.
- Trustworthy: Safe and respect users' privacy.
- Responsive: Clear feedback after manipulation.
- Appropriate: Considerations of the culture, situation and context where the design is used.
- Meaningful: Fulfill users' need.
- Playful: Relax and less error.
- Pleasurable: Good look and feel.

2.4 Metaphor

Metaphor provides a framework that allows the user applying the knowledge from a familiar area to an unfamiliar area and enable users use their pre-existing to deal with a new situation such as an interface. (Carroll & Thomas, 1982) It provides the scaffolding for user learning how the interface works. (Bruner, 1960) From active learning theory (Carroll & Thomas, 1982), users retrieve some known knowledge based on the surface similarity. Through the interaction with the system, they understand more about the mapping between the source and target domain by context of use and their goal. And they form a representation of system finally.

Norman (1988) built a framework of the interaction among the designer, user, and interface. The designer's conceptual model is comprehension of how the system works and used to build the system. The user's mental model is the representations of how the system works. The user's model is constructed by interacting with objects, people, environment, etc. Designers want the user's model could consist with the designer's model. And designers only communicate with user through the system image. In model of the user interface (Figure 2.3), metaphor could be the bridge between the designer's model and user's model.

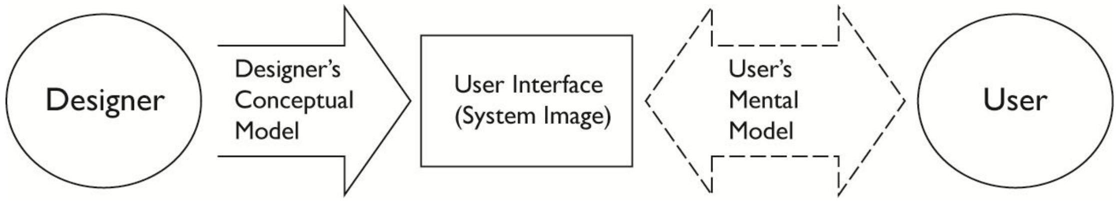


Figure 2.3 Framework of the interaction among designers, user and interface. From *The psychology of everyday things,* by D. A. Norman, Basic Book.

2.4.1 Metaphor Classifications

Many researchers have provided various classification of metaphor. Marcus (1994) identifies two distinctions in user interface metaphors: organization and operation. Organization metaphors consist of structure, classes, objects, attributes of system. Operation metaphors are the action that users could do.

Hutchins (1989) has provided a classification of metaphor based on different level of interaction:

1. **Activity metaphor** refers to the users' highest level goals. It is about the intention related to the outcome of interaction. For example, what the user does could be creating an artifact, cooperating with people, or doing an exercise.
2. **Mode of interaction metaphors** concerns the relationship between the user and the computer. These metaphors are task independent and determine what kind of things the user views the computer is, such as a band, a toolbox, a car, and etc.
3. **Task domain metaphors** enable users realize how tasks are structured.

2.4.2 Methodology of Developing Metaphors

When designer develop metaphors for a system, system functionality must be identified first. (Erickson, 1995) User's need and the capabilities of the system should be concerned.

Then designer generate possible metaphors. They could be tools and artifact in physical world (Carroll, Mack, & Kellogg, 1988), such as the most famous "desktop" metaphor in computer. From the existing metaphors that user is already familiar with, designer could apply some appropriate aspects to new metaphors such as the buttons and menus metaphor are used in many windows application. (Smyth, Anderson, & Altyc, 1995) Because user have already used before, they would learn the new metaphor easily. In addition, Idea sketching is a method to generate metaphors. The metaphorical words inspire designer to sketch metaphors for new systems. (Neale & Carroll, 1997) To realize the user's work context is another way to generate metaphors. (Marcus, 1994) Contextual inquiry or interviewed could be applied.

Next is evaluating metaphors to choose the most appropriate one. Carroll et al. (1998) presented a scenario-based method. The scenario concerns about the goals, procedures, and appearance (Table 2.2). By scenario-by-scenario comparison, designer could indentify matches and mismatches between source and target domains.

Table 2.2 The scenario for evaluating metaphors.

Tasks	What people do and their goals
Methods	Procedures, actions and objects
Appearance	Look and feel

From "Interface metaphors and user interface design," by J.M. Carroll, R.L. Mack, and W.A. Kellogg, 1988, *Handbook of Human-Computer Interaction*

Metaphor could help user deal with unfamiliar situation by applying their pre-existing knowledge. This study would investigate the usage of metaphor in different level of interaction. The past study has demonstrated that the goals, procedures, and the appearance need to be concerned while applying metaphors.

2.5 Design Pattern

Alexander (1977), an architect, defines "Pattern" as a description of good practices to a design problem within appropriate context. In architecture, patterns were originally created by inhabitants but not by architects. They are used to address the "forces" (design tensions) or interests (Borchers, 2001). Patterns are influenced by culture, time and environment. (Alexander, 1979)

In Human-Computer Interaction, patterns also could be used to description the good practice. The initial definition of interaction patterns are presented in the workshop of ChiliPLoP'99.

"An Interaction Pattern Language generates space/time interaction designs that create a system image close to the user's mental model of the task at hand, to make the human-computer interface as transparent as possible." (Borchers, 2000)

Patterns define a context the user involve, a problem of designer, the solution, examples and some suggestions. The items of suggestions are based on different type of design and their needs. (Tidwell, 2005) In the workshop of ChiliPLoP'99, they also define three main dimensions of problems that pattern address:

1. **Levels of abstraction**: complete task, style of the interaction, and physical or virtual objects.
2. **Function:** perception, manipulation, and navigation.
3. **Physical Dimension**: spatial layout, sequence of tasks, and reaction time.

The patterns are good form to express design guidelines and are more concrete than design guidelines. In contrast with toolkit, patterns are more elasticity, they let designer could think more outside the toolkit. (Borchers, 2001)

In practice, patterns could improve habitability of user interface, website, and etc. Patterns provide a quick way to designer; let them realize the different solutions of a design problem in varied context. By using patterns, the design could be more understandable, pretty, usable, and etc (Tidwell, 2005). Every design group could use pattern to describe the best practice they found and share with group members or other people. In this study, design patterns were used to demonstrate the application of design guidelines. The format of design pattern is based on past studies.

2.6 Summary

We have shown how symmetric and asymmetric bimanual interactions are applied in interface design. Each hand plays different roles to complete tasks. They manipulate different physical controllers or virtual tools on the screen. This thesis focuses on asymmetric bimanual interaction with the sensing technology in mobile device. The analysis of bimanual interactions is based on Kinetic Chain model. In this model, each hand is a motor. There are three kinds of assembly of them: orthogonal, parallel and serial. This concept defines the possible coordination of two hands.

Besides the actions of two hands, this thesis is also concerned with activities related to movements. Observation is a common method to study human's activity. In contextual design, work models are a well-structured way to analysis the observation data. The three level of an activity in activity theory would also support the analysis.

Gesture interface allow people use their whole body to interact with computer. In HCI, gestures are categorized as deictic, manipulative, semaphoric, gesticulation and language. In the remainder of this work we will look at manipulative gesture. This kind of gestures manipulates objects and need feedback. When users use gestures to interact with a system, the meaning of gestures is depend on the context. Designer must design appropriate gestures for appropriate context.

Metaphors enable users to use pre-existing knowledge to address unfamiliar interface. Metaphor design could apply to activity, interaction, and task domain. Users have different levels of interpretations depends on the domain that metaphor apply to. Metaphors are used in visual, organization, operation, and etc. This thesis will look at visual and operation metaphors. In procedure of developing metaphors, designers define the users' need and the function of system; then they generate possible metaphors. Last, the most important thing is to indentify matches between source and target domain.

In this thesis, design patterns are important ways to explain the design guidelines. In HCI, patterns define a context the user involve, a problem of designer, the solution, examples and some suggestions. Patterns have been used to address problems in different levels and parts of interface design. This thesis would choose an appropriate form of pattern to explain the design guidelines for bimanual interaction in mobile devices.

3. METHODOLOGY

In order to discover what aspects of physical world and physical interaction could be applied in mobile device interaction design. The process consists of two stages. First, an exploratory study was conducted to identify the role of each hand and patterns of collaboration through observation of the manual actions in physical world. Second, we presented guidelines in mobile device interaction design. Then, we employed a user evaluation to modify guidelines (Figure 3.1).

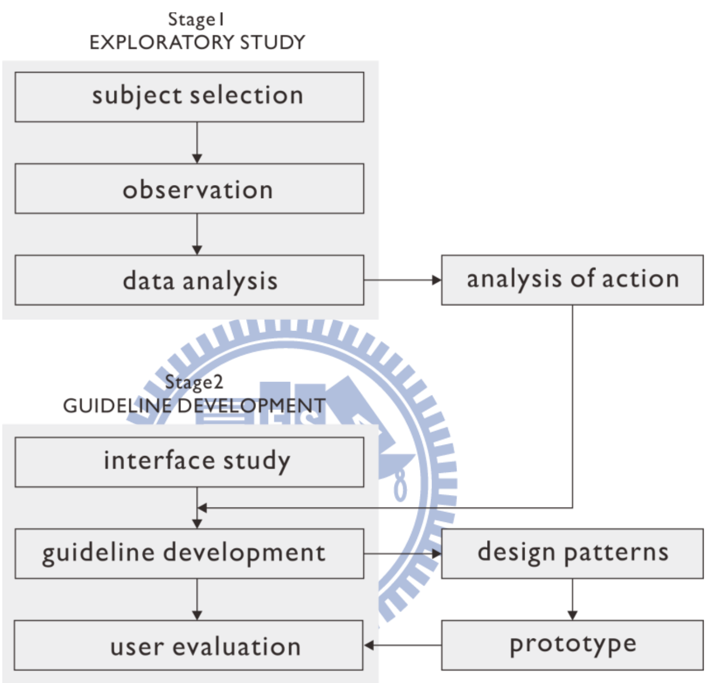


Figure 3.1 The research structure of this thesis.

3.1 Exploratory Study

In order to gain insight into how two hands cooperate with each other, we conducted an exploratory study of a Chinese traditional handicraft - **pinching dough dolls.** We recorded whole process of each subject and performed an in-depth video analysis. The inspiration for this method was based partially on some similar research that applies the aspects of physical world and physical interaction to design. (Fitzmaurice, Balakrishnan, Kurtenbach, & Buxton, 1999; Guiard, 1987; Kruger et al., 2003)

3.1.1 Selection of Subject

To investigate aspects of physical world and make interfaces more meaningful and useful, some researchers observed activities that are similar to virtual activities in the real world. For example, the study of orientation and collaboration on the table could be applied to tabletop interface design (Kruger et al., 2003). People always use the mobile device without support for arms. So it is appropriate that the activity we observed consists of manifold bimanual interactions without support for arms. The hand's movements are more similar. In traditional Chinese handicrafts, the handicraftsman performs manifold skilled hands' actions. Handicraftsmen use their hands or tools to interact with the object they held. This kind of bimanual interaction is similar to the interaction with mobile devices. After wide reviews of Chinese handicrafts, there are four kinds of handicrafts that handicraftsman works without support for arms: embroidery, pinching dough dolls, paper-cut, and weaving grass. Then we classified three main attributes for comparison: (1) *freedom of hands,* the amount of kinds of manual actions and the range of hand movement, (2) the dimension of *objects* they made, and (3) whether they use *tools* or not (Table 3.1).

Table 3.1 Comparison among different handicrafts.

	Embroidery	Pinching Dough Dolls	Paper-Cut	Weaving Grass
Freedom of hands	Medium	High	Low	Medium
Objects	2D	3D	2D	3D
Tool	Y	Y	Y	N

As table 3.1 showed, in pinching dough dolls, the hands' actions are freer and more manifold. Handicraftsmen rotate and move the object both in 3-axis like interaction with mobile devices. The object they made is 3D and the most complicate. People use many kinds of tools to help them pinch. This activity contains more kinds of manual actions than other handicraft. So we choose pinching dough dolls to be our subject.

3.1.2 Procedure

We did observation in the real environment where subjects used to pinch dough dolls. First, each subject placed all tools and dough on the table.Then they made several dolls and showed their skills as much as possible. The whole process would be recorded by video camera; we focused on two hands' actions and interactions with tools and dough. After they completed, we reviewed the video tape and asked them some questions if the role of each hand changed. Final, we asked them the benefit of the stick, how they use each hand, and how they arrange the tools on the table.

3.1.3 Qualitative Video Analysis

We marked the actions of each hand in the video. Then we built sequence models to analysis this activity. Beyer and Hohzblatt (1998) produced five working model – culture model, flow model, sequence model, physical model, and artifact model – to completely describe the context of works as a contextual design method. Sequence model reveals the strategy, intent, step, and breakdown of a work. Our research focuses on the bimanual collaboration. In order to clearly analysis the motivation, goal, and breakdown of every action and the temporal issue of collaboration, we combine sequence model and the activity's three levels in activity theory. Steps in sequence model consist of actions of each hand. We would reveal goals and operations of these actions.

3.2 Guideline Development

3.2.1 Study of Appropriate Tasks on Mobile Device

In order to realize what kinds of tasks in mobile device are appropriate for our study. We collected different gesture designs in present mobile devices. Then according to the goals of the task, the tasks that are similar to the tasks in pinching dough doll would be selected. The gesture and visual feedback of them would be analyzed.

3.2.2 Guideline Development

Depending on the finding of exploratory, we developed design guidelines for the appropriate tasks. To explain the practical application of design guidelines, several design patterns are built. The patterns consist of the problem designer faced, the context of usage, and the interaction.

