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Implementation of natural hand gestures in holograms for 3D object manipulation

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Abstract: Holograms provide a characteristic manner to display and convey information, and have been improved to provide better user interactions Holographic interactions are important as they improve user interactions with virtual objects. Gesture interaction is a recent research topic, as it allows users to use their bare hands to directly interact with the hologram. However, it remains unclear whether real hand gestures are well suited for hologram applications. Therefore, we discuss the development process and implementation of three-dimensional object manipulation using natural hand gestures in a hologram. We describe the design and development process for hologram applications and its integration with real hand gesture interactions as initial findings. Experimental results from Nasa TLX form are discussed. Based on the findings, we actualize the user interactions in the hologram.

Keywords: Hologram; Gesture interaction; Natural hand gesture; Three-dimensional object manipulation; Gesture recognition

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1 Introduction

Holograms involve the storage, recording, and subsequent reconstruction of the phase and amplitude of the light field scattered by objects[1]. In general, a hologram helps convey project information in the form of light. Hologram elements such as mirrors, lenses, and directional diffusers can implement light on a single material based on frequency characteristics[2]. Thus, holograms can be used in various types of mediums and devices such as hologram memory, hologram projection screen, head-mounted display, and holographic printer[3].

Hand gesture is a complex and nonrigid target with dynamic components[4]. Fingertips, thumbs, and palms are the usual subresolution limits of a conventional device. Hence, a conventional device has to be expensive, large, or complex to recognize small motions. Although the hardware can track tiny motions for gesture recognition applications, tracking algorithms are computationally limited.

Command signals from the user′s hand are transmitted to an external device such as a robotic arm in a

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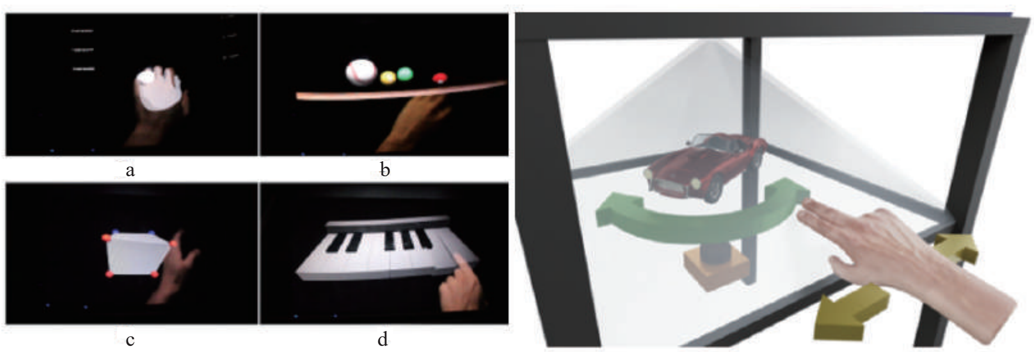
remote plant[5]. Users use only a holographic representation of a physical object with a less direct interaction with the hologram object. A conventional input gesture, such as a holographic keyboard, has been used to manipulate the images[6]. However, this type of gesture is not intuitive. Hence, the proposed holography interaction intends to implement real hand gestures in a hologram, allowing users to easily command a three-dimensional (3D) object on a hologram with a natural sense.

Figure 1a shows the hologram proposed in a previous study with basic interactions such as touch reception and throw. In the first scenario, the user can move multiple balls[7]. When the user sways left and right, the touched balls are scattered. In the second scenario, it rains when the user clenches his/her fist. The user can receive or accumulate the raindrops and watch scattered scenes if they throw the drops. The last basic example includes pickup. The user picks up and moves a dice. The hologram environment and haptic technology when they combined Leap Motion with Arduino. Additionally, studies on holography and gesture recognition have been performed[8]. Gesture recognition, which allows the user to interact with virtual objects through intuitive hand motions, has been introduced. Four gestures including single touch, swipe with one finger to rotate, swipe with two fingers to change images, and use of two fingers to zoom in or out, were implemented as shown in Figure 1b.



(a) Interactive hologram (b) Gesture interaction with 3D virtual objects

Figure 1 Related studies.

2 Hologram

Hologram is defined as a photographic technique that records and presents the light emitted from an object as a 3D illusion. One of the commonly used holograms is a photographic film that contains a layer of light-reactive grains. In general, holograms help convey information in the form of light. A holographic screen displays an image by diffracting and dispersing the projected image light using an image projection apparatus. Holographic 3D image projection methods make the depth perceived by the brain compatible with the focus of the eye[9]. In these methods, 3D images are suspended to stimulate the viewers′ sense of presence and move the 3D images closer to the viewer. Such images are different from the presentation of two-dimensional (2D) images, and can be used to enhance memorization and improve the effectiveness of learning. There are several ways to interact with virtual holographic objects. The interactive holographic display can be improved[10], for example, by adding a tracking sensor that allows the user to interact with 3D objects using hand gestures. In addition, tablets are often used for the interaction. However, the human–machine interface of most instructional systems is still largely controlled using a mouse and keyboard.

