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Designing Ray-Pointing using Real hand and Touch-based in Handheld Augmented Reality for Object Selection

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***Abstract*—Augmented Reality (AR) have been widely explored worldwide for their potential as a technology that enhances information representation. As technology progresses, smartphones (handheld devices) now have sophisticated processors and cameras for capturing static photographs and video, as well as a variety of sensors for tracking the user's position, orientation, and motion. Hence, this paper would discuss a finger-ray pointing technique in real-time for interaction in handheld AR and comparing the technique with the conventional technique in handheld, touch-screen interaction. The aim of this paper is to explore the ray pointing interaction in handheld AR for 3D object selection. Previous works in handheld AR and also covers Mixed Reality (MR) have been recapped.**

***Keywords*—3D Object Selection, Handheld, Gesture, Manipulation, Interaction, Raycasting, Augmented Reality, Mixed Reality**

I. Introduction

In today's modern world, smartphones have evolved into an indispensable means of communication in our everyday lives. As a handheld device, smartphones have always been nearby and becoming necessary with the latest advancement such as high-resolution cameras and displays. It widens the possibilities of development of AR and Mixed Reality (MR) for handheld device.

According to the virtuality continuum introduced by [1], MR enables the merging of AR and AV (augmented virtuality) between real and virtual environments. MR is generally recognised as an innovative technology that has the ability to offer a smooth and practical approach for natural interaction by allowing users to communicate with virtual objects which have been superimposed over our physical environment in real time. Meanwhile, AR has been defined as a system that: 1) integrates the real and virtual worlds; 2) is real-time interactive; and 3) is registered in 3D [2, 3]. Thus, to provide such interaction, the essential task should be performed precisely and correctly, which is the target selection task.

3D object selection task is commonly known as the essential feature of interaction in AR, MR, and Virtual Reality (VR). In handheld AR and MR environments, only one hand is free for interacting, which will only allow the use of basic one-handed touch gestures for selection. Further research remains to be done to enhance the overall user experience when selecting object on a handheld platform for these technologies. Currently, issues of distant and tiny object selection, occluded object, and object selection in a dense environment are still challenging for AR, MR, and VR [5]. Meanwhile, interaction in handheld environments is always restricted to simple 2D pointing and clicking through device's limited touchscreen [4].

Furthermore, interaction through 3D surfaces encounters several other issues such as occlusion on the screen (fat finger), small screen resolution, and fatigue feeling caused by holding the handheld for too long while performing the interaction [6]. Hence, the issue of interaction for a single-handed handheld system remains unresolved. We intend to explore the potentiality of hand gesture interaction technique of implementing the raycasting technique and comparing with touch-based the conventional technique for object selection in handheld AR in this paper.

II. Related Works

Many researchers have come out with their own or advance interaction metaphor, either by the interaction itself or by improving tracking or marker used for the interaction. By utilizing actual real objects and equipment, tangible interfaces allow direct interaction with the physical world. Three big trends have identified in tangible AR experiences: (1) interact by using paddle (2) interact by using glove, and (3) interact by using direct hand [7].

Yusof *et al.* [8] has proposed a marker to marker interaction using paddle-based to perform tangible interaction in handheld AR. Their biology prototype is built on the principle that the user will adjust the light strength in the atmosphere to observe changes in the pace of the water molecule flow by bringing the paddle-based marker near to the simulation (see in Fig. 1). The prototype developed by [9] represents before the virtual objects interact (Fig 2(a)) and when they both interact with each other (Fig 2(b)).

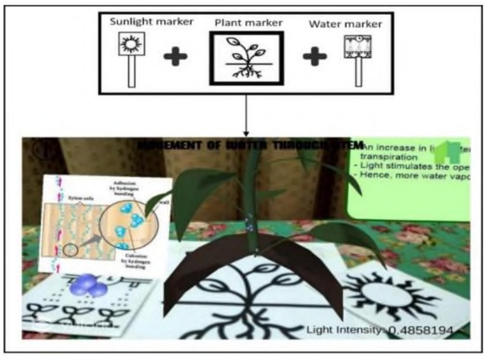
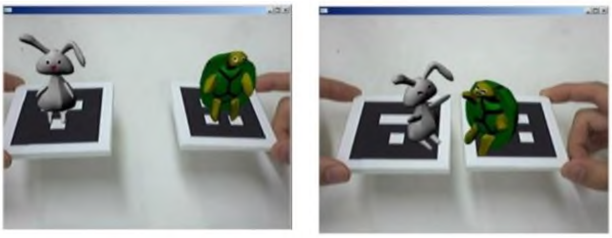


