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EXPLORATION OF THE SMARTPHONE AS AN INPUT DEVICE FOR MANIPULATING 3D SPACE

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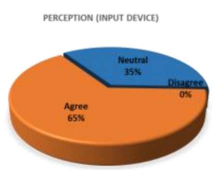
Graphical abstract



Abstract

The emerging capabilities of smartphones are fuelling a rise in the use of mobile phones as input devices. The complexity of 3D object manipulation has become a challenge for traditional input. Sensors and interaction methods available in a modern smartphone may turn it into an interactive input device for manipulation of 3D objects. This study investigates the usability of a smartphone as an input device for 3D, and also explores its potential as an optimal input method for manipulating 3D space. As such, usability study requirements are formulated, and prototype 3D software with defined tasks developed, to aid in the usability studies. User satisfaction is investigated for each defined task, with the aim to explore optimal interaction methods for different approaches in manipulating 3D objects.

Keywords: 3D object; 3D space; 3D manipulation

1.0 INTRODUCTION

Smartphones are an important piece of personal technology that many own nowadays. With the rapid advancement of technology, the way people use mobile devices has changed. This is due to the emerging capabilities of smartphones. Modern smartphones now come with several kinds of sensors. The most common includes accelerometer, gyroscope and multi-touch displays. With these sensors, performing various tasks has become more convenient and simpler.

In this paper, the focus is on the exploration of the smartphone as an input device for manipulating 3D space. The overall aim is to investigate the usability of smartphone as an input device for manipulating 3D space, as well as to find its optimal input method for manipulating different circumstances in 3D space. The ability of a user to efficiently manipulate a 3D object in a virtual world viewed on a desktop display is a challenging task for many users due to complex 3D interactions [1]. Limitation on the instruction or controllability of ordinary input device has significantly decreased the performance of manipulating 3D objects.

2.0 LITERATURE REVIEW

An experiment based on surface and motion gestures to manipulate 3D objects using mobile device was conducted in [1]. The purpose of the experiment is to capture the usability of having multiple interactive inputs (multi-touch, dual-touch, and motion) in manipulating 3D objects with mobile devices. Participants have been asked to define a set of gestures that they feel most comfortable and convenient with for different sets of manipulation tasks via the prototype device, where the participants have basic knowledge on using touch-based mobile devices. The study shows that the surface gesture interaction is the most preferred interaction method and easier to perform compared to motion gestures, due to unfamiliarity with motion gestures and the relative size of the prototype which makes it hard to move [1]. In addition, participants also preferred this to traditional mouse inputs because of the intuitive controllability [1]. The experiment in [2] also notes that although 3D-oriented rotation, scaling and translation techniques have limited range of actions in multi-touch surfaces, the interface is still valuable as it allows novice users to well perceive 3D objects by manipulating them easily.

In addition to touch based surfaces, other forms of interaction for 3D space manipulations had also been conducted. An experimental evaluation of the use of the Microsoft Kinect to perform 3D object manipulation tasks was conducted in [3]. The objective of the experiment is to study the performance of using the Kinect input method to manipulate 3D object. Raj, *et al*., [3] discussed that the performance of manipulating 3D object will be optimal when the control space of the input devices is as close as possible to the real rotation movement of the 3D object. Two visualize feedback methods were used in the experiment. The first one uses a generic sphere as a pointer to a virtual object when the user's gesture is operating, while the other uses a rendered self-avatar, which is synchronized with user's hand while performing the task. The studies show that the portrayal of a self-avatar had little effect on the performance, but the rotation time for the self-avatar was faster than the sphere [3]. In addition, [3] also notes that differences in gender and gaming experience also affect the performance in performing the rotation.

Kumar *et al*., [4] conducted a study involving data gloves and 3D manipulation. The research was mainly focused on the usability and the accuracy of the data glove [5] in performing several actions, namely, air-writing, pointing and 3D object rotating. Data glove based interfaces are designed to replace static keyboard and mouse input, so as to provide a natural way of interaction by making gestures while communicating [4]. In order to achieve higher accuracy on virtual world manipulation, all gestures have to be pre-defined and trained to be recognized by the system. The study collected all perform gestures and their precision is analyzed. The results in [4] show that the degree of freedom of the data glove has made it more efficient than traditional keyboard and mouse in manipulating 3D objects.