Gestures are described as sequences of poses in time[11]. A static hand pose is detected from a single frame. The user must follow a specific sequence of poses to complete a gesture, with the time interval between poses not exceeding a certain threshold parameter. Sensors, including structured light cameras, time-of-flight cameras, stereo depth cameras, and 2D and 3D cameras, can track a user′s hand movement[12]. These cameras can track the user's hands or fingers to deduce the desired operation. Therefore, the gesture recognition unit can determine a user′s gesture based on the tracked movement of the hand. In a 3D gesture coordinate system, a user′s gesture may be determined based on the *X*-, *Y*-, and *Z*-axes.

The gesture recognition unit determines whether the user′s hand is within the defined range for 3D holographic object interactions[12]. Therefore, it is necessary to have a 3D viewing system capable of conveying depth perception to the audience through binocular stereopsis (e.g., advanced glasses). It can also be achieved through pyramid prism viewing and *z*-hologram displays. Despite the use of pyramid holograms in several studies[10,13], a *z*-hologram was used in this study. The *z*-hologram is ideal for holding the tablet at the top to monitor a 180° image in a rotating view[14]. The visuals are designed to appear as they are floating within the hologram system. The *z*-hologram also extends the area of interaction in which users can touch and move, thereby providing a wider space on the hologram screen compared with the pyramid view. The combination of gesture recognition and 3D holographic technology can create an instructional system that can determine the users′ operating intentions based on the intuitive movements of hands in the air, thereby replacing the mouse and keyboard with gestures to move, rotate, scale, and replace 3D objects on the display[13]. This system allows users to operate and control 3D models using intuitive hand gestures.

3 System overview

This section provides an overview of the system. Unity engine was used to develop and render the application. As shown in Figure 2, the system consists of a hologram screen, 3D object data in fbx format, and tracking technique used for hand gestures. Gesture tracking was based on a motion-based device using Leap Motion. The list of interactions for 3D object manipulation includes selection, spawning, rotation, release, and translation. This indicates a six-degree-of-freedom manipulation using right and left hand gestures.

This system also provides a list of interactions such as selection, spawning, rotation, translation, and release. The model that we used has undergone the modelling process, and some of the models required textures. An overview of the system is presented in the following subsections.

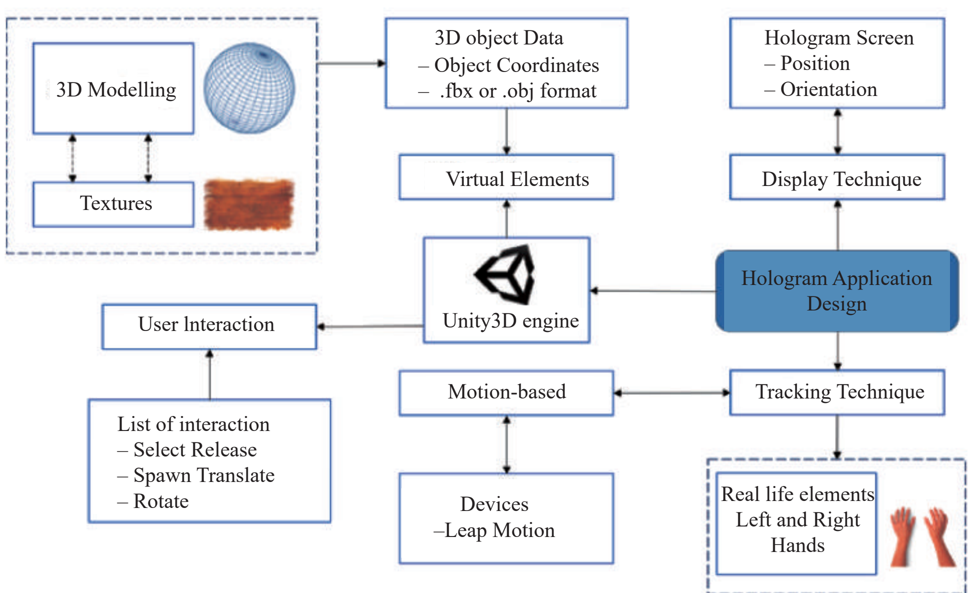


Figure 2 System overview.