3.2.3 User Evaluation

In order to modify the design pattern and realized the concerns of bimanual interaction in mobile devices, we conducted user evaluation. The design of prototype and whole procedure will be described in Chapter 5.

4. EXPLORATORY RESULTS

This chapter described the process and bimanual actions of pinching dough dolls from exploratory study.Through critical analysis of these actions, we have identified roles of each hand and benefits of the stick that is a very distinctive jig in this activity

4.1 Overview of Pinching Dough Dolls

Like many kinds of sculptures, pinching dough dolls is that handicraftsmen make a doll by hands and tools. But the most distinguishing feature of pinching dough dolls is that handicraftsmen need to hold a stick to help them made the doll. Traditionally, the dough is made by rice and flour. And recently, it is made by resin. This kind of dough has very good malleability and viscosity and poor elasticity, so handicraftsmen could shape it very easily.

The main tools in pinch dough dolls are (1) the **hairpin made by bull horn** is used to carve, raise, and pierce the dough; (2) the **scissor** is used to made fur or clothes; (3) the **comb** is used to make parallel line, such as hair or beard; (4) the **brush** is used to paint some decorative patterns. (Figure 4.1)

Figure 4.1 Tools in pinching dough dolls. From "民俗技藝~捏麵人", 月英, 2004, http://163.20.14.1/~offic-fu/other/3344cake/title.htm.

4.2 Subjects

We observed three participants and one series of films on YouTube (Table 4.1). Three participants are right-handed. U1 is a professional handicraftsmen. He pinches dough dolls for wholesale. The speed is the main issue which he concerns for. He is used to hold the stick by left hand and pinch by right hand. He made three dolls – parrot, cat, and zombie – with the stick and a panda without the stick. U2 is a novice which had learned pinching dough for one year. He is used to hold the stick by left hand and pinch dough by right hand. Because he wasn't very familiar with stick, he often needed to put the stick way and pinched dough with two hands. U3 is a professional busker.

She has a very special habit. Her left hand is responsible for pinching dough; right hand is responsible for use tools e.g., hairpin, pen. U4 is a series of tutorial film on YouTube. He held the stick by left hand and pinch by right hand.

Table 4.1 Subjects.

	Gender	Skill	Habit	Object
U1	Male	Expert	Right hand-Pinch Left hand-Stick holding	Parrot, Cat, and Zombie
U2	Male	Novice	Right hand-Pinch Left hand-Stick holding	Spiderman, Robot
U3	Female	Expert	Right hand-Stick holding & Tool Using Left hand-Pinch	Monkey
U4 (from YouTube)		Expert	Right hand-Pinch Left hand-Stick holding	Tiger, Sheep

4.3 Sequence Model

From consolidated sequence model (Figure 4.3) of all subjects, the process of pinching dough dolls consists of three main stages: **Parts Preparation, Parts Assembly**, and **Posture Adjustment and Detail Sculpture.** For example, the participant kneaded the dough to make a leg and then put it to the doll. Then he/she bended the leg to make particular posture (Figure 4.2). We present separate analysis of the bimanual action in these stages as follows. In analysis, the hand that holds the stick is named "holding hand" (HH) and the other hand is named "free hand" (FH). Due to the differences of each subject, we presented views of the data for individual subjects rather than summarizing across all subjects.

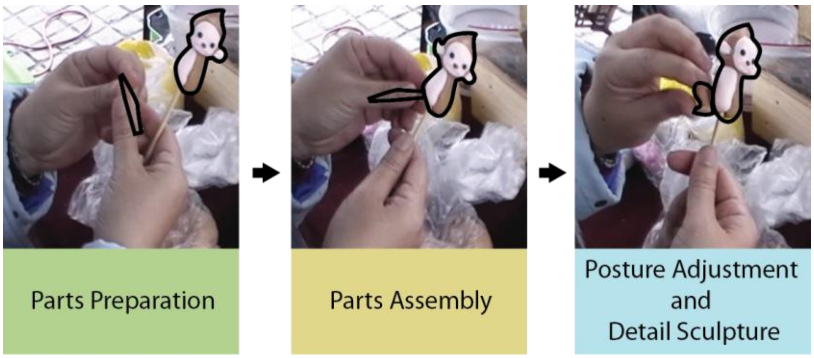


Figure 4.2 Procedure of making a leg.

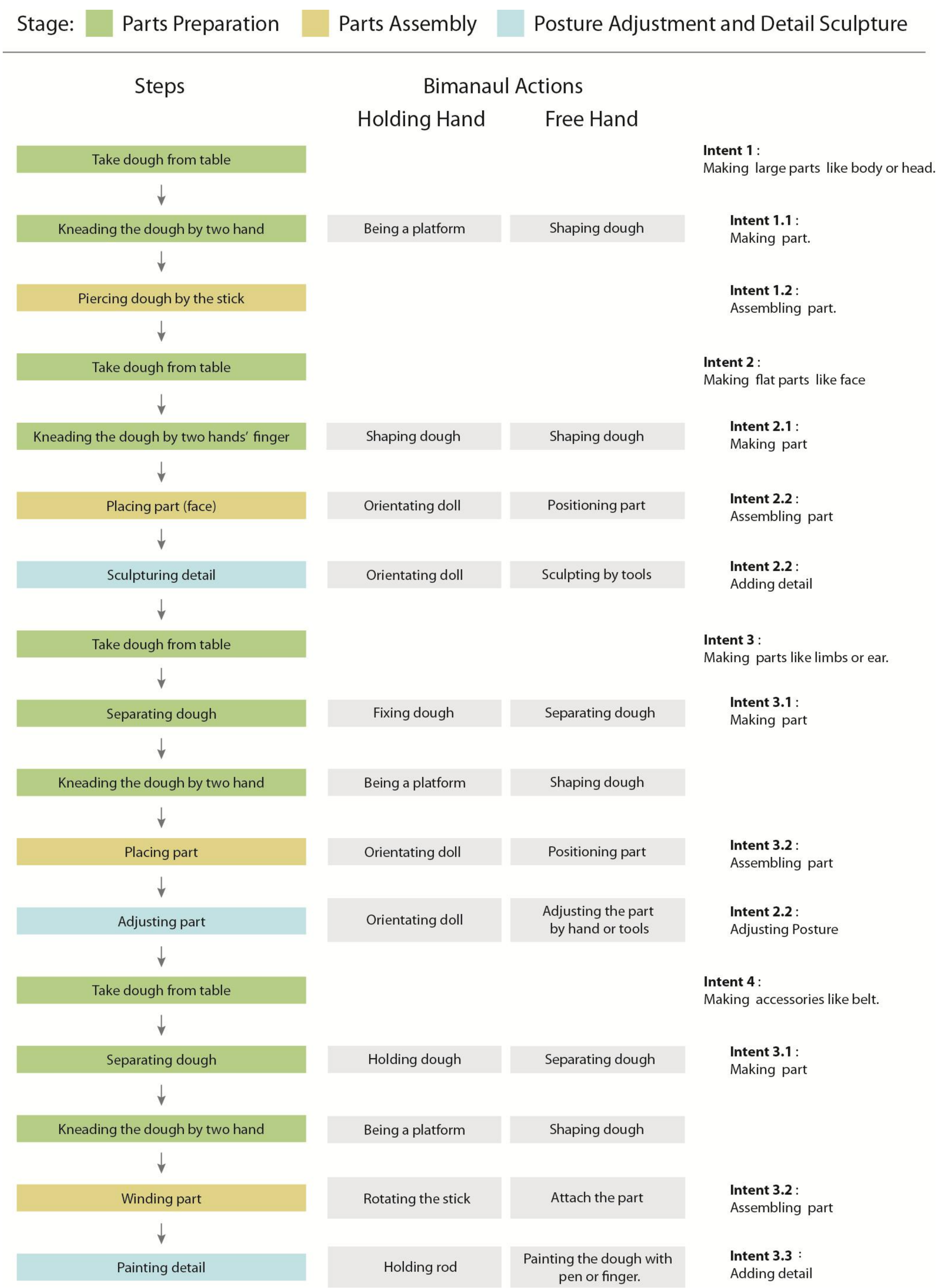


Figure 4.3 Consolidated sequence model.

4.3.1 Parts Preparation

In this stage, subjects took little piece of dough from table first; they adjusted the size of the dough appropriate by taking some piece off. Then they shaped the dough by kneading it. There were many different types of parts e.g., big, small, ball, rod, single, pair. The bimanual actions were different when they made different types of parts. There are two main kinds of bimanual actions as following. (Table 4.2)

Kneading with two hands

To make flat parts e.g., face, clothes, two hands need to collaborate with each other. The experts could use holding hand (U1 used left hand, U3 used right hand) to hold the stick and collaborate with the free hand in meanwhile. (Quote 1) This action could increase the efficiency because participants could put the part on the doll immediately after they finished it. In contrast, the novice need to put the stick away and kneaded the dough with two hands. After the part is finished, he needed to take the stick and then put the part on the doll. This kind of bimanual action is similar to parallel assembly. Two hands' actions are symmetric.

[U3] *When she made face of the monkey, she kneaded the dough with two hand's fingers. Left hand held the stick in meanwhile.* **(Quote 1)**

Kneading with one hand

When size and shape (ex., ball, rod, or drop) of the object were appropriate, subjects would use free hand to knead dough on the holding hand's palm. After subjects finished the part, they could quickly put the part on the doll. (Quote 2)

[U1] *When he made limbs of the cat, he took a piece of dough from the dough on table, and then used right hand to knead dough on left hand's palm.* **(Quote 2)**

When the part was very small and more than two such as ears and eyes, some subjects would hold stick and dough simultaneously. So after free hands finish and place a part, it could quickly take some dough from the hand holding stick to make second one. (Figure 4.4) Most of subjects used left hand to hold the stick and dough. Only U3 used right hand because her habit. (Figure 4.5)

Figure 4.4 Making ears of the cat (Left hand held the stick and right hand pinched).

Figure 4.5 Making ears of the monkey (Right hand held the stick and left hand pinched).

Table 4.2 Key steps in parts preparation stage.

Key Steps	Hands	Action	Goal of Action	Operation	Role of the Stick
Kneading with two hands	HH	Shape dough	Shape dough	Knead by fingers or palm	The stick could be set aside and recover easily
	FH	Shape dough	Shape dough	Knead by fingers or palm	
Kneading with one hand	HH	Be a platform Set the stick aside	Be a platform for FH	Hold stick	
	FH	Shape dough	Made dough flat	Knead by palm	

4.3.2 Parts Assembly

After the part had been made, subjects would put the part on the doll. Some parts need to be placed to an appropriate position and some parts need to be wound around the doll. (Table 4.3)

Placing Parts

In order to place the part to an appropriate position, holding hand would rotate the stick and let the appropriate position face to the free hand first, and then free hand puts the part to the position. If they need to rotate a lot on z-axis, they would use both wrist and finger to rotate the stick (Figure 4.6). If the angle is small, they just need using wrist. If they need to rotate on other axis, they also would use wrist. They usually use left hand to rotate the stick and right hand to place the object. Sometimes they would use left hand to place object because the orientation (Quote 3) and habit. This kind of bimanual is serial assembly. First, holding hand rotates the doll to appropriate position. Then free hand place part to the doll.

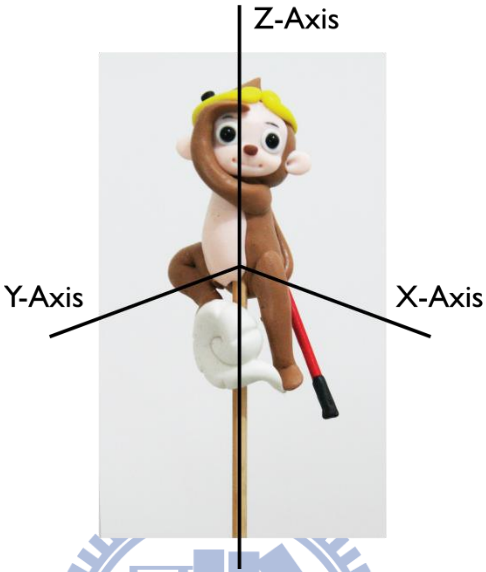


Figure 4.6 Three axis of the doll.

[U2] *When he wanted to place left armor to the doll, he used right hand to hold the stick and left hand to place left armor. (Figure 4.7)* **(Quote 3)**

Figure 4.7 Using left hand to place the left armor.

Winding Parts

Some parts, like circle or belt, need to be wound around the doll. They used free hand to pinch the parts and control the vertical position; holding hand rotated the stick to control the orientation on z-axis. In this task, two hands work simultaneously; we considered this bimanual action as a kind of orthogonal assembly. Although two hands manipulate different objects, their goal is to control the position of the parts in orthogonal dimension. (Figure 4.8)

Figure 4.8 Winding the circle around the head.

Table 4.3 Key steps in parts assembly stage.