A new motion interaction technique called AirMouse is presented by [6]. The AirMouse makes use of a camera to track the movements of fingers on top of the keyboard in a laptop computer. The objective of the AirMouse is to eliminate large space for interaction and provide a more promising 2D and 3D interaction compared to touchpads or similar devices. According to [6], previous studies show that exiting devices that are specifically designed for 2D or 3D interaction are bulky and expensive. Due to the lack of flexibility, some devices are unable to perform well in certain circumstances. The AirMouse is benchmarked against two off-the-shelf devices which are the PHANTOM [7] an isotonic arm-based pointing devices, and the Spacemouse [8]. The Spacemouse is found to be slower than the PHANTOM and the AirMouse due to users having to decompose the pointing movements before starting to manipulate [6]. Users prefer a device that is intuitive, direct and easy to learn while leading correct performance [6].

3.0 METHODOLOGY

This section details the methodology of this research. Research requirements and project designs are elaborated in the following Sub-Sections.

3.1 Usability Study Requirements

The usability study is divided into aspects of manipulating 3D space. The established requirement will act as a framework in designing the tasks that will be given to participants for usability testing. The aspects are camera rotation, object rotation, camera translation, object translation, camera zooming and selection. The requirements are shown in Table 1. To design the tasks, a 3D space environment is created, with 3 different scenes taking place.

Table 1 Usability study requirements

Usability Aspects	Manipulation	Descriptions
Camera Rotation	About X-Axis	Rotate the viewing angle of the object/environment around X-Axis
	About Y-Axis	Rotate the viewing angle of the object/environment around Y-Axis
	About Z-Axis	Rotate the viewing angle of the object/environment around Z-Axis
Object Rotation	About X-Axis	Rotate the object around X-Axis
	About Y-Axis	Rotate the object around Y-Axis
	About Z-Axis	Rotate object around Z-Axis
Camera Translation	About X-Axis	Move the viewing angle of the object/environment around X-Axis (Left/Right)
	About Y-Axis	Move the viewing angle of the object/environment around Y-Axis (Up/Down)
Object Translation	About X-Axis	Move the object around X-Axis (Left/Right)
	About Y-Axis	Move the object around Y-Axis (Up/Down)
Camera Zooming	Zoom In	Diminish the environment viewing area.
	Zoom Out	Enlarge the environment viewing area.
Selection	Select	Select an object in the environment.
	Unselect	Unselect a selection of an object in the environment.

3.2 Test Cases and Tasks Design

Figure 1 shows the scene for the object manipulation task which include an Earth and a half transparent cube. The interactions involved are object selection and movement. The objective of this task is to move and place the Earth into the half transparent cube.

Figure 2 shows the environment for the second task which focuses on rotation. The objective of this task is to rotate the Moon and having to look for the three astronauts standing on it.

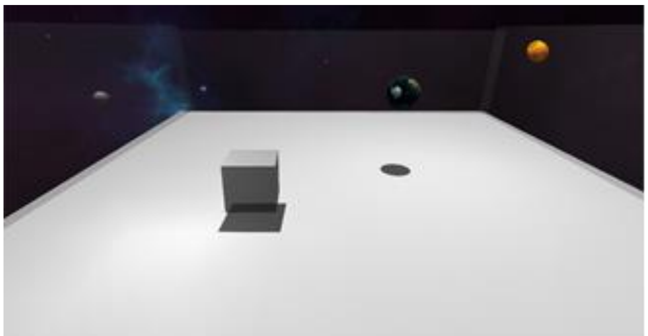


Figure 1 Scene for object manipulation task

Figure 2 Scene for rotation task

Figure 3 show the scene for camera manipulation (third task). The objective of this task is to manipulate the camera position and angle in order to identify the object that is located behind the Sun.