Fig. 1. Bio-WTiP Handheld AR application [8]



(a) (b)

Fig. 2. A marker to marker interaction in Tangible AR application [9]

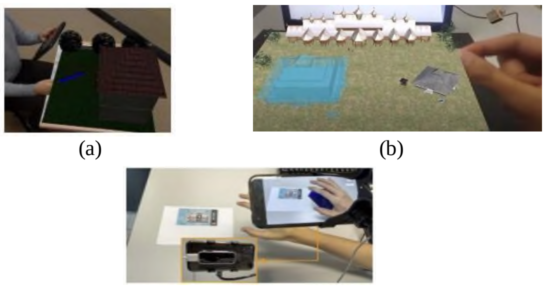
Meanwhile, [10] demonstrated a low-cost three-dimensional interaction technique using ARToolKit planar markers for interaction with and manipulating the virtual objects in an MR world (refer Fig. 3(a)). Although the AR paddle is capable of performing simple interactions, it is unable to communicate naturally and intuitively with the actual world of AR environment. Unlike a controller which usually takes more learning efforts, when we communicate with the virtual object, we are more likely to use our common behaviour with hands [11]. As a result, numerous scholars have explored on the interaction using hand gesture in AR environment. Through gesture interaction of natural actions, an effective and intuitive interaction can be allowed.

A suitable technique for the interaction is critical since they allow a smooth experience while interacting with the virtual object, which is a significant field of AR research. A study by [12] introduce a manipulation method by using fingertip-based to interact with the virtual object in AR application as shown in Fig. 3(b). Meanwhile, Battisti *et al.* [13], has proposed an interaction using bare hand with the setup consisting of a Leap Motion fixed on the back of a smartphone as shown in Fig. 3(c).

Table 1 describes the focus area of interaction metaphor in the timeline. For this study, the focus areas are divided into two, (1) hand gesture-based, and (2) touchscreen-based. AR interaction using handheld devices mostly revolve around the touch screen design.

TABLE I. The Interaction Metaphor in Handheld AR

Researcher	Research Title	Year	Interaction Metaphor
Yusof & Ismail [14]	Virtual Block Augmented Reality Game Using Freehand Gesture Interaction	2020	Hand gesture-based
Asokan et al. [15]	Assistance for Target Selection in Mobile Augmented Reality	2020	Touchscreen -based
Ababsa et al. [16]	Combining HoloLens and Leap-Motion for Free Hand-Based 3D Interaction in MR Environments	2020	Hand gesture-based
Qian et al. [17]	Modality and Depth in Touchless Smartphone Augmented Reality Interactions	2020	Hand gesture-based
Nor'a et al. [12]	Fingertips Interaction Method in Handheld Augmented Reality for 3D Manipulation	2019	Hand gesture-based
Qian et al. [18]	Portal-ble: Intuitive Free-hand Manipulation in Unbounded Smartphone-based Augmented Reality	2019	Hand gesture-based
C.-J. Lee & Chu [19]	Dual-MR: Interaction with Mixed Reality Using Smartphones	2018	Touchscreen -based
Huo et al. [20]	Window-Shaping: 3D Design Ideation by Creating on, Borrowing from, and Looking at the Physical World	2017	Touchscreen -based
Viyanon et al. [21]	AR Furniture: Integrating Augmented Reality Technology to Enhance Interior Design using Marker and Markerless tracking	2017	Touchscreen -based
Sharma et al. [22]	Designing to Split Attention in a Mixed Reality Game	2015	Touchscreen -based
Fritz et al.[23]	Markerless 3D Interaction in an Unconstrained Handheld Mixed Reality Setup	2015	Hand gesture-based
Mossel et al. [4]	DrillSample: Precise Selection in Dense Handheld Augmented Reality Environments	2013	Touchscreen -based
Caballero et al. [24]	Behand: Augmented Virtuality Gestural Interaction for Mobile Phones	2010	Hand gesture-based



(a) (b) (c)

Fig. 3. Tangible interaction for handheld AR

Based on Table 1, recently researchers have been more interested in hand gesture-based metaphor to perform an interaction with the virtual content within the environment. [12] has presented a prototype that allows fingertip manipulation method in handheld AR interface for the user to interact and manipulate the virtual 3D objects. Within this study, the hand gestures were tracked using a sensor tracking device that is being attached to the back of the handheld device. Meanwhile, [14] has explored the implementation of freehand gestures to create and interact within a virtual block game in AR. Other than selection, several other interactions were also included which are, translation, release, and rotation.