Key Steps	Hands	Action	Goal of Action	Operation	Role of the Stick
Placing parts	HH	Orientate the doll	Let the position face to FH	Rotate the stick by finger or wrist	Prevent HH from obstructing the manipulation of FH
	FH	Place the part	Let the part fix in the appropriate position	Move Press	
Winding part	HH	Orientate the doll	Control the orientation of doll on z-axis	Rotate the stick by finger or wrist	Prevent HH from obstructing the manipulation of FH
	FH	Position the part	Control the position of the part on x and y-axis	Move	

4.3.3 Posture Adjustment and Detail Sculpture

After the parts are placed on the doll, subjects would adjust the posture of parts by bending, winding, and etc. They also would sculpture the dough to make some detail e.g., cheek, ear canal by hands or tools. (Table 4.4)

Adjusting Posture

After the part was placed on the doll, subjects adjusted the posture and detail by moving and rotating the part. They rotated the stick and let the part face to the other hand. During the adjustment, they would rotate the stick in different directions to check the balance of the doll. They usually used left hand to hold the stick and right hand pinch but sometimes exchange because the orientation such as making a pair of symmetric parts. (Quote 4) In addition, when participants want to make the part symmetric, two hands also adjust the part alternately. (Figure 4.9)

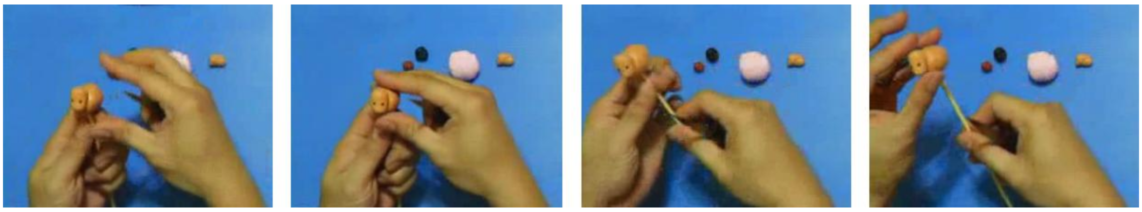


Figure 4.9 Two hands adjust the head alternatively. From "捏麵人教學影片綿綿小羊", 蘇逸民, 2007, http://www.youtube.com/watch?v=oDbBWdl7g7Y.

[U4] *When he wanted to make horns of sheep spiral, he use right hand to twist the right horn and left hand to twist the left one. (Figure 4.10)* **(Quote 4)**

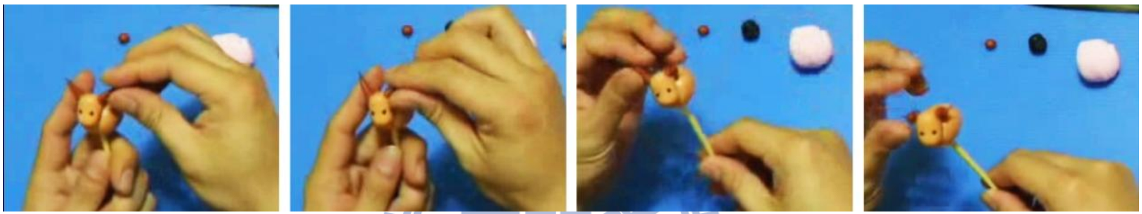


Figure 4.10 Making a pair of spiral sheep's horns. From "捏麵人教學影片綿綿小羊", 蘇逸民, 2007, http://www.youtube.com/watch?v=oDbBWdl7g7Y.

Beside, in order to make some symmetric detail or adjust symmetry of doll, subjects sometimes use both hand to pinch dough. (Quote 5)

[U4] *When he made cheeks of the doll, he used both hand to press the face of the doll in meanwhile.* **(Quote 5)**

Adjusting 3D Position

There was a more complicated adjustment that involves 3D rotation and movement. Two hands cooperate simultaneously in this step. Holding hand rotated the stick to control the orientation of objects on z-axis. Free hand moved the part on both three axes and adjusts the posture. This kind of bimanual interaction is similar to orthogonal assembly in KC model. Each hand controlled movements in orthogonal dimensions simultaneously. And they have the same goal. (Quote 6)

[U3] *When she wanted to make the monkey looks like it is viewing something, she need to put its hand upon its eyebrows. She pinched its hand to adjust the position on z-axis and hand's posture by left hand. Right hand rotated the stick in meanwhile (Figure 4.11).* **(Quote 6)**

Figure 4.11 Making the monkey look like viewing something.

Sculpturing By Tools

Subjects used hairpin to sculpt lines, pierce holes, and make planes because these details were too precise to use finger. If the position didn't face to the free hand that holds tool, they will rotate the stick and let the position face to free hand.

Subjects also used brush to paint some decoration. When they painted, holding hand will rotate the stick and let the position face to the free hand. In addition, holding hand's finger would support free hand (Figure 4.12).

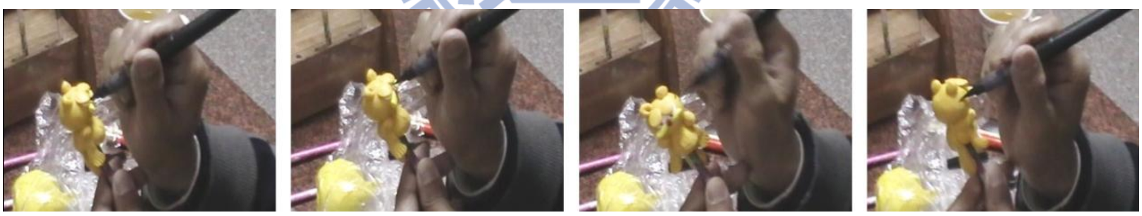


Figure 4.12 Left hand's middle finger supports right hand.

Table 4.4 Key steps in posture adjustment and detail sculpture stage.

Key Steps	Hands	Action	Goal of Action	Operation	Role of the Stick
Adjusting Posture	HH	Orientate the doll Fix the doll	Let the part face to FH	Rotate the stick by finger or wrist	Support the manipulation
	FH	Adjust parts by hand or tools	Make particular posture	Move	

Table 4.4 (continued)

Key Steps	Hands	Action	Goal of Action	Operation	Role of the Stick
Adjusting 3D position	HH	Orientate doll	Make particular posture (Orientation on z-axis)	Rotate the stick by finger or wrist	Prevent HH from obstructing the manipulation of FH
	FH	Position parts	Make particular posture (Control the position of part on x and y-axis)	Rotate or move	
Sculpturing by tools	HH	Orientate doll	Let the position that need to be sculpted face to FH	Hold the stick	Support the manipulation
	FH	Sculpted by tools	Make tiny or geometric details	Press or pierce by tools	

4.4 Spatial-Temporal Patterns

From the analysis of bimanual actions, we saw two main kinds of spatial-temporal pattern of bimanual actions in assembly and adjustment stages. First kind is **sequent placing/adjustment.** It is similar to serial assembly in Guiad's Kinematic Chain model. This kind of pattern emerges in placing part, adjusting posture and sculpturing by tools tasks. Two hands collaborate with each other step by step (Figure 4.13). Holding hand turned the doll and let the appropriate position to face to free hand. Then free hand puts the part on the doll or adjusts the part. The participants focus on the particular position. So the process proceeds very fast.

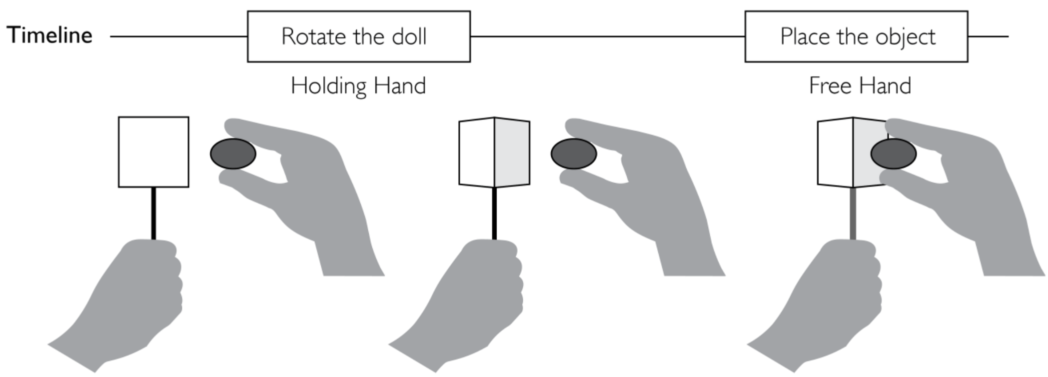


Figure 4.13 Sequent placing/adjustment

Second kind is **concurrent placing/adjustment.** It is similar to the orthogonal assembly in Guiard's Kinematic Chain model. This kind of pattern emerges in winding part and adjusting 3D posture tasks. Two hands move objects simultaneously. Holding hand control the orientation on z-axis and free hand control the position on x- and y-axis. The participants focus on every position of the part in whole process. So the process proceeds more precisely and slowly (Figure 4.14).

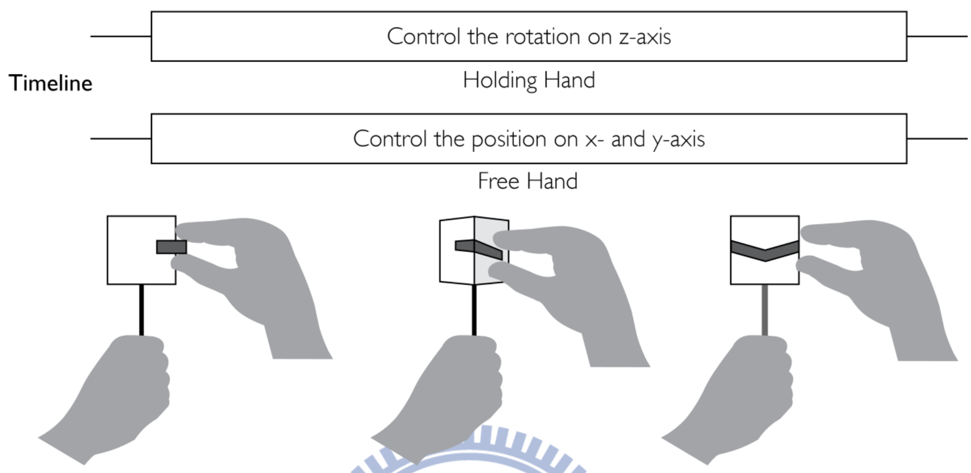


Figure 4.14 Concurrent placing/adjustment

4.5 Each Hand's Role

Holding hand and free hand play different roles in different tasks. Holding hand is usually non-dominant hand and free hand is usually dominant hand. But they would interchange because orientation (Quote 3), symmetric (Quote 4) or personal habit. The roles of each hand are presented as follows.

Holding hand's roles

(1) Assistance: Holding hand assists free hand to complete task. It fixes the object, so free hand could place object and add details on the doll. And it rotates the stick to let the appropriate position or parts to face to free hand, then free hand could place parts, adjust posture, and sculpt the doll conveniently.

(2) Coordination: When participants need to wind the part around the doll, two hands collaborate with each other simultaneously. Holding hand controls the orientation of the part on z-axis.

(3) Perception: Users could efficiently view the doll from different points of view by rotating and moving the stick. (Quote 7)

[U1] *He said the stick could help him view the doll more conveniently and completely than without the stick.* **(Quote 7)**

Free hand's roles

(1) Manipulation: Free hand directly manipulates the parts. It precisely places the part to the appropriate position. It move and rotate the part to adjust the posture.

(2) Coordination: As we noted above, free hand needs to collaborate with holding hand in more complicated task such as winding.

4.6 The Stick is a Jig

From video analysis, the stick is used to hold and orient the doll. Holding hand could rotate and move the doll with it. It could be considered a **jig**. By definition of Wikipedia, "*jip is a type of tool used to control the location and/or motion of another tool. A jig's primary purpose is to provide repeatability, accuracy, and interchangeability in the manufacturing of products.*" It helps participants view and manipulate when they pinch dough dolls. In addition, the roles of each hand are distributed clearly through the jig.

(1) View: People view the doll more conveniently and completely with jigs compared to only by hands. Because jip is a long and thin stick, they could use both finger and wrist to rotate it. The range of rotation could be huge in small hand movement. (Quote 7) The jig could be a physical center line. It is a good reference for people checking the symmetry of doll. (Quote 8)

[U2] *He says he could confirm where the center line of doll is by watching the stick.* **(Quote 8)**

(2) Manipulation: In the 3D assembly, when people places parts or adjust parts, holding hand could keep distance from the doll. Holding hand could avoid interfering with the manipulation of free hand and rotate the doll in meanwhile. In addition, the jig makes the manipulation more facile. People could let the jig between fingers and knead the dough. After the part is finished, they could place it on the doll efficiently.

4.7 Correlation between Feedbacks, Operation, and Goal

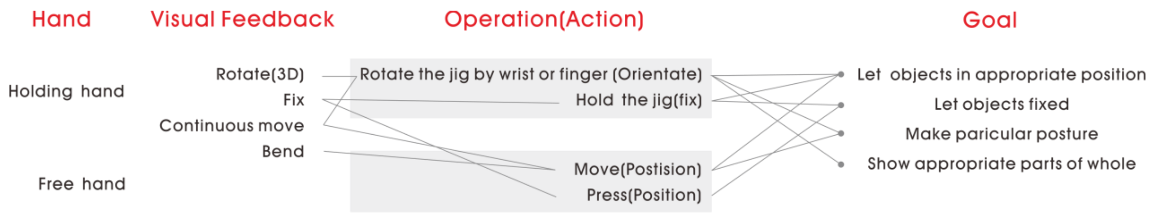


Figure 4.15 Correlation diagram.

To apply the pre-existing knowledge to mobile device interface design, the goal, interaction method, and feedback are the important issues. Since the jig is an important tool in pinching dough dolls like the mobile device held by hand. We focused these issues of the bimanual collaborations with the jig. There were four main goals of these bimanual interactions. We connected the operations and the related goals. Then the visual feedbacks that occur during these operations would be connected to related operations. (Figure 4.15) Four main goals and their correlate issues are described as follow.