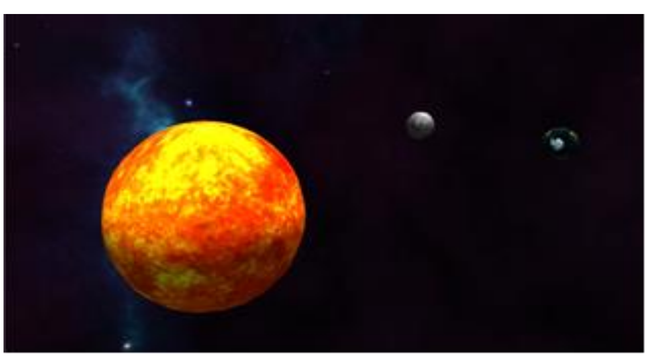


Figure 3 Scene for camera manipulation

Interaction is observed in three different scenes to reduce confusion. Each scene is focused on an interaction study to ensure that the users clearly understand the test requirements and reduce bias in the response.

The test cases are constructed around the usability study requirements and serve as the guideline for the survey. Two test cases are presented for each task, with a 'main' and an 'alternative' interaction options for control. Tables 2, 3 and 4 model the test cases for object selection and movement, rotation and camera manipulation respectively.

3.3 Screen Design

For the screen design, the three major functions: Select, Rotate and Forward are emphasised. The design is inspired by the laptop touch-pad, which has two buttons (right or left button) in addition to a touch sensor pad. Figure 4 shows the design of the screen. A movable Select (A) button is for selecting, while the other two buttons; Rotate (B) and Forward (C) are for rotating and moving respectively.

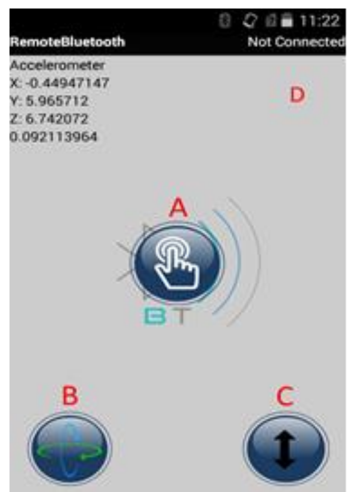


Figure 4 Screen design of input application.

3.3 Questionnaire Design

The questionnaire is categorized into 3 sections (A, B and C). Section A consists of experience and demographics of the participant.

In the Section B, all the questions primarily focus on the degree of intuitiveness, and user satisfaction towards the system. USE (Usefulness, Satisfaction, and Ease of Use) Questionnaire [9], a questionnaire for usability measure is used as a reference for the questions in Section B (section 2).

In Section C, the questions are also developed using the USE Questionnaire [9] as a template and primarily focused on system usefulness and user acceptance. Responses follow a five-point rating scale.

Table 2 Test cases for object selection and movement

Test Case ID	**T01 (Type 1)**
Test Case Summary	Translation of the Planet Earth into the semi-transparent cube by using touch-screen interaction.
Test Steps	1. Navigate the on-screen environment cursor by using the mobile touch-screen to select the Earth. 2. Move the "Select" button while holding down to navigate the Earth. 3. Press the "Forward" button to turn on the forward function and dragging up or down on the screen to move the Earth along the Z-axis. 4. Move the Earth into the cube.
Expected result	The Earth is successfully moved into the cube.
Test Case ID	**T02 (Type 2)**
Test Case Summary	Translation of the Planet Earth into the semi-transparent cube using the accelerometer.
Test Steps	1. Navigate the on-screen environment cursor by rotating or tilting the smartphone physically to select the Earth. 2. Holding down "Select" button and rotate or tilt the smartphone physically to navigate the Earth. 3. Hold down "Forward" button and tilt forward and backward to move the Earth along the Z-axis. 4. Move the Earth into the cube.
Expected result	The Earth is successfully moved into the cube.