Users can interact with virtual objects more naturally and intuitively in an AR environment by combining virtual object selection and manipulation with real-hand gestures. This blurs the line between virtual and real-world environment [25]. However, there are several common issues that need to be faced. Firstly, the tracking process, if not smooth, will hinder the interaction progress. Due to the limited display space of the handheld device, users may be unable to translate and rotate virtual objects due to the distance (objects are far away, making them appear smaller) [26]. Third, as the object is being occluded by the other object, making the area available for target selection is smaller, thus making it hard to select for manipulation [4, 27, 28].

Touchscreen-based metaphor is implemented in Window-Shaping [20], a MR interaction metaphor that is tangible for ideation that enables the direct development of 3D forms on and around real objects. In this study, the interactions are done using input from the touch screen of the handheld used. The study employs a straightforward multi-touch interface to facilitate the development and editing of 3D models on any physical surface. In ARFurniture [21], the study develops a handheld application that enables users or consumers to imagine how furniture parts would appear and function (to scale) in their homes, as well as providing product information to aid in consumer decision-making. Although the interaction of touchscreen-based metaphor is more familiar to the user, an efficient and intuitive interaction can be performed with gesture interaction of natural actions.

III. Ray Pointing and Touch-Based in handheld AR

This section discusses on the metaphor of interaction in handheld AR. The interaction metaphors have been explored and divided into two categories, ray-pointing interaction and touch-based interaction.

A. Ray-Pointing Interaction

As stated by [29], in performing object selection, there are two primary types which is virtual hand and ray casting technologies. In handheld device interfaces, ray-casting is often used to manipulate 3D objects according to [30]. They enhanced the ray-casting interface's virtual object manipulation accuracy by adjusting the sensitivity based on the distance between the user and the object. Raycasting is commonly used for a target pointing technique in VR environments [31]. Although this technique is implemented in the VR environment, because of the nature of the process selection, it may also be used in an AR environment. Manipulation tasks are always preceded by (and depend on) selection tasks. As a result, badly designed selection techniques frequently have a detrimental effect on overall user performance. Meanwhile, success on smaller and distant objects is affected by precision of the pointing device and motor capabilities of the user. Present pointing facilitation techniques are only implemented in the form of virtual hands, i.e., for targets within reach.

Meanwhile, a study proposed AR Pointer using an integrated 6-degree of freedom (DoF) inertial measuring unit (IMU) sensor in an off-the-shelf handheld device to cast a virtual ray used to accurately select objects [32]. AR Pointer has implemented simple touch gestures widely used for 3D object manipulation in smartphones, allowing users to quickly interact with 3D virtual objects using AR Pointer without a lengthy training time. A raycasting-based interface was built to produce a method similar to a laser pointer, as demonstrated in Fig. 4. In [32], they agreed that by using basic touch gestures implemented for AR Pointer, users will be able to manipulating the 3D objects easily

Recently, ray-pointing has been used to select the distant object in handheld AR interface [34]. They have agreed that pointing a ray in the same manner as pointing using laser, thus it would help to hit the distant object in AR scene. They used bare hand to select the object, as shown in Fig. 5. Handheld device limited to small screen, to see the distant object in AR scene is difficult and to select the distant object that hidden by other object also would be difficult tasks. Ray-pointing has been chosen to solve the distant object and depth issues in AR [28]. In Yin *et al.* [28], they agree that touch-based interaction is a standard and aesthetically appealing mode of input for AR applications. However, designing AR selection techniques for mobile applications equipped with touchscreens is not an easy feat. One concern is when users occlude target object with their fingertips when interacting with them. Additionally, selecting targets by touch becomes more complex as they are occluded from one another owing to variations in spatial depth. Hence, ray-pointing has been proven appropriate as object selection technique that able to accurately perform the selection although the target object are in small size or occluded in handheld AR [28].