(1) Let objects in appropriate position: In placing parts, holding hand would rotate the jig to assist free hand moving the parts. In winding parts, holding hand rotates the jig and the free hand moves the part simultaneously. The people could see the 3D rotation of doll and the movement of the part with hand.

(2) Let objects fixed: In placing parts and winding parts, free hand would press the part to fix it, and holding hand would fix the doll.

(3) Make particular posture: In adjusting posture, holding hand would rotate the jig to assist free hand adjusting the posture of part.

(4) Show appropriate parts of whole: In placing parts and adjusting posture, holding hand rotates the doll to let the appropriate position to face to free hand. For viewing, it also rotates the doll to display the appropriate face for people checking shape of the dolls.

4.8 Summary

In the process of pinching dough dolls, handcrafters need to prepare parts, to assemble parts, to adjust the posture, and to sculpt detail. In these stages, there are many different kinds of bimanual interaction which are similar to parallel, orthogonal, and serial assembly in KC model. Based on the analysis of bimanual interaction, we have investigated the spatial-temporal patterns, roles of each hand, and the usage of the stick.

When handicraftsman focus on a particular position, holding hand rotates the stick and let the doll face to free hand. Then free hand could place or adjust part conveniently. When they need to focus on every position during a more complicated manipulation, two hands would cooperate with each other seamlessly and simultaneously.

In these bimanual interactions, each hand's roles are separated due to the stick. Holding hand play three key roles: assistance, coordination, and perception. Free hand play two key roles: manipulation and coordination. Non-dominant hand's and dominant hand's role would interchange because the orientation and habit.

The long and thin stick is like a jig in pinching dough doll. This jig could help distribute roles to each hand. It could let the manipulation and view task more convenient and efficient.

5. DESIGN PATTERNS FOR BIMANUAL INTERACTION IN MOBILE DEVICE

Our intention is to allow two hands interacting naturally with mobile devices. The exploratory results showed smooth bimanual collaborations of moving, fabricating, winding, viewing, and adding detail in pinching dough dolls. Furthermore, before applying the pre-existing knowledge to interface design, the context of task should be considered (Carroll et al,. 1998). First, we explored the similar contexts between mobile device interaction and pinching dough dolls. The goal of tasks in each area would be considered. Second, through critical analysis of pinching dough dolls, roles of each hand, and benefits of the jig, we presented three design patterns for bimanual interaction in mobile devices.

5.1 Mapping between Physical and Virtual

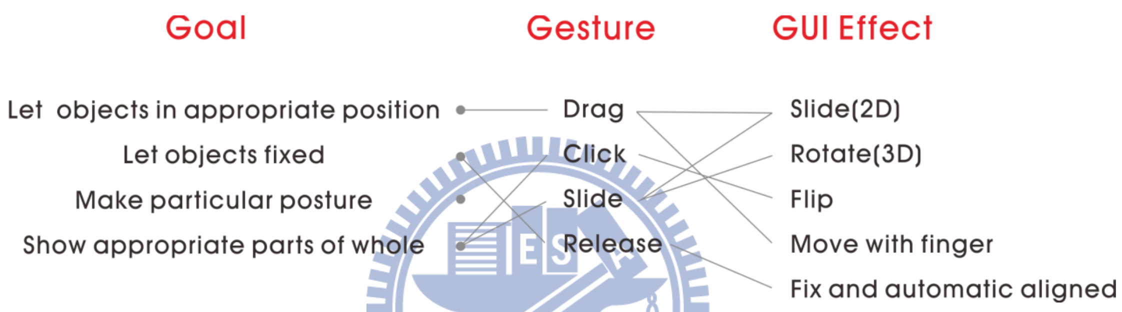


Figure 5.1 Analysis of gesture designs in mobile devices.

In chapter 4, we have found out the main goals of bimanual interactions and the related manipulations and feedbacks in pinching dough dolls. In order to find appropriate context in mobile devices, we surveyed gesture designs that have similar goals in mobile phone first (Saffer, 2008; http://www.youtube.com). According to the four main goals found in chapter 4, the gestures were connected to related goals. Each gesture also connected to the GUI (graphical user interface) effect caused by the gesture. Figure 5.1 showed the correlation between goals, gestures and GUI effect. But in mobile devices, users seldom adjust an object's particular posture. For example, when users want to let objects in appropriate position, to let objects fixed and to show appropriate parts of whole, there are correlate designs.

Then, we made a mapping between the physical (pinching dough dolls) and virtual (mobile devices) (Figure 5.2).

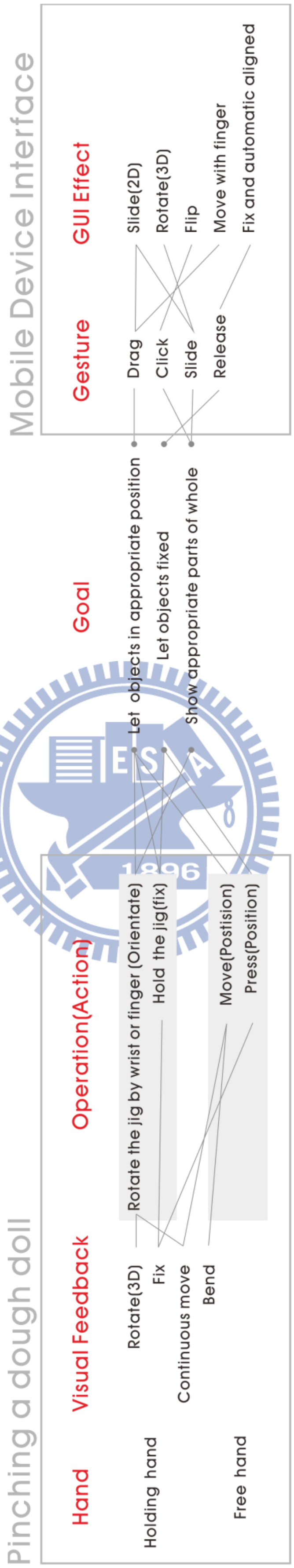


Figure 5.2 Mapping between tasks in pinching dough dolls and mobile device interface.

Figure5.2 revealed a clear relationship between pinching dough dolls and manipulating mobile phone. People use different operation/gesture while pinching dough doll and using mobile phone, but they have the same goal while doing some tasks. In these tasks, we thought the pre-existing knowledge in pinching dough dolls could be mapping to mobile device interaction. Following are descriptions of three kinds of goal and related tasks.

(1) Let objects in appropriate position: In mobile device, when users use some functions such as relocation (Table 5.1) or category, they usually drag the object to the appropriate position no matter the position is on the screen or out of screen. If the position is out of screen, they drag the object near the side of screen, then background slide to next page. In pinching dough doll, if the target isn't face to free hand, holding hand would rotate the doll and let the target position face to free hand. Then free hand place the object to target.

Table 5.1 Steps of relocation task in iPod/iPhone.

Steps	Operation	Goal
Switch to movable mode.	Long press	Let the icon movable
Move the icon to the edge of the screen.	Drag	Let the icon place to appropriate position
The screen slides to next one.	Automatically	Show the appropriate part of the whole.
Move the icon to appropriate position	Drag	Let the icon place to appropriate position
Switch to regular mode	Press the hardware button	Fix the icon

(2) Let objects fixed: After users move objects, they need to fix them, they would tap or release the object in mobile device because the objects are be align or stuck. In pinching dough dolls, people need to press the object because of the gravity.

(3) Show appropriate parts of whole: When people want to view other parts of an object in mobile device such as different pages of menu or the track list of an album, they usually use slide on the screen to switch the pages. For example, when people rearrange icons, they often need to select appropriate area to place the icons (Table 5.2). In pinching dough dolls, they rotated the jig to view different faces of dolls.

Table 5.2 Steps of placing the icon to the appropriate panel in Android.

Steps	Operation	Goal
Let the icon that is in the menu move above the panel	Long press	Let the icon movable.
Select the appropriate panel	Slide	Show the appropriate part of the whole.
Switch to regular mode	Long press	Fix the icon

The goals of steps in aforementioned task are similar to tasks in pinching dough dolls. People relocate objects or move objects from one place to another. Sometimes they need to move the object outside the screen or to another application. Current system would automatically switch to next page or another application. To aim at this kind of task, the exploration of pinching dough doll could be applied to build bimanual interaction.

5.2 Design Patterns for Bimanual Interaction in Mobile Devices

Design patterns are used to describe good practices. They are clear documents which help designers address similar questions quickly. They describe not only the solution but also the problem context (Borchers, 2001). After concerning the appropriate tasks, contexts, and limitations in mobile devices, following three design patters are built according to the results of exploratory study. They indicated the division of labor, gesture designs, and metaphor while designing bimanual interaction in mobile devices.

5.2.1 Pattern 1 3D Manipulation with Jig

This pattern describes the gesture design for rotating the 3D object with the jig. When system provides a 3D object for information visualization, user could rotate the jig to select different faces of the 3D object. The jig could be mobile device itself or be a graphic. When it is the mobile device itself, users tilt the device to rotate the objects (as shown in the figure of type 1 in Table 5.3). When it is a graphic on the screen, users could use finger slide on it to rotate the object (as shown in the figure of type 2 in Table 5.3). The goal of rotation is to select the appropriate face of the 3D object. When users rotate the jig or tilt the mobile device, the 3D object would rotate to next face automatically. The motion graphic of rotation provide a feedback. The designer should notice that the manipulation of jig shouldn't bother the manipulation of the other hand (Table 5.3).

Table 5.3 Pattern 1 3D Manipulation with Jig

What

3D objects could be rotated through manipulation of the jig. The jig could be graphic on the screen or the mobile device itself.

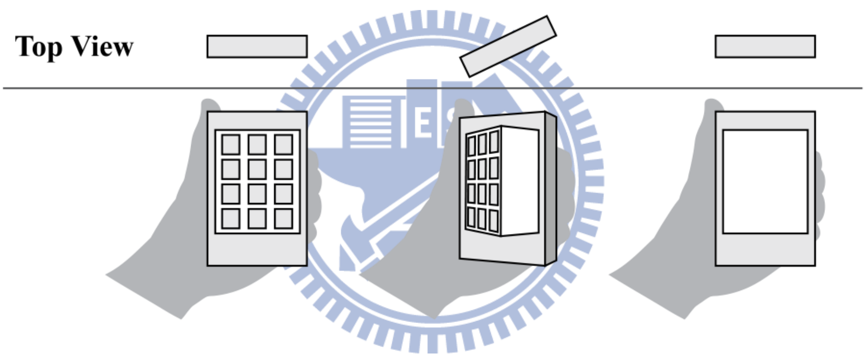
When

When system provides a 3D object for information visualization and each face of the 3D objects consists of different information, users need to select different faces for viewing or placing objects.

Interaction Suggestion

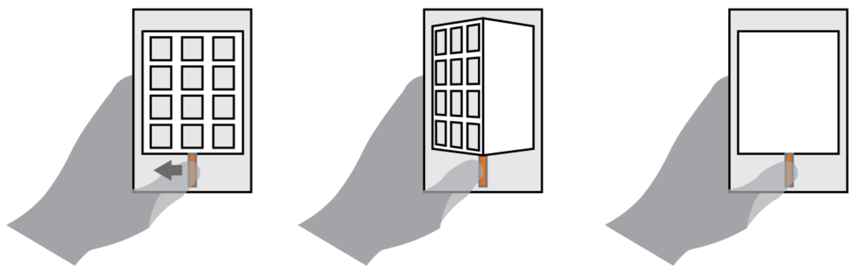
[Type 1] Mobile device is the Jig

There is a 3D object on the screen. Users tilt the device and the 3D object would automatically switch to next face. The direction of rotation is as same as the direction of tilt.



[Type 2] Graphic Jig

The virtual jig would under the 3D object. The finger lightly touches the jig and moves horizontally to rotate the object. When the object rotates more than a specific angle, it would automatically rotate to next face.



5.2.2 Pattern 2 Bimanual Relocation of Object

This pattern describes the layout and interaction for relocating an object with two hands, especially when users want to move the object outside the screen. There are two components in the relocation task: the background and movable items. The manipulations of object and the background could be distributed to free hand and holding hand. The background could be the faces of a 3D object, like the doll in pinching dough dolls. Holding hand could select different face of the 3D object by rotating it with the jig. The movable object could float above the 3D object (background). When the item floats up, it wouldn't move with the object, and the object rotates behind it. When the item is attached on the face, it would move with the object. Free hand could move and position it. The visual effect should let users to feel clearly that the object is floated. This pattern is a natural interaction that mimics the physical world like moving the item to different position on the face or to different face of a 3D object such as pinching dough dolls (Table 5.4).

Table 5.4 Pattern 2 Bimanual Relocation of Object

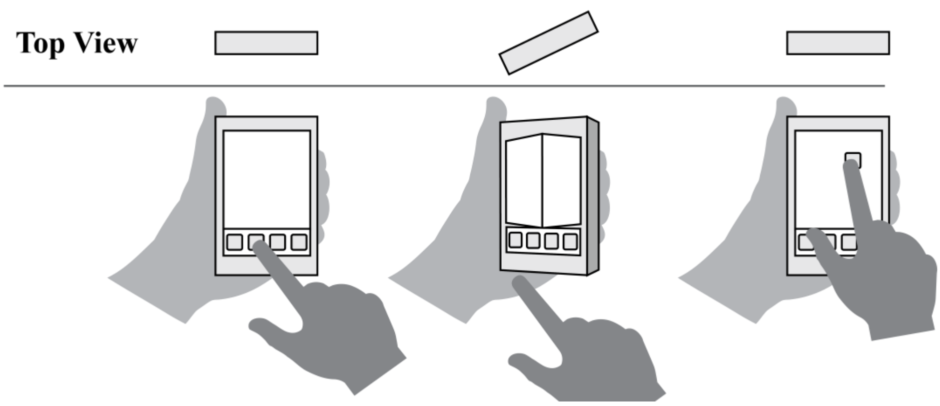
What
The object and the background could be separately manipulated by each hand. Two hands collaborate to relocate objects.
When
Users need to relocate the object, especially moving it to outside the visible viewing area.
Interaction Suggestion
The system could provide a spatial metaphor that the items are placed on a 3D object such as a cube. User could select different faces of the 3D object by rotating it. The item could be floated above the 3D object. When the item floats up, it wouldn't move with the cube. The cube would rotate behind it. Holding hand could control the 3D object by the jig. Free hand could move the item, float it up and attach it to the face.