Table 3 Test cases for object rotation

Test Case ID	**R01 (Type 1)**
Test Case Summary	Rotate the Moon to find out the number of astronauts on it using touch-screen interaction.
Test Steps	1. Navigate the on-screen environment cursor by using the mobile touch-screen to select the Moon. 2. Press the "Rotate" button to turn on the rotate function and use the touch-screen to rotate the Moon. 3. Zoom-in by pinching the touch-screen.
Expected result	The number astronauts on the moon is accurately identified.
Test Case ID	**R02 (Type 2)**
Test Case Summary	Rotate the Moon to find out the number of astronauts on it using the accelerometer.
Test Steps	1. Navigate the on-screen environment cursor by rotating and tilting the smartphone physically to select the Moon. 2. Rotate the Moon by holding down the "Rotate" button and rotate or tilt the smartphone physically. 3. Zoom-in by pinching touch-screen.
Expected result	The number astronauts on the moon is accurately identified.

4.0 DATA ACQUISITION

4.1 System Setup

The test system involves a computer, where the 3D environment takes place and a smartphone, from which the inputs come from. The smartphone is a Samsung Galaxy W I8150, with a 3.75 inch TFT capacitive touchscreen, accelerometer and gyroscope.

4.2 Acquisition Setup

For each participant in the study, the investigation was conducted in three separate sessions. Each session consisted of one task. Each participant was given 30 minutes to complete the task. Participants were given approximately 5 minutes to familiarise with the system before each actual task began. When a task was completed, the participant was asked to fill up the questionnaire accordingly and proceed to the next task. A total 20 students of

Multimedia University (17 male, 3 female) took part in this study. The age of the participants was between 20 and 30 years old. All participants completed the tasks within the given time.

Table 4 Test cases for camera manipulation

Test Case ID	**C01 (Type 1)**
Test Case Summary	Move and rotate the camera viewing angle to identify the object hidden behind the Sun using the touch-screen.
Test Steps	1. Moving the camera up or down or left or right by moving the select button while holding down to get an ideal position. 2. Press the "Rotate" button to turn on the rotate function and using the touch-screen to rotate the view angle. 3. Zoom-in by pinching the touch-screen.
Expected result	Successfully identify the object.
Test Case ID	**C02 (Type 2)**
Test Case Summary	Move and rotate the camera viewing angle to identify the object hidden behind the Sun using the touch-screen and accelerometer.
Test Steps	1. Moving the camera up or down or left or right by moving the select button while holding down to get an ideal position. 2. Rotate the camera by holding down the "Rotate" button and rotate the smartphone physically. 3. Zoom-in by pinching the touch-screen.
Expected result	The object is successfully identified.

5.0 RESULTS AND DISCUSSIONS

On the preference of the interaction type, the rating score of each interaction method for object movement was relatively close, with the motion sensors (accelerometer and gyroscope) (Type 2) getting a slightly higher score (Figure 5). This shows that the touch-screen is accepted by the participants, but many prefer to use motion sensors if given the choice. From analysis and feedback, motion sensors provide a direct expected response, and they liven up the interaction to provide some form of gratification.

As for the camera or object rotation, the touch-screen (Type 1) obtained the higher score. This is due to the negative responses on the second task for the motion sensors (Figure 6). Participants explained that they needed more time with the motion sensors due to the unfamiliarity and difficult controllability. Ortega, *et al*. [6] confirmed this with participants preferring a method that is intuitive and easy to learn while providing correct performance.