More advanced ray-casting technique in GyroWand [33], a 3D interaction technique based on raycasting for self-contained AR head-mounted displays (HMD). Unlike conventional raycasting, which relies on the absolute spatial and rotational tracking of a user's hand or joystick to guide the ray, GyroWand relies on the relative rotation values recorded by a handheld controller's inertial measurement unit (IMU). Fig. 6 shows the user enables raycasting in HMD.

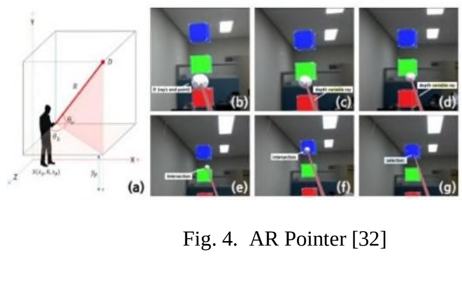


Fig. 4. AR Pointer [32]

Fig. 5. Finger-ray on handheld device using real hand gesture [34]

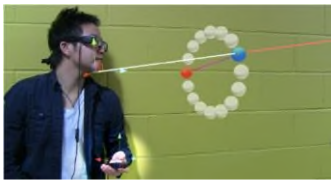


Fig. 6. GyroWand enables raycasting in HMDs [33]

B. Touch-based Interaction

Input from a handheld device's touch screen is familiar to users, making it easy to understand and perform. In some cases, the researchers take a different approach to explore other available possibilities in MR to enable improved interaction user experience [20, 35].

In DrillSample [4], the issue of the virtual object being occluded in a dense environment was addressed, and a new selection technique was designed. Due to one hand is required to hold the handheld, only one hand is available for interactions which only suitable for selection using basic touch gestures. Additionally, selecting objects with touch input may be imprecise due to the wide region covered by the user's fingertip on the touchscreen. The selection process was done in three-step: (a) target selection and DrillSample construction, (b) optional inspection during refinement step, and (c) final target selection as shown in Fig. 7.

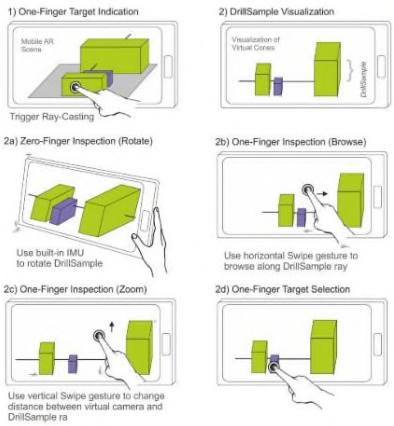


Fig. 7. DrillSample by Mossel *et al.* [4]

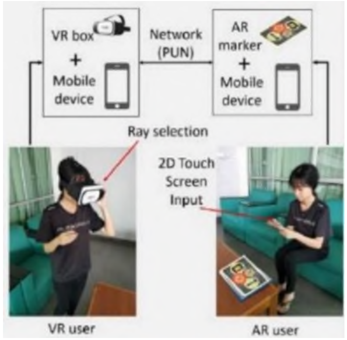


Fig. 8. Gaze input using ray and touch-based in handheld AR [36]

Fig. 9. ARGarden using touch-based approach with titling using gyroscope in handheld AR [37]

Meanwhile, in [36], they have combined touch-based with ray pointing. They hit the object using gaze input in VR and AR fusion interface. They combined AR and VR into one interface and performed gaze input with touch-based. Touch-based has been implemented for AR. While ray-pointing for VR. Fig. 8 shows the architecture where they have AR/VR fusion and combining gaze interaction using ray and touch-based for 3D matching game. ARGarden [37] has implemented collaborative AR interfaces in handheld devices and using touch-based for multi-user interactions as shown in Fig. 9. The touch-based methods consist of *Tap*, *Spread* and *Pinch*. They also proposed the titling using device-based method. When the device is tilted to the right, the object is rotated to the right as well. When the user rotates left, the object rotates left as well. The tilt input is obtained from the gyroscope. ARGarden is handheld AR interface that combines touch-screen with gyro-meter for titling.