5.2.3 Pattern 3 Bimanual Object-Placing

This pattern describes how to place items from one place to another with two hands such as moving the photos to different albums. The area of destination and area of the items are displayed separately on the same screen. Holding hand could select the sub-areas of the destination. Free hand could select and move the item in the meanwhile. This interaction is similar to that subjects kneaded the dough on their palm and then placed on the particular position of the doll (Table 5.5).

Table 5.5 Pattern 3 Bimanual Object-Placing

What
Placing items from one place to another with two hands on the same screen.
When
When users need to move items from one place to another place such as moving the photos to different albums, they need to select both the items and the appropriate sub-area in the destination.
Interaction Suggestion
Two hands could select the items and sub-areas separately. Free hand selects the item and moves it. The destination could be represented as a 3D object. Holding hand could select the face of the 3D object by tilting the device. For example, the area where items originally are is displayed in the lower area of the screen. The destination, the cube, is displayed in the upper area. Free hand's finger slides to select the items and drag the item to appropriate face. Holding hand tilts the mobile device to select between different face of the cube.



Based on results of exploratory study, following are two concerns for building bimanual interaction in mobile device.

(1) Two hand's roles must be interchangeable.

From the exploratory study, although all subjects are right-handed, and they usually used left hand to hold the stick and right hand to pinch dough, two hands would exchange their roles because of orientation or personal habit. The interface design must let two hands easily exchange their roles. No matter which hand they use to hold device, they could complete the task smoothly.

(2) System should allow two hands manipulate simultaneously.

Subjects in our study always move the part and rotate the stick in meanwhile especially when they wind part around the doll. There isn't an obvious division between two hands' action. System should allow two hands to manipulate the jig and the object simultaneously.

5.3 Summary

In mobile device, the goals of some task are similar to the bimanual interaction with the jig in pinching dough dolls such as relocation and categories. Different subtasks in these tasks could distribute to each hand. In these contexts, through the analysis of exploratory study; we presented three design patterns for bimanual interaction in mobile devices. These patterns indicate natural ways for viewing the 3D objects, relocating objects, and placing objects with two hands. They described the problem, the solution, division of labor, usage of metaphor, and examples.

6. USER EVALUATION

This chapter described the process and result of user evaluations for the design guidelines presented in previous chapter.The prototype design and process of user evaluation was described in Section 6.1. In Section6.2, data of questionnaire and interview would be analyzed. Last, concerns of bimanual interaction in mobile device and the modification of design patters are described in Section 6.3.

6.1 Experiment

The experiment had two parts. First was the usability test. We built three prototypes according to the design patterns in chapter 5. Subjects provided their subjective feeling about easy-to-use, effectiveness, efficiency, joyful, and intuitiveness of prototype through questionnaire. The second part is semi structured interview. Following is the description of the prototype, and then the whole procedure is described in Section 6.1.2.

6.1.1 Design of prototype

According to the design patterns, three prototypes were built in iPod touch. Subjects could interact with multi-touch screen and accelerometer. We chose cube as the 3D object in the prototype because cube has already used in many mobile phones (LG GC900). The cube is only rotated on z-axis. Each face of the cube has different color. The items on cube were collected from icons of iPod's applications.

(1) Sequent relocation

This prototype had subjects perform a relocation task. They could let an item to float up by tapping it. This floated item could be dragged. Then subjects could tilt the device to rotate the cube and to select which face they need to put the item on. If subjects keep tilting the device, the cube would rotate continuously until they turn the device back. After they selected appropriate face, they could move the item to appropriate position and fix the item by tapping it. In this task, because the item could float up without pressing it, two hands could collaborate step by step (Figure 6.1).

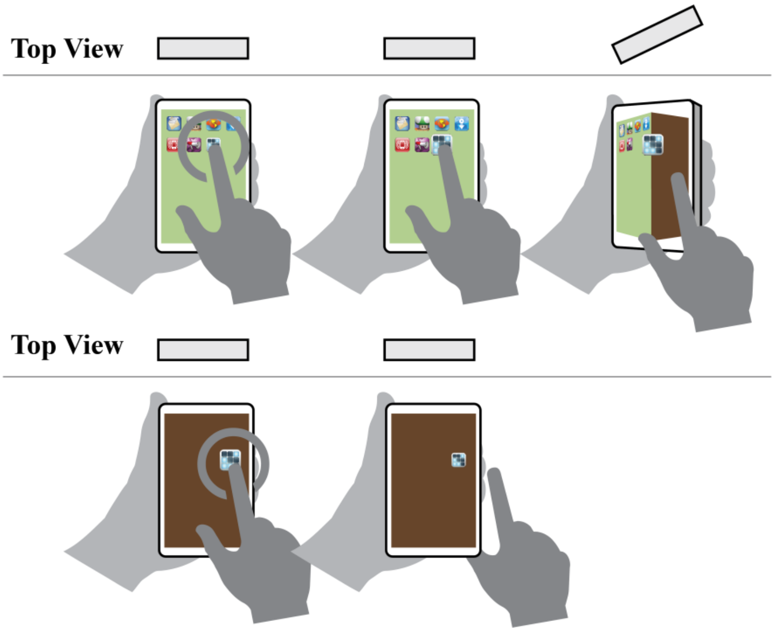


Figure 6.1 Design of the sequent relocation.

(2) Concurrent relocation

This prototype is similar to the first prototype. Holding hand tilts the phone to rotate the cube to select the face. But the way of floating the item up is pressing on it. And when the finger release, the item would be attached to the cube automatically. They need to press the item during the whole task. So subjects must use two hands simultaneously when they relocate items (Figure 6.2).

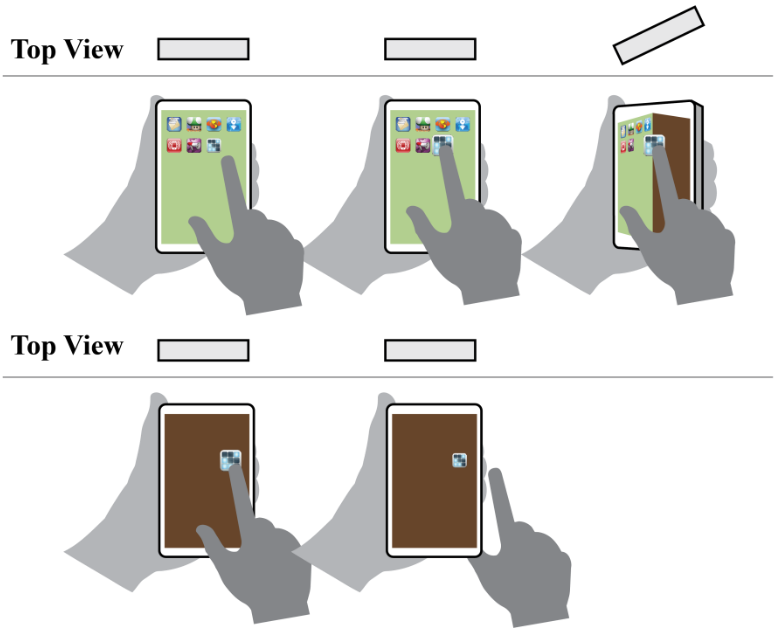


Figure 6.2 Design of the concurrent relocation.

(3) Object-placing

This prototype had subjects perform object-placing task. Subjects could select the item in the lower area and drag the item to the face of the cube. They could tilt the device the select different face of the cube (Figure 6.3).

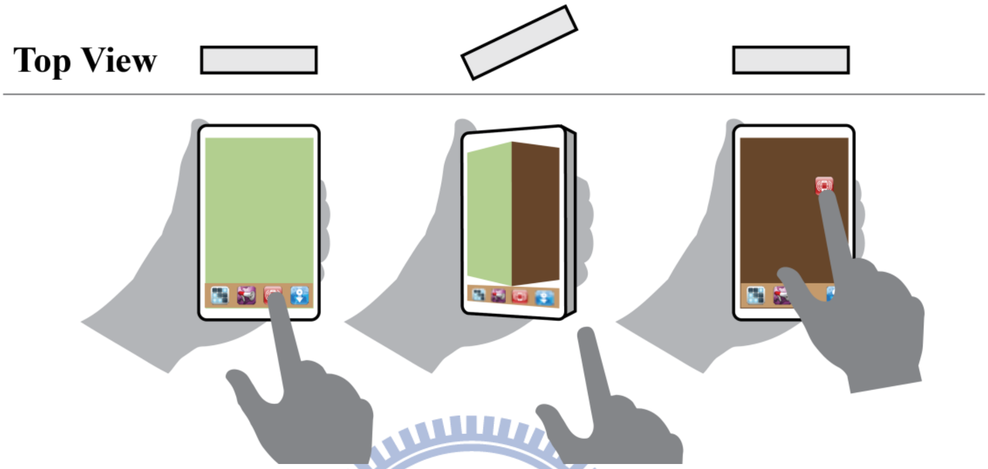


Figure 6.3 Design of the placing objects

6.1.2 Procedure

There are two session in the user evaluation. The first session is usability test. Subjects would use each prototype to complete a task. Then they need to complete questionnaires that evaluate the subjective feeling of usability for each prototype. In the second session, a semi structured interview is conducted to realize design issues, demands, and problems of the concepts we presented.

6.1.2.1 Usability test

In usability test, participants needed to complete tasks of each prototype. The contexts of these tasks were similar to the context of the problems that design patterns solve. In two kinds of relocation task, subjects all start from the same face of the cube. There are several items on that face. They need to move three items to three other faces one by one. They could move any item as they wanted. We assigned the order of faces and the position on faces (Figure 6.4).

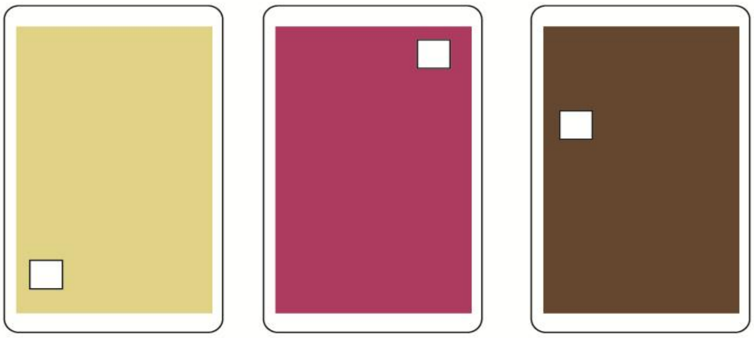


Figure 6.4 Instruction of the relocation task.

In object-placing task, we had subjects move particular objects to the particular faces of the cube. They need to place three objects in particular order (Figure 6.5).

Figure 6.5 Instruction of the placing task.

After each task was completed, subjects could manipulate the prototype few minutes. Then they need to write a questionnaire based on IBM Computer Usability Satisfaction Questionnaires (Lewis, 1995). The questionnaires are used to evaluate the learnability, effectiveness, efficiency, and joyful of the system from subjects' subjective opinions. From the previous study of gesture, we add three additional questions about intuitiveness, feedback and whether they would gesture in this way (Fikkert, 2010). All questions are scored on a seven-point Likert-syle scale. The problems and suggestions are also collected in questionnaires. These data were used to evaluate the design guidelines and design patterns.

6.1.2.2 Interview

Subjects provide their opinions on four main issues in the semi structured interview. The first issue is how people think about the concept of 3D relocation. The second issue is the difference between sequent relocation and concurrent relocation. The third issue how people think about the concept of placing object with the 3D cube. The fourth issue is the difference between two kinds of representation of jigs. The manipulation of graphic jig just demo by PowerPoint (Figure 6.6). The whole process of interview would be recorded for analysis. In order to evaluate the design patterns, the problems that each concept solves were notified to participants. Participants could comment about these concepts in particular context.

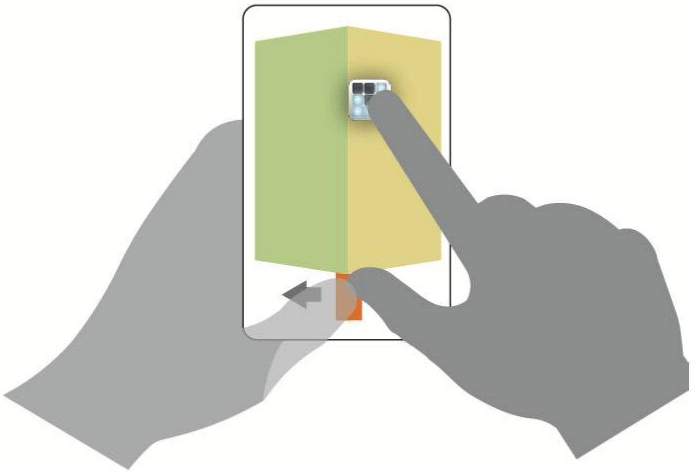


Figure 6.6 One of the slides used to demo the manipulation of the graphic jig.