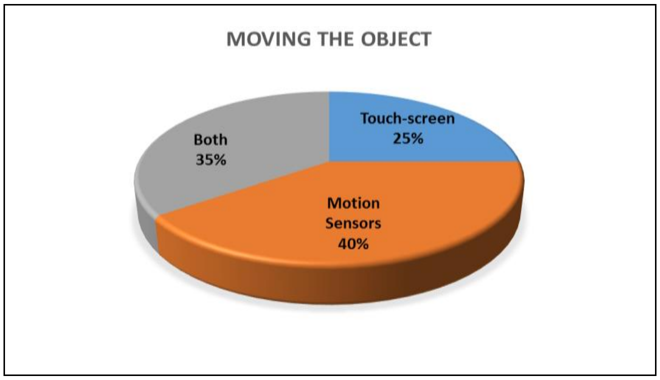


Figure 5 Preference for performing object manipulation

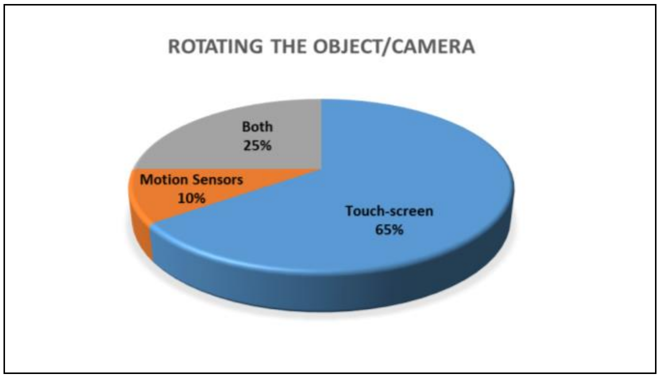


Figure 6 Preference for rotating object or camera

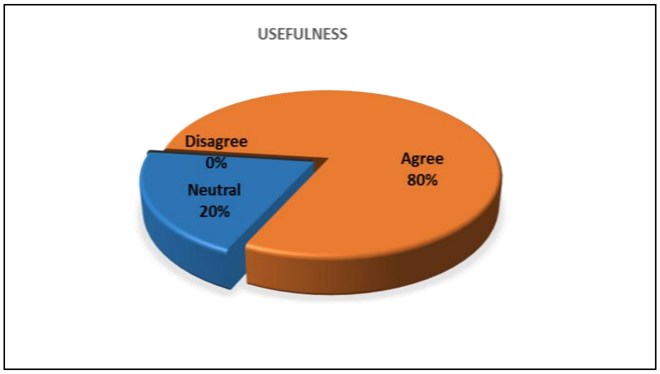


Figure 7 Participants' reception on the usefulness of the interaction methods

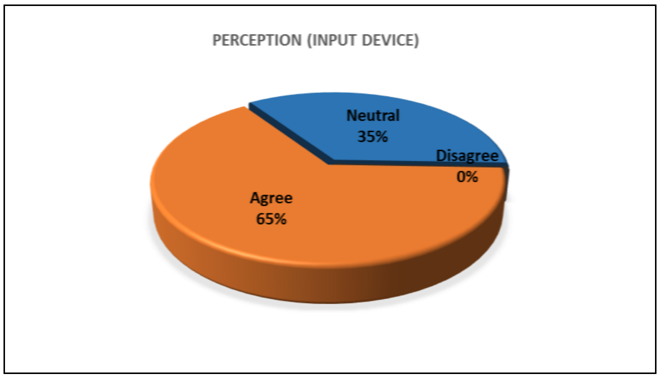


Figure 8 Participants' reception on the capability of the interaction methods to replace traditional input methods

As for the last stage of the survey, user acceptance and usefulness of the system obtained a promising response. As shown in Figure 7, 80% of the participants agree that the proposed interaction methods are useful in terms of manipulating 3D objects. Despite the participants' optimism towards the usefulness of the methods, as shown in Figure 8, 15% percent of participants disagree that the system have the ability to replace traditional input devices (mouse or keyboard) in 3D object manipulation.

6.0 CONCLUSIONS

The study has shown that technologies present in a smartphone have turned it into an input device that is able to provide different types of rich interaction methods for 3D, namely touch and motion. In addition, this study has shown promising result in terms of usability for interaction methods present in smartphones as input methods for manipulating 3D space. Preferred interaction methods, namely touch or motion, for typical 3D manipulation tasks have also been presented.

In future, it would be interesting to investigate good mappings between surface and motion gestures and other 3D tasks. Further research into these interaction methods in the 3D landscape may be used to form best practices or guidelines for interactions in 3D applications. Correlations can also be investigated for forms of interaction in different 3D modes, in particular virtual reality (VR).

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