3.1 Hologram and apparatus setup

In this project, a hologram display was set using the Ghost′ pepper technique[14]. A Leap Motion device[15] was placed in front of the hologram box. To obtain a better perspective while observing the hologram content, the distance between the hologram and the user was set to 65cm. The equipment used for the testing included a monitor, *z*-hologram display, and Leap Motion device. The Leap Motion device was placed on the table 10cm away from the hologram setup. Figure 3 shows the positions of the user and hologram. A physical motherboard was used along with the *z*-hologram placed at a position of 5° under the hologram display, because the motherboard depended on the hologram content to create an interactive relationship between hologram objects and real-life objects. A transparent case was placed at an angle of 45° inside the cardboard box. The distance between the Leap Motion device and *z*-hologram box was 5cm. The user's position was 65cm away from the transparent case with a view angle of 45° to the hologram display. The monitor was connected to a computer and placed on top of the *z*-hologram to display the hologram content.

• Leap Motion detects the actual hand movement. The recognition process is performed to obtain depth data from the motion-based tracking system of the Leap Motion device.

• The hologram display was set using Pepper's ghost technique. A transparent case was customized to create a Z-shaped box with space on top to place a monitor display. The box was constructed using a black-cover cardboard.

• The *z*-hologram[16] consisted of several materials, such as hard cardboard, transparent plastic case, and monitor display. The cardboard structure was modified to support the monitor placed above it and a transparent case was angled at 45°. The hardware was properly set to allow the user′s hand to be visible in the

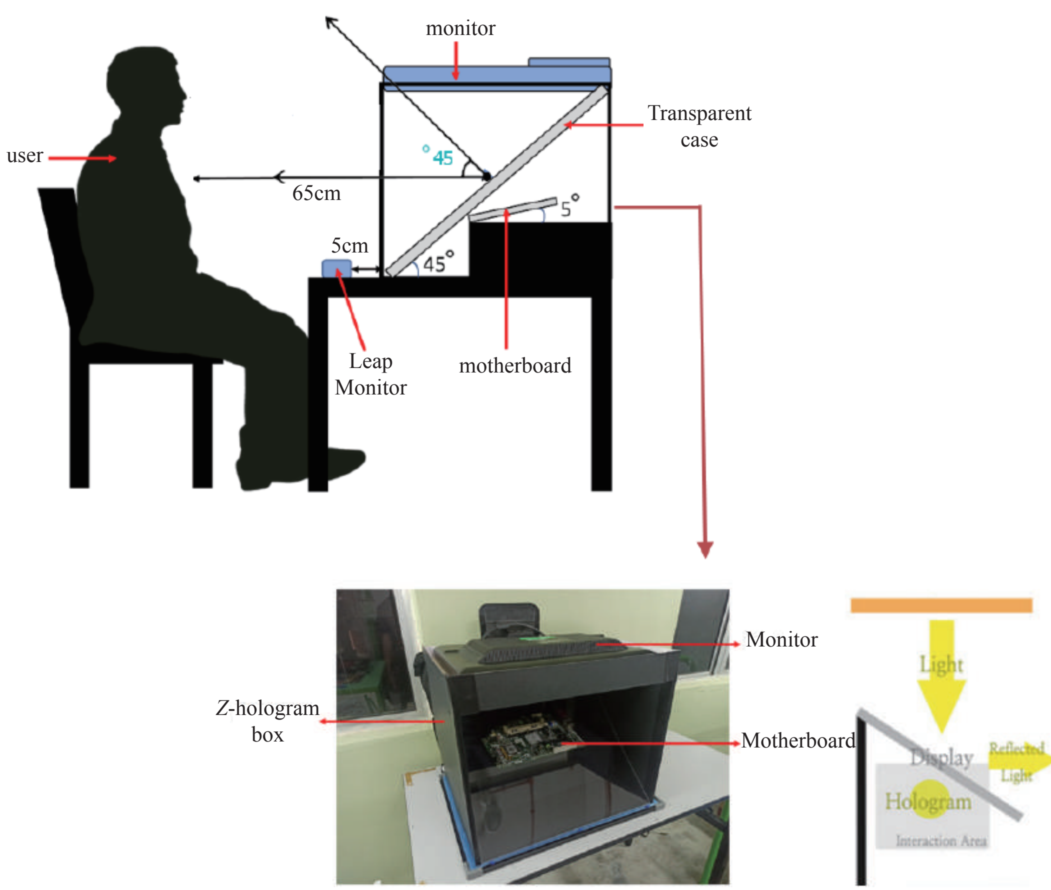


Figure 3 **System workspace.**

foreground.

- A monitor was used as an output display device to project the running application onto the case. The light emitted from the screen of the monitor reflected the case and produced a holographic effect.
- The hardware specification used to develop the application was an Intel(R) Core (TM) i7-7700HQ central processing unit (CPU) with a random-access memory (RAM) of 12 GB. A Leap Motion device was used for gesture interaction on the hologram. A *z*-hologram box with a length of 60 cm, width of 45cm, and height of 45cm, and liquid-crystal display monitor with a resolution of 1680×1050 were required to display the hologram. A physical motherboard was used as a reference.
- The software specifications were Microsoft Windows 10, as the operating system, Unity3D engine version 2019.2.9f1 as the core development kit for the application, and Leap Motion SDK as the plug-in to support the enablement of hand gestures.