6.1.2.3 Analysis

In order to confirm the usability satisfaction of each prototype, we use descriptive statistics to analyze the average score of each question in questionnaires of each prototype.

From the record data of the interview, we transfer subjects' demands, problems, and comments to statements. The statements would be categorized and then built up affinity diagrams. The affinity diagrams could reveal the subjects' opinions of the four main issues and help us to modify the design guidelines and design patterns presented in Chapter 5.

6.2 Result

In this section we reported on the results of the questionnaire and interview. We described our participants in Section 6.2.1. Section 6.2.2 describes comments about the concept of relocation, manipulation of tilting the device, and the cube metaphor. Then comments about the concurrent relocation and the sequent relocation are presented in Section 6.2.2.1and Section 6.2.2.2. Last, evaluations of placing concept and the comparison between two types of jig are described in Section 6.2.3 and Section 6.2.4.

6.2.1 Participants

A total of 20 subjects participated in this user evaluation. Participants were 25 years old on average (ranging 22-27 years). As can be seen in Table 6.1, 10 participants were female and 10 were male. 4 participants are high familiar with smart phone, 10 participants are medium familiar, and 6 participants are low familiar. In all subjects, 8 subjects were design students, 6 subjects were non-design students, 2 were designers and 4 were non-designers.

Table 6.1 Participants.

	Gender	Age	Job	Level of familiar with smart phone
UX01	Female	25	Designer	High
UX02	Male	25	Software	High
UX03	Male	26	Design Student	Medium
UX04	Female	27	Design Student	Low
UX05	Male	25	Design Student	Medium
UX06	Female	25	Design Student	High
UX07	Female	26	Researcher	Low
UX08	Female	27	Design Student	Low
UX09	Male	29	Business	Low
UX10	Female	22	Sport Student	Medium
UX11	Female	22	Engineer Student	Low
UX12	Female	24	Design Student	Medium
UX13	Male	25	Design Student	Medium
UX14	Female	27	Designer	Medium
UX15	Male	22	Electronic Student	Medium
UX16	Male	25	Management Student	High
UX17	Male	25	Chemistry	Medium
UX18	Female	25	Music Student	Low
UX19	Male	26	Musician	Medium
UX20	Male	26	Design Student	Medium

6.2.2 Bimanual Relocation

The design of relocation is that users could move the icon and rotate the cube under it separately. All participants accepted this design of relocation. They expressed opinions of the benefits of this concept, obstruction of tilting device, and what should be enhanced. Following are the main finding of three categories. (Table 6.2)

(1) Benefits

Most of participants expressed this design is more efficiency than general relocation that only use dragging because they could switch the face as fast as they want. It's is easy to learn and to use because the interaction is natural to participants. They could easily understand the sense of space and 3D by the manipulation and the visual effect of rotation. The role of each hand is reasonable, natural and relaxes. The movement of tilting device is definite and let subjects select the face more carefully then sliding on the screen. The relationship between the cube and icon is natural to subjects. It's easily understood that the icon could be picked up and wouldn't rotate with the cube.

(2) Obstruction of tilting device

The obstruction is mainly related to the tilting gesture. Most of participants indicated that the rotation of the cube is too sensitive. The strength and angle of manipulation isn't easily controlled. So it's easy to rotate so far, and then they need to rotate the cube back. And the movement of tilting let some subjects feel tired.

(3) What should be enhanced

Subjects provided some suggestions about the gesture and visual cue. The tilting gesture should be taught. The feedbacks of the icon and cube should be stronger when the icon floats up (Quote 9). Some participant indicated there should be some information about the faces near current face because they would forget what the next face is.

[UX14] *When the icon floats up, the cube could zoom out to enhance the sense of space.*

(Quote 9)

Table 6.2 Affinity diagram of the relocation

Benefits	More efficiency	This kind of manipulation is more efficiency.
		The collaboration of two hands is more efficiency and convenient than dragging by one hand.
	Easy to learn and use	Tilting device need to be learned, but it is easy to learn.
		Manipulation of the cube could help subjects confirm the separation between cube and floated item.

Table 6.2 (continued)

Benefits	Easy to learn and use	Sense of space and 3D is easy to understand.
		It is relaxed that each hand just plays a role.
	Intuitive design	Tilting device to rotate cube is intuitive.
		That the icon wouldn't rotate with the cube after it floats up is reasonable.
	Let manipulation more carefully and definite	Because the movement of tilting is obvious, subjects would select face more carefully.
		The sense of manipulation is more definite.
	Naturally manipulation	It is could be imaged that there are a cube and the items on it could be moved.
		It is a natural division of labor that each hand controls two layers separately.
		The roles of each hand are reasonable and natural.
Obstruction of tilting device	Should be more controllable	The strength and angle of tile isn't easily controlled.
		Rotation of cube is too sensitive
		It is easily to rotate too far.
		Rotation of cube should be easy.
		Want to stop the cube when the cube rotates too fast.
	Human factor problems	Tilting the device makes wrist tired.
What should be enhanced	Need to be taught	Don't know the mobile device could be tilted at the beginning.
		This way of rotation need to be taught.
		This way of relocation is different from the regular way.
	Need more feedback and information	When the icon floats up, the cube could zoom out to enhance the sense of space.
		Need stronger feedback when the icon float up
		When the item floats up, the cube could also have some change to show that it could be rotated.
		Should prompt what the faces near current face are.

6.2.2.1 Concurrent Relocation

The result of the questionnaire shows subjects agree this design is easy to learn, effective, efficient, intuitive and enjoyable (average scores > 5). The score of learnability is significantly high. This design could satisfy subjects. The participants would use this design to relocate the items (table 6.3).

Table 6.3 Result of satisfaction questionnaire of the concurrent relocation

	Average Score
Learnability	6.2
Effectiveness	5.55
Efficiency	5.35
Enjoyable	5.55
Satisfying	5.575
Intuitive	5.75
Would use	5.4

Comments that we gathered from the participants include three main issues, "high mental load", "obstruction", and "benefits". Following are the finding of three issues. (Table 6.4)

(1) High mental load

Some participants had divided attention problem and need to pay more attention in this task when they pressed the floated and tilted the device simultaneously. They also felt nervous because they were afraid to lose the floated item on improper face because when they tilted the device, the finger pressing on screen would move a little bit. It isn't easy to tilt the device and to press the screen simultaneously, so some participants were afraid to drop the device. Some participants gave advices that the feedback of pressing need to be stronger.

(2) Obstruction

Several participants indicated that it is hard to recognize what is on each face because the finger covered on it. That the finger pressed on the screen makes tilting the device harder. So some participants often rotated the cube too far. Some participants felt this kind of hand's movement is unnatural.

(3) Benefits

Most of participants expressed that the concurrent relocation is more intuitive than the sequent relocation.The manipulation match the daily life experience just like pick an object from one place to another.This design is more efficient than the sequent relocation because the steps are fewer.

Table 6.4 Affinity diagram of the concurrent relocation

High mental load	Divided attention problem	Couldn't focus on two things - pressing the icon and tilting device - in meanwhile.
		Need to focus on the floated icon and tilting device simultaneously.
	Feel nervous	Afraid to lose the floated item accidently
		Afraid to drop the device.
		The feedback of pressing need to be stronger.
Obstruction	Hard to see the screen	The screen is hard to see because it is covered by right hand.
		When the device is tilted, it isn't easy to see what is on the screen.
	Problem of tilting	It is hard to tilt the device because right hand presses on it.
		It is easily to rotate too far.
		Usually wouldn't press an object and rotate it simultaneously.
Benefits	Intuitive manipulation	That the finger presses the floated icon is like pick an object in daily life.
		It is natural that one hand holds the item and the other hand rotates the cube.
	Efficiency	It is more convenient because subjects needn't tap many times.

6.2.2.2 Sequent Relocation

The result of the questionnaire shows subjects agree this design is easy to learn, effective, efficient, intuitive and enjoyable (average scores > 5). The score of learnability and effectiveness is significantly high. This design could satisfy subjects. The participants would use this design to relocate the items (Table 6.5).

Table 6.5 Result of satisfaction questionnaire of the sequent relocation

	Average Score
Learnability	6.225
Effectiveness	6.2
Efficiency	5.65
Enjoyable	5.825
Satisfying	5.85
Intuitive	5.65
Would use	5.8

Comments that we gathered from the participants include three main issues, "benefits", "obstruction", and "natural parts of manipulation". Following are the finding of three issues. (Table 6.6)

(1) Benefits

Most participants expressed this design is more comfortable and convenient than the concurrent relocation. Their physical load and mental load were lower. They weren't afraid of losing the floated icon because the system would hold it. They could pay less attention and concentrate on rotating the cube. That the finger needn't press the device make tilting the device more easily. The gesture - tap to let the icon float up – is clear and definite because of the experience from operation of computers. In addition, several participants expressed that this design is more efficiency when they want to move more than one icon.

(2) Obstruction

Some participants had more errors in this design than in concurrent relocation. Most of the errors happened when the icon need to be attached to the face. Some participants tapped the icon first and then wanted to move it. One participant directly tapped the position where she wanted to put the icon instead of dragging the icon first. Some participants express this kind of manipulation doesn't match to the daily life experience.

Sequent relocation is more complicated than concurrent relocation because the steps are more, especially tapping to attach. And the feedback of floated icon should be stronger than the feedback in concurrent relocation because the finger would leave the icon.

(3) Natural parts of manipulation

Some participants expressed the manipulation is predictable and natural. They could match the manipulation to real life experience. (Quote 10, Quote 11)

[UX03] *When the item move to next face, it is reasonable that the face come to hold it. So finger needn't pick the item all the time.* **(Quote 10)**

[UX12] *Like in the drama, the background would move instead of actors move when the scenes need to change.* **(Quote 11)**

Table 6.6 Affinity diagram of the sequent relocation

Benefits	Feel comfortable	Manipulation is more relieved because subjects needn't afraid losing the floated icon
		Step-by-step is more relaxed.
		Could concentrate on rotating the cube.
		After the item float up, subjects needn't to pay attention to it.
		The finger needn't press the device all the time.
	Feel clear and definite	The gesture - tap to let the icon float up - helps subjects confirm the status of icon and what they are doing.
	More efficiency	If more than one icon needs to be moved, this way of relocation is more efficiency.
Obstruction	Unanticipated manipulation	When the cube turned to the appropriate face, subjects would tap the icon imprudently before dragging it.
		When a subject wanted to place the icon on the face, she directly tapped the position where she wanted to put instead of dragging the icon first.
		Subjects want to move the item on the same face by dragging.
		In daily life, people don't move an object step by step.
	More complicated	It is more complicated because the steps are more.

Table 6.6 (continued)

Obstruction	More complicated	The gesture - tap to let the icon float up - is acceptable, but that the icon attach to face by tapping it is not convenient.
	Need more feedback	Because the finger would leave the screen, the differentiation between the floated icon and icon on the face should be stronger.
Natural parts of manipulation	Predictable manipulation	When the item move to next face, it is reasonable that the face come to hold it. So finger needn't pick the item all the time.
		The gesture - tap to let the icon float up - is intuitive.
	Match to real life experience	Like in the drama, the background would move instead of actors when changing the scene.
		Feel like pulling the item out and then putting it back.

6.2.3 Obejct-Placing

The result of the questionnaire shows subjects highly agree this design is easy to learn, effective, efficient, intuitive and enjoyable (average scores > 6, intuitive = 5.95). This design could satisfy subjects. The participants would use this design to relocate the items (Table 6.7).

Table 6.7 Result of satisfaction questionnaire of the placing

	Average Score
Learnability	6.475
Effectiveness	6.35
Efficiency	6.475
Enjoyable	6.025
Satisfying	6.075
Intuitive	5.95
Would use	6

Comments that we gathered from the participants include three main issues, "benefits", "obstruction", and "what should be enhanced". Following are the finding of three issues (Table 6.8).

(1) Benefit

This design is very practical and useful for categorizing objects. Participants felt fluent and relieved during the task because the design is clear and simple (Quote 12). Some participants indicated that the manipulation of this design is flexible. They could put any icon to the appropriate face whenever they want, and both single hand and two hands could manipulate well.

[UX03] *That the items are definitely static in the lower area makes me relieved.* (Quote 12)

(2) Obstruction

The layout is the main thing that confuses participants. The differentiation between upper area and lower area is vague. That makes participants couldn't predict how to manipulate at the beginning. Some participants assumed that both upper area and lower area could be rotated, but they also express that the way of manipulation could be learn through manipulation. Some participants weren't aware of that the icon could be moved to the upper area.

(3) What should be enhanced

Some participants suggested the feedback of dragging the item should be stronger. The manipulation of each area should be taught.

Table 6.8 Affinity diagram of the placing

Benefit	Practical design	This design is useful for categorizing objects.
	Comfortable manipulation	The bimanual manipulation is fluent.
		The role of each hand is natural and appropriate.
		The manipulation is clear and definite because participants only need to select the face and to drag the item to it.
		That the items are definitely static in the lower area makes participants relieved.
		The division of labor of each hand is convenient.
	Flexible	Participants could switch the face freely and then put the item on appropriate face whenever they want.
		This design is suitable for single hand and two hands.
	Learnable	Could understand the division between up and lower area because up area could rotate.