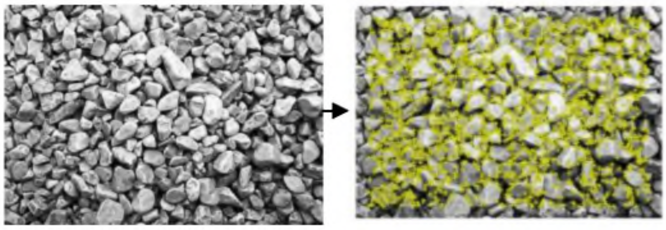
IV. Ray-Pointing in Handheld AR

This proposed method uses an AR with the use of Leap Motion to enable hand tracking to track the hand gesture while interacting with the virtual object.

A. Enabling AR Tracking

This process focuses on the AR tracking method, which is used to establish a real-world focal point for viewing the virtual object correctly. The Vuforia SDK is used to allow the AR tracking in the real world. The tracking technique used is feature-based tracking, which compares feature point data contained in the Vuforia database to determine the location of the assigned image marker. Additionally, the tracking technique requires the virtual target to be registered on top of the actual marker in the real world.

By capturing the original RGB image (refer Fig. 10(a)) and converting it to feature, the camera then able to recognized the image as the target marker. In the process, the marker would be transformed to grayscale through image processing and processed as an image target in the form of features, as shown in Fig. 10(b). The system recognised the features as distinctive identifiers. Once the system recognises the marker, it is associated with the virtual object.



(a) (b)

Fig. 10. AR marker converting process

B. Executing Real-Hand Gesture Tracking

Leap Motion device has been used to track human real hands. It has been placed at the back of the smartphone, attached in the middle position to track user's bare hand and must be activated and connected properly. Fig. 11 shows the setup of Leap Motion with the handheld device being hold by the user.

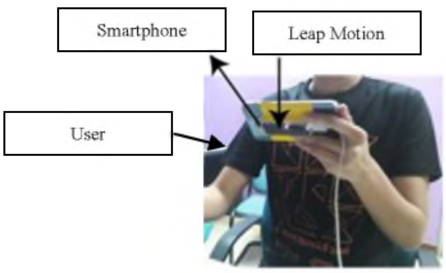


Fig. 11. Leap Motion setup with the user [12]

The tracking device enables the system to access the depth data, allowing it to track and map the user's hand position in the real world. This data are used by the device to interpret the hand's skeletal calibration, which leads to skeletal hand tracking. The Leap Motion would be able to distinguish the hand hierarchy, including fingertips, using this tracking method. These hand regions would then be used to track the hands, especially the fingertips, as well as to interpret gestures made on it.

The application then produce data on the tracked hand's positions and orientations. The position of the tracked user hand is mapped into the application by the system. The process then continues on to modelling the virtual hand skeleton, which is then used in conjunction with the rigid body to allow interaction cues. The last step enable the production of the gesture input and dynamic gestures. Fig. 12 shows the flow of hand gesture tracking process.

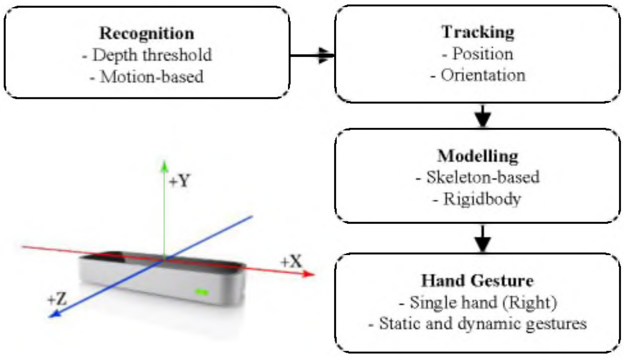


Fig. 12. Flow of the tracking process for hand gesture

The Leap Motion device cannot be directly connected to handheld device due to device limitation and Leap Motion is not design for handheld purpose. Therefore, the gesture data that has been captured by Leap Motion needs to be sent over the network to the AR scene. The application needs to ensure the internet perfomance in a stable bandwidth to make gesture movement smooth and robust. Otherwise, the data transmission has been delayed to obtain real-time hands movement if the network is weak. To accomplish this, we allow multiplayer networking, as illustrated in Fig. 13 adopted from [12]. The data from the tracked and captured hand gestures in real time (position and orientation) by Leap Motion will be transmitted through PUN (Photon Unity Networking) [38] as the network protocol in the handheld AR application.