3.2 Hand recognition process

In this subsection, we explain the device input used, hand gesture recognition process, and 3D object manipulation that allows user interaction. The key component of this project is hand gesture tracking, which serves as an input metaphor for a user to interact with a 3D object. The Leap Motion controller understands and tracks hand gestures in the real world and creates a virtual hand. Since, virtual hands are a representation of real hands, certain hand movements, such as tapping and pinching, can be replaced by the virtual hand.

As shown in Figure 4, the cycle starts with the camera capturing the user′s hand and translating it to raw data. The user hand recognition involves the generation of the user's hand gesture information, location, and orientation. The monitoring layer collects data from sensors that track the user′s hand movements and identifies relevant information, such as the position and orientation of the fingers and the devices being used for tracking. The tracking algorithms deduce the occluded object positions from the 3D data. Filtering techniques are applied to ensure a smooth temporal coherence of the data. The 3D objects are placed inside the interaction area so that the hand module could interact with them.

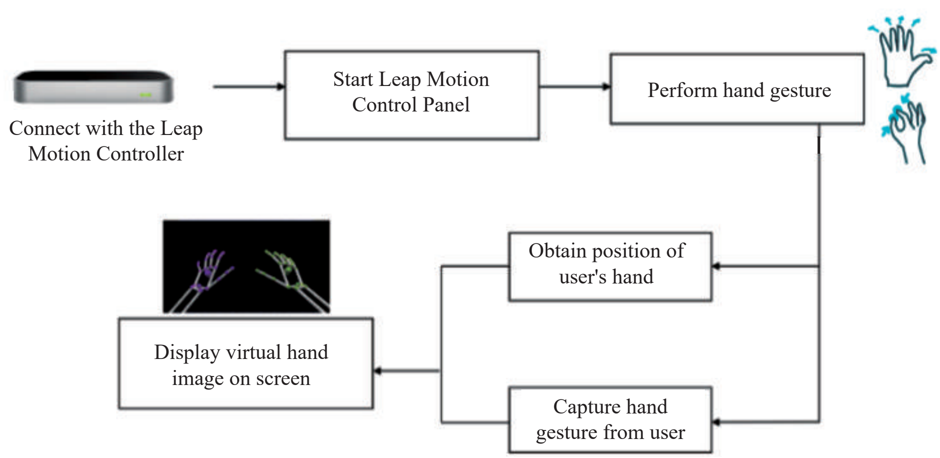


Figure 4 Gesture recognition process using Leap Motion device.

3.3 Gesture interaction in the hologram

The gesture inputs for 3D object manipulation consist of tap, pinch, release, drag, and rotation. Tapping, pinching, releasing, and rotating gestures were specifically designed to be performed only by the right hand. Additionally, palm-up gesture was used to spawn the menu to select different types of 3D objects. This gesture required the user to tilt his/her left palm up by 180° along the *y*-axis.

Table 1 presents the list of desired gesture inputs with its definition. Figure 5 shows the hand gestures used to

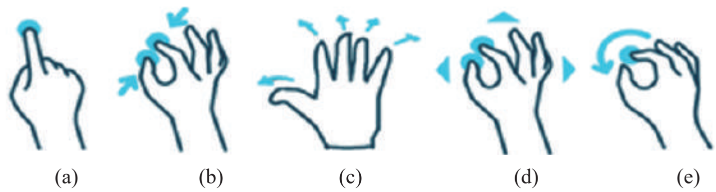


Figure 5 **List of gesture inputs: (a) tap, (b) pinch, (c) release, (d) drag, (e) rotate.**

perform the tap, pinch, release, drag, and rotation. A pinch gesture is used to grab the 3D object and move it from one location to another in a scene. The rotation gesture is performed during pinching. The user can rotate his/her wrist around the forearm and update the 3D object's angle at the same time.

A user can perform a palm-up gesture to spawn a menu option. The user can also perform a tap gesture to select the button from the menu and display the information of a specific component. Pinch gestures enable translation interactions. The user performs pinch and drag gestures to translate the position of the interface menu to a certain value on the x-axis. After pinching the 3D object, the user can perform translation interactions by dragging it into the highlighted area of the scene. The user can rotate the object by rotating his/her wrist while translating it. A release interaction occurs once the user performs the release gesture.

Table 1 **Gesture interaction list**

Interaction	Description
Spawning	Instantiate information for the components
Translation	Use of pinch and drag gestures to manipulate 3D objects
Rotation	Use of pinch and rotate gestures and rotation of the wrist around the forearm with the palm downward
Release	Freeing of the 3D object from the hand of the user
Selection	Tapping action on the desired object to select

The index finger model containing a collider was used to detect the collision once the collider hit