Table 6.8 (continued)

Obstruction	Visual confusion	At the beginning, participant felt the item in lower area couldn't be moved because lower area looks like the dock of normal operation system.
		The differentiation between upper and lower area is vague.
		If there were full of icon in both areas, it would be difficult to distinguish between upper and down area.
		Would assume that upper and lower areas are both controlled by tilting device.
		Lower area could be a 3D object.
What should be enhanced	Need more feedback	Need more feedback of dragging the item.
	Need to be taught	That the item could be dragged to upper area needs to be taught.

6.2.4 Tilting Device vs. Graphic Jig

Most participants expressed that tilting the device is better and more convenient than sliding the graphic jig on the screen. Only two participants thought the graphic jig is better. Most subjects felt that tilting device is more definite, more intuitive, more comfortable, easier and freer. The holding hand wouldn't cover the screen during tilting the device. The physical feedback of tilting device is better. The problems, demands and concerns of tilting the device have been described in section 6.2.2. The following are comments of the graphic jig that includes "benefits", "obstruction" and "need to be enhanced" (Table 6.9).

(1) Benefits

Several participants expressed that using the graphic jig could be more accurate and simpler. Because the graphic jig is a picture on the screen, it provides a better visual cue for user, and that makes the sense of manipulation clearer. In the concurrent relocation task, using jig makes the bimanual collaboration more convenient because participants needn't press the screen and tilt the device in the meanwhile. The screen is more stable because it needn't tilt.

(2) Obstruction

The mental load and physical load are higher than tilting the device. Some participants expressed that it's too busy that two hands' fingers work on the screen. They would interrupt each other. The coordination of two hands is hard because the direction of movement of each hand is different. The manipulation of the graphic jig may cause some errors such as accidental activation. It is inflexible that single hand is hard to complete the relocation task.

(3) Need to be enhanced

The sense of connection between the jig and the cube should be enhanced. The visual design and the way of manipulation should be more interesting.

Table 6.9 Affinity diagram of the graphic jig

Benefits	Easy to manipulate	Using the graphic jig could be more accurate.
		Using the graphic jig is simpler.
		The sense of manipulation is clearer than tilting the device.
		Using jig is more convenient for bimanual collaboration in the concurrent relocation than tilting device.
	Feel comfortable	Using graphic jig is more relaxed then tilting device.
		The screen is stable rather than inclined.
	Easy to understand	The visual cue that the jig could control the cube is stronger.
Obstruction	High mental and physical load	The mental load is stronger because both hands' fingers work on the screen simultaneously.
		It is too busy that both hands' fingers work on the screen simultaneously.
		The thumb is tired when using the graphic jig.
		It is inconvenient that both hands' finger work simultaneously.
		Tow hand's finger may interrupt each other.
		The coordination of two hands is hard because the direction of movement of each hand is different.
		Afraid to lose the device.
		If the jig were thin, controlling it would be hard.
	Causing some errors	More easily touch the icons on cube inadvertently when using graphic jig
		If the jig were very thin, users might felt that they rotate the jig a little, and the cube rotate a lot.
	Hard to see the screen	The thumb would cover the screen.
	Inflexible	Single hand couldn't do the task.
Need to be enhanced	Bad feeling	Lack of physical feedback.
		Using the graphic jig is boring.
	Hard to understand	The sense of connection between the cube and jig is weak.

6.2.5 Summary of Finding

We gathered subjective rating on 3 prototypes and the interview data from 20 participants. The results show participants agree 3 prototypes are easy to learn, effective, efficient, intuitive and enjoyable and they would use the prototype to complete particular tasks. Most of participants felt natural to rotate the cube by tilting it, but they thought the prototype is too sensitive to control. For relocation, most of participants felt the concept is natural and useful. The concurrent relocation is more intuitive but increase the mental load. The sequent relocation is more convenient but is complicated. For placing, most of participants felt this concept is natural and useful. The main problem is the differentiation between two areas is unclear. For the graphic jig, most of participants didn't like it because it is hard to manipulate, but several participants express it is intuitive.

6.3 Discussion

Based on result of user evaluation, two main concerns of design mobile bimanual interaction are discussed in following section. To let the design patterns to fulfill users' need, the three design patterns are modified. The modifications would become the recommendations of the design patterns.

6.3.1 Concerns of Designing Mobile Bimanual Interaction

Relieving mental load of each hand's manipulation

When people interact with mobile device with two hands, the mental load of each hand is added together. Two hands interrupt with each other more easily because the device is small. The result of the interview shows that participants have high mental load when they did the concurrent relocation task. They feel more nervous than in real world when they tilt the device and press the icon simultaneously because the physical feedback is weaker than the real objects. Designers need to relieve the load of each hand. The manipulation could be easy or the feedback could be obvious. Or designers could apply sequent bimanual interaction. Because the task is step by step, the mental load wouldn't increase.

Also supporting single-handed manipulation

When designers develop a bimanual interaction design, they must let the design also support single hand manipulation. Some participants expressed that they are used to manipulate the cell phone by one hand. And in many daily life situations, people sometimes only use one hand to manipulate the mobile device. The system could provide a way of manipulation that both support single-handed and bimanual interaction, such as our relocation and placing prototype. Or the system could provide some function to assist the single-handed interaction such as automatic flipping page.

6.3.2 Modification of Design Patterns

6.3.2.1 Pattern 1 3D Manipulation with Jig

First type of jig is the device itself. The key issue of this kind of jig is sensitivity. The active angle of tilting must be concerned carefully. The system could add deceleration when the cube rotates. The design of continuous rotation also causes users to rotate the cube too far and increases the mental load and errors. When the task is complicated, the design of continuous rotation could be canceled. The cube only rotates one time when users tilt the device and turn back once. This manipulation is more definite. Last, the system should provide visual cue or tutorial to help users realize the cube could be rotated.

Figure 6.7 Placing the jig to the side of the screen.

The second type of jig is a graphic jig on the screen. The first issue is about the position that two hands interrupt with each other. The position could be changed to the left or right side of the screen. The movement of the thumb is more natural and convenient (Figure 6.7). The second issue is the support of single-handed manipulation. The cube could rotate automatically when users move the item to special position. The third issue is the feedback. Although it is hard to provide the physical feedback, the visual feedback should be stronger and more interesting.

6.3.2.2 Pattern 2 Bimanual Relocation of Object

The first type is the concurrent relocation. The result of user evaluation shows it is hard to tilt device and press the item simultaneously. The graphic jig may be appropriate in this design. The most important issue is to reduce the mental load because users need to use their both hands in the meanwhile. The manipulation of each hand should be very simple and light. That the feedback should be very obvious and definite could relieve users' nervousness.

The second type is the sequent relocation. There is a valuable finding in the user evaluation. When users relocate the item step by step, they easily do the wrong gesture that is unnatural to them. For example, some users always tap the item inadvertently without dragging the icon after they rotate the cube. These subtasks couldn't group into a well "chunk" when they are unnatural to users. Buxton (1986) indicated that designer could build a chunk of subtasks to let novice learn the task fast. The visual effect of the floated item should be stronger to remind user that the item is still floated and movable and make the whole task more natural. In this design, the distinction between the cube and the upper layer where icon float is very clear, and users would see them as two independent layers. So they considered that the icon is moveable in both layers.

6.3.2.3 Pattern 3 Bimanual Object-Placing

The main issue is about the differentiation between upper and lower area. The differentiation of two areas should be more obvious. The look and feel of each area could be different. Or the items in each area could be different.

6.3.3 Summary of Discussion

Based on the comments gathered from user evaluation, we understand that relieving the mental load and supporting single-handed interaction should be concerned when designers develop a bimanual interaction in mobile device.

The modification of three design patters is summarized as follows:

(1) Pattern 1 3D Manipulation with Jig
For the Type 1 jig, mobile device itself, the additional recommendation is when the task is complicated, users tilt the device and turn back once, and then the cube only rotates one time. For the Type 2 jig, graphic jig, the recommendation is the jig shouldn't be the lower of the screen because it is hard to operate.

(2) Pattern 2 Bimanual Relocation of Object

For the concurrent relocation, the recommendation is the graphic jig might be the appropriate solution for bimanual interaction. For the sequent relocation, there are two recommendations. One is the visual effect of the floated item should be obvious. The other is the item should be movable

(3) Pattern 3 Bimanual Object-Placing

The recommendation is the differentiation of the two areas should be obvious.

6.4 Extended Implication

We have built and evaluated three design patterns. These patterns apply the division of labor to a 3D context. Two hands could control objects separately in different layers. Holding hand tilts the device to rotate the cube and free hand interacts with the screen such as tap and press. Besides, this kind of labor of division could be applied to different tasks and contexts.

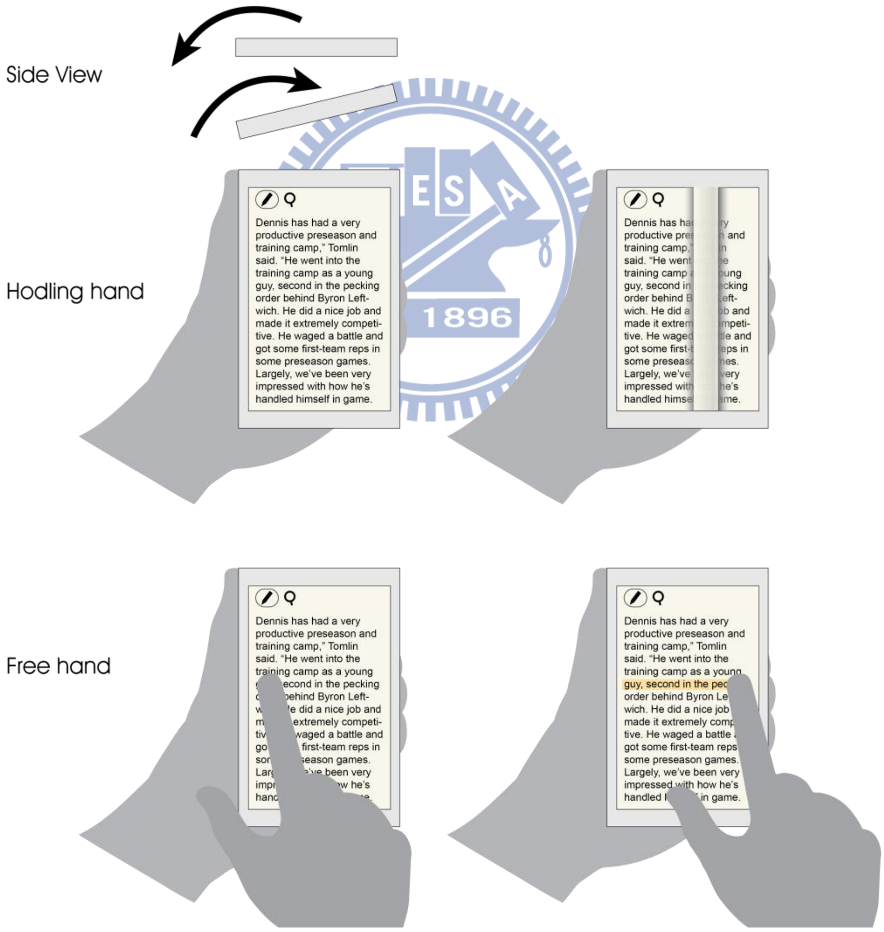
Pattern 4 Tilting to flip the page

There are many functions in reader software such as flip, mark, dictionary, enlarge and note. This pattern allows user tilt the device to flip the page. The other hand could use different function on the touch screen. For example, user could activate the mark tool, and they could slide on the words or sentences to mark them.The tool is activated until user deactivates it.

In contrast with the general gesture, this design could avoid accident touch when the tool is activated. User could keep the tool activated without flipping the page nervously (Table 6.10 in next page).

Table 6.10 Tilting to flip.

What
Allow user flip the page by tilting the device.
When
When people read a book, they sometimes want to use some tools such as mark, dictionary, note and etc. This pattern could distribute flip and other function to each hand.
Interaction
They could tilt the device to flip the page and use the other hand to do other functions on the screen. User need to tilt the device and turn it back, then the page is flipped. For example, user could activate the mark tool, and they could slide on the words or sentences to mark them. The tool could keep activated until user deactivates it. (see the figure below.)



7. CONCLUSION

The aim of this thesis is to explore which kinds of interaction design are suited to the bimanual interaction in mobile device. To this end, we performed two investigations. The exploratory study of pinching dough doll provides the basis for understanding the bimanual collaboration in the air where people use mobile device regularly. After building prototypes according to design guidelines, the user evaluation provides the basis of the additional concerns for the bimanual interaction in mobile device. The following findings are worth summarizing:

7.1 Finding

Through the exploratory study of pinching dough dolls, which ways of division of labor, gestures, and metaphors are suited to apply in bimanual interaction design were analyzed. The main divisions of labor are orientation / position (holding hand's action / free hand' action) and orientation / adjustment in the context of 3D assembly and adjustment. The jig, the stick, is an important tool of two hands' collaboration. It distributes roles of two hands. During the work, because of the jig, holding hand could assist or cooperate with free hand without interrupting it.

In mobile devices, several tasks such as relocation and categories have the similar goals to the tasks in pinching dough dolls. For these kinds of task, we presented five design guidelines for designing bimanual interaction in mobile device based on the observation of pinching dough dolls. In addition, three design patterns were built to present the practical application of the design guidelines.

According to the design patterns, we built three prototypes in the iPod touch for user evaluation. In the user evaluation, the concepts we presented of bimanual interaction satisfy participants. They expressed that the bimanual interaction of relocation and object-placing are natural and practical. They also felt that tilting the device to rotate the cube is intuitive and natural. Furthermore, the most important concerns of bimanual interaction in mobile device are relieving mental load and supporting single-handed interaction. Most participants preferred the sequent relocation because they only need to operate one thing at a time. However, the concurrent relocation is more intuitive to most participants, but it's hard to tilt the device and press the screen simultaneously. The graphic jig might be the appropriate solution of this task.