Fig. 13. Flow of the data send by sender and receive with PUN to client [12]

PUN always enables the use of a master server with one or more game servers. The master server is responsible for managing the games that are currently playable as well as for matchmaking. After locating or creating a room, the actual gaming takes place on a game server. Both servers are hosted on hardware devices.

The user's hand's position and rotation are monitored and transmitted across the network from the desktop (sender) to the handheld device (client). The Leap Motion that were connected to the computer (laptop) act as the sender and secured at the handheld device's back, will transmit the data pertaining to the recognised hand gesture to the PUN server. The receiver/client, which is the AR application on the handheld device, then receives the data. The application will collect the data for the hand gesture signal from the server and will manage the interaction.

C. Ray-pointing using Real Hand (Finger-Ray)

There are several types of interaction that can be performed using Ray-pointing which include object selection and manipulation. However, the object manipulation which involve translation, rotation, and scaling on the 3D object will not be discussed in this paper, as our main focus is for selection only. The virtual objects in the AR scene are consists of primitive objects, five cubes which will displayed to the user as the marker were detected. The virtual object will only be selected if and only if the ray is hit the virtual content to perform selection as shown in Fig. 14.

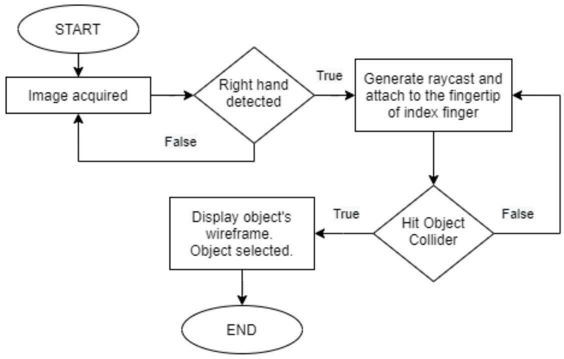


Fig. 14. Flowchart for performing selection

Fig. 15 shows a ray-casting has been drawn when user's finger has been found. The handheld AR interface captures user's real fingertip and draw the sphere to indicate the finger. To select the object, user will need to point the attached ray on the index finger to the object. Ray pointing is used to select the object. When object shows yellow wireframe, it indicate the object has been hit and selection was performed.

In the AR scene, the virtual object consists of primitive objects, five cubes were displayed. Finger-Ray shows that instead of projecting the raycast from the center of the camera for the selection purpose, in this technique, the raycast is attached at the tip of the index finger, with pointing gesture to perform the selection, making sure the ray intersects with the virtual object in the scene.

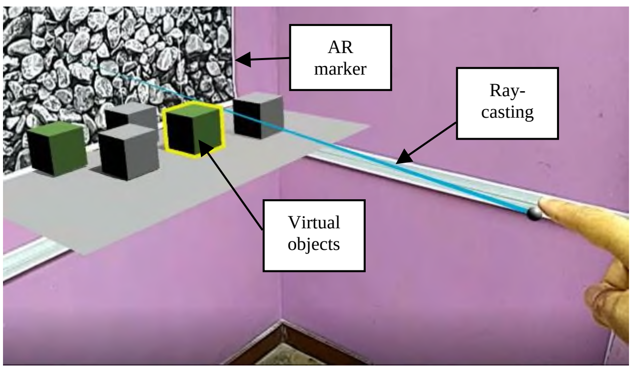
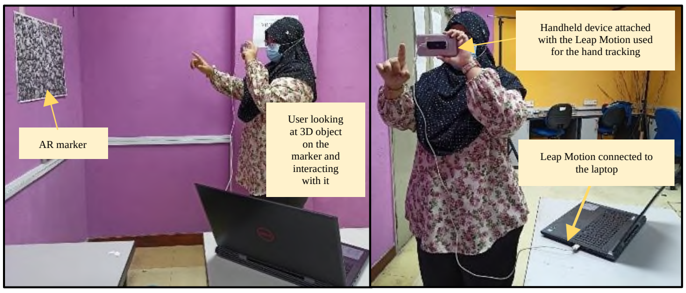


Fig. 15. Ray-pointing used to hit the cube

The user workspace setup is demonstrated in Fig. 16. Fig. 16(a) shows the workspace setup from the side view while Fig. 16(b) shows the workspace setup from the front view. As shown in the Fig. 16(a), the AR marker was placed on the wall. It was not been placed on the table like the common setting of handheld AR. We use Vuforia AR marker with the stone pattern. The AR marker is printed with A2 size paper. User's left hand will be holding the handheld device, while the right hand will interact and perform the selection on the virtual object.