Based on the results of exploratory study and user evaluation, this thesis presents three design patterns for designing bimanual interaction in mobile device:

Pattern 1 3D Manipulation with Jig

Pattern 2 Bimanual Relocation of Object

Pattern 3 Bimanual Object-Placing

Pattern 4 Tilting to flip the page with touching to use tools

While designing bimanual interaction in mobile devices, there are several concerns based on the exploratory study and user evaluation.

(1) Two hand's roles must be interchangeable.

(2) System should allow two hands manipulate simultaneously.

(3) The manipulation of each hand should be light, especially in concurrent bimanual interaction.

(4) The system should support single-handed manipulation.

7.2 Reflection

This thesis consists of exploratory study and user evaluation. Even though these study methods offer valuable insights into the design of bimanual interaction in mobile device, they have some limitations:

(1) The context of pinching dough doll and the context of using mobile device are not exactly same. Although users accepted the design guidelines and design patterns, some tasks of pinching dough doll didn't apply to mobile device appropriately such as 3D winding. In addition, there are some limitations of the mobile devices such as the finger need to touch the screen. Because of it, the concurrent relocation caused obstructions when users need to tilt the device and press the screen simultaneously. In the future, the finding of pinching dough dolls could be applied to different platform.

(2) Because of time and budget, the prototype of the graphic jig is made by PowerPoint. Participants only image the feeling and feedback. However, some participants expressed that the graphic jig is more intuitive. It is still worth to be used in the manipulation of 3D objects. So the design of the graphic jig could be studied deeply by the evaluation of working prototype in the future.

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APPENDIX A: The Interview Script of Observation of Pinching Dough Dolls

User Evaluation訪談腳本

開場白

你好，我是交大應藝所的碩士生翁晨豪，很高興你能讓我訪問，我的研究主要是想要瞭解人們如何製作捏麵人。實驗的過程將會全程錄音錄影，所獲得的聲音影像僅供研究之用，且僅僅拍攝你的手部動作。接下來會請你製作幾個捏麵人，製作完畢我會檢視所錄下來的影像，如果有什麼想要更瞭解的我會在詢問你

基本資料：

- 年紀：
- 捏麵人齡：
- 慣用手：

進行捏麵人

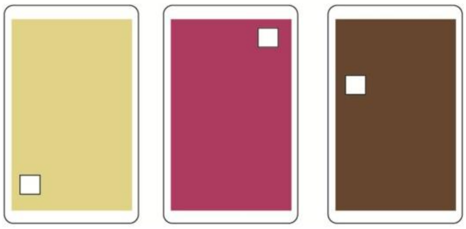
請師父多捏幾種不同類別的捏麵人，然後盡量可以運用到不同的工具。

追問問題：

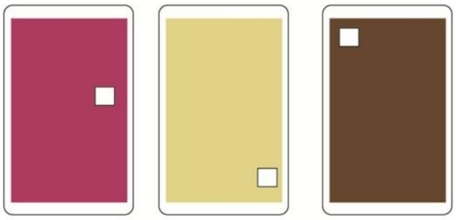
- 慣用手與非慣用手的習慣？
- 桌面擺設的原因？
- 棍子有什麼好處？跟沒有棍子的差別
- 為啥會交換手？
- 其他習慣。

APPENDIX B: Instruction Slides of User Evaluation

Prototype1



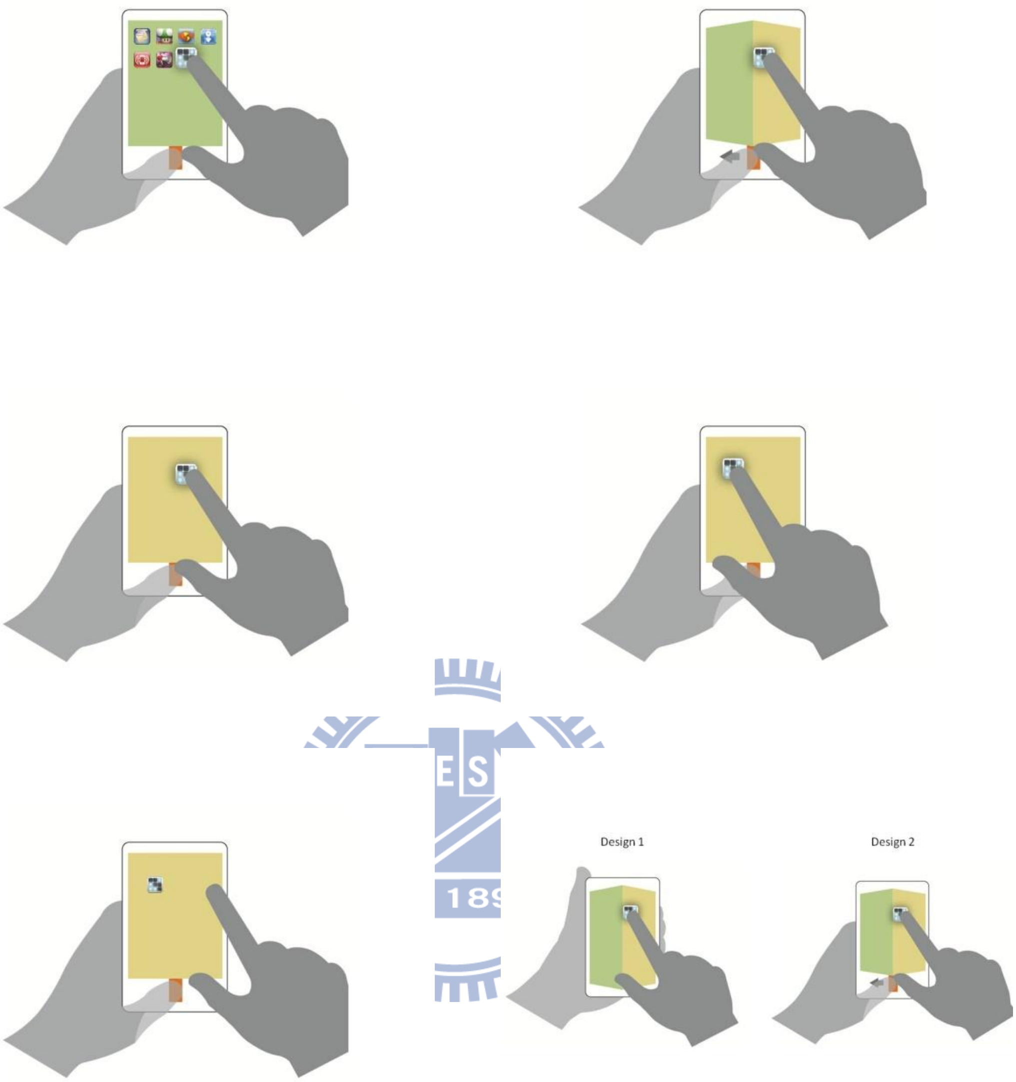
Prototype2



Prototype3

Session2 比較

Session3 轉手機 vs. 轉棍子


Design 1
Design 2

APPENDIX C: Satisfaction Questionnaire

滿意度問卷

			1	2	3	4	5	6	7	
1	這個系統的使用方式很簡單	不同意								同意
2	這個系統的使用方式符合直覺	不同意								同意
3	藉由使用這個系統，我可以有效的完成工作	不同意								同意
4	藉由使用這個系統，我可以迅速的完成工作	不同意								同意
5	藉由使用這個系統，我可以有效率的完成工作	不同意								同意
6	當使用這個系統時，我感到舒服自在	不同意								同意
7	學會使用這個系統是簡單的	不同意								同意
8	系統的使用介面讓我感到愉悅	不同意								同意
9	我喜歡使用這個系統的操作介面	不同意								同意
10	整體而言，我對這個系統感到滿意	不同意								同意
11	操作這個系統時，系統的回饋符合預期	不同意								同意
12	我會想要使用這個操作方式來進行指定的任務	不同意								同意

1. 此系統在操作上是否有任何讓你感到困惑不清楚的地方，如果有，請試說明之。

2. 你喜歡這個系統的哪些使用方式？

3. 你不喜歡這個系統的哪些使用方式？

4. 你認為其他人使用此系統時，會遇到什麼困難？他們會是什麼樣的人？會遇到什麼困難？

5. 對於此系統你是否能提供任何建議？

APPENDIX D: The Interview Script of User Evaluation

User Evaluation訪談腳本

開場白

你好，我是交大應藝所的碩士生翁晨豪，很高興你能來參加我的實驗，由於需要觀察手部的操作，實驗的過程將會全程錄音錄影，所獲得的聲音影像僅供研究之用，且僅僅拍攝你的手部動作。這次的實驗是一個使用性評估的實驗，所想要測試的僅僅是互動的部份，介面的美觀程度不再這次的評估範圍之內，所以畫面不會像市面上的軟體一樣美觀。且 ipod 僅僅是作為實驗的平台，並沒有特殊的目的，即使你使用過 ipod 或是 iphone，也不需要考量概念設計與目前 ipod/iphone 設計上的差異。接下來我會進行三個 Session，第一個大約 15 分鐘，會請你操作兩個介面，然後填寫問卷並訪談。第二個大約 10 分鐘，會請你操作一個介面，然後填寫問卷並訪談。第二個大約 10 分鐘，會請你比較兩個設計，詢問你的看法。

問題：<u>是否有使用過有觸控螢幕，加速器感應的手持裝置？ 低 中 重</u>

Session1 Relocation

Task1 階段性移動 item

說明：你所看到的這個畫面他是一個 3D 的方塊(如圖)，可以藉由手腕的轉動來轉動他的面相，而上面的 icon，可以用 tap 的方式將他拉起，拉起之後就如同跟下面的方塊脫離，當轉動下面的方塊時，拉起的 icon 並不會隨著方塊旋轉，當你 tap 他的時候，他才會在貼回 cube 上。

任務：現在請你任選三個 icon，然後依照我所指定的順序，一一放到不同的面相上面。

填寫問卷

問題：

- 這樣的雙手操作是否流暢？
- 這樣的立體感容易理解嗎？
- 會想要用雙手去操作嗎？
- 是否可以感覺到兩個物件與背景是不同的層次且分別可以被控制？
- 你覺得現在這樣的回饋可以嗎？需要提供怎樣的回饋可以幫助你理解？
- 你覺得這跟 iphone 現有的設計比較起來，哪個比較好？為什麼？

Task2 同時移動 item

說明：這個 prototype 跟第一個一樣是移動 item，但不需要 tap，直接把手指移上去，item 就會脫離表面，手指放開 item 就會自動黏回去，所以雙手必須要同時操作。

任務：現在請你任選三個 icon，然後依照我所指定的順序，一一放到不同的面相上面。

填寫問卷

問題：

- 這樣的雙手操作是否流暢？
- 會想要用雙手去操作嗎？
- 是否可以感覺到兩個物件與背景是不同的層次且分別可以被控制？
- 你覺得現在這樣的回饋可以嗎？需要提供怎樣的回饋可以幫助你理解？

瞭解 Relocation 整體概念感受與比較階段和同時

問題：

- 你覺得旋轉 cube 加上移動物品這件事情，對於雙手操作是自然且直覺的嗎？為什麼
- 這樣分別可以控制的設計(分工)喜歡嗎？為什麼？適合兩隻手作嗎？
- 哪個設計你覺得比較容易記得？
- 兩個設計分別的 mental model？
- 同時和 sequence 的雙手操作你比較喜歡哪種？
- 那個設計你覺得雙手操作起來比較直覺？為什麼？若考慮可以同時移動多個的狀態，會改變嗎？
- 哪個設計你覺得雙手操作起來比較方便？為什麼？若考慮可以同時移動多個的狀態，會改變嗎？
- 對於這兩個，使用上你覺得會有什麼優缺點？

Session2 Placing Object

Task1 放置物品

說明：現在這個畫面，上面綠色的部份跟下面棕色的部份是獨立的，上面綠色的部份跟第一個 Task 是一樣的，可以利用手腕的轉動來轉動上面的方塊。下面的 item 則可以用拖曳的方式移上去。

任務：現在請你將三個指定的 icon 分別移到相對應的畫面上面。

填寫問卷

問題：

- 這樣轉動 Cube+放置物品的方式，對雙手操作而言是自然 and 直覺得嗎？
- 這樣的雙手操作是否流暢與舒適？
- 會想要用雙手去操作嗎？
- 覺得是否適合用於分類的任務？

- 你覺得這樣的操作可以用在哪樣的任務？
- 你覺得現在這樣的回饋可以嗎？需要提供怎樣的回饋可以幫助你理解？

Session 3 Comparison with two types of jig

第三個 session 也是想要請你比較兩個設計，第一個是透過轉動方塊的方式是透過轉動手機。第二個是我現在要展示的，轉動方塊得方式則是透過螢幕上一個虛擬的棍子。棍子的粗細可以自行想像。

問題

- 哪個設計你覺得操作起來的感受比較好(比較扎實、比較好操作)，對於雙手合作而言？
- 這樣的間接操作，你覺得可以自然嗎？
- 那個設計你覺得雙手操作起來比較直覺？為什麼？
- 哪個設計你覺得雙手操作起來比較方便？為什麼？
- 對於這兩個，使用上你覺得會有什麼優缺點？
- 對於這兩個設計你有沒有什麼建議，或是覺得他會有什麼樣的問題？