(a) (b)

Fig. 16. User workspace setup

The computer (laptop) has connected to Leap Motion device which has been attached behind the smartphone as handheld display device. User's hand has been tracked by Leap Motion and gesture input is then recognized during the hand tracking system running in real-time. In this experiment, we used finger-tip to represent a sphere and to indicates ray casting. Through the application running on the handheld device, it will capture the marker to overlay the AR scene which is the displayed to the user.

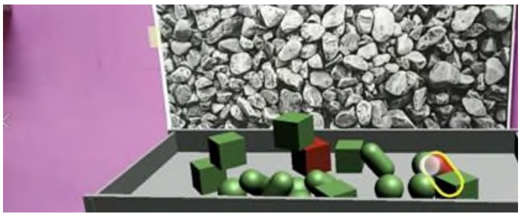
D. Ray-pointing using Touch-based

Ray-pointing using touch-based is perform by the user with tapping gesture. The user will need to tap on the virtual object displayed to perform the object selection. As the AR marker were captured to view the AR scene, raycast will be projected towards the object with the method of tapping on the touchscreen to hit the virtual objects. When the yellow wireframe of the object were displayed, it indicates that the object has been hit and selected. The object are now ready to be manipulated. To give further understanding for the manipulation, we demonstrate the interaction of translation for this part. With the object being selected, Fig. 16 shows a virtual button "Pick" has been tap by user to further enable the translation process on the selected cube. The AR scene consists of primitive objects, five cubes. We were using the same workspace setup to compare between ray-pointing and touch-based.

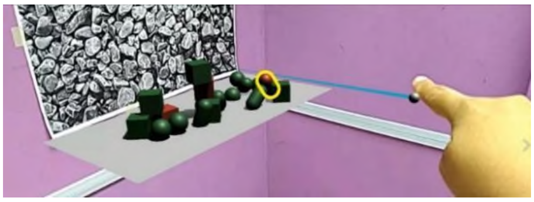
Fig. 17. Ray-pointing using touch-based

V. Discussion

In this study, a finger-ray technique was proposed for the interaction technique with the virtual 3D object, enabling the virtual object manipulation in handheld that provides intuitive experience for the user. The finger-ray technique can perform the manipulation tasks of selecting, translating, rotating, and scaling of the virtual object. However, this paper only focus on selection purpose.



(a) Touch-based to hit occluded-object



(b) Finger-ray to hit occluded-object

Fig. 18. Occluded-object has been selected by user using both touch-screen and finger-ray his real hand

Touch-based also use raycast to hit the object to perform selection. For touch-based, virtual button become an essential to compliment touch-based interaction for translation. However if we attempt to use for selection, raycast on touch-based will be enough, a virtual button is not required. The virtual button used to hold the object for translation. While the virtual object is being selected, the user simply needs to tap at the button provided on the device's touch screen to perform translation or move the desired object.

Fig. 18 shows the experiment when involve the occluded-objects in AR. We have used two techniques to pick the occluded object (red object) in the AR scene. The experiments to measure the occluded object are based on procedure from [29]. The selection method has been performed using touch-screen and finger-ray.

This paper discusses the designing of the raycasting technique using real hand gesture and touch-based in handheld AR for object selection. Further experiment need to be conducted, usability testing also need to be carried out for the future works. Other than that, the experiment can be expanded for 3D object manipulation such as translation and rotation in the future works. We have conducted a time measurement for the occluded object selection experiment to compare the techniques. The raycasting method not only excels at choosing distant and tiny objects, but it addresses the issues of occlusion with the 3D object and dense object selection in AR. Finger-ray much faster, but depends on network performance because the gesture input has been captured in real-time by Leap Motion. As a conclusion, we found that finger-ray is faster than touch-based, however touch-based is easier compare to the finger-ray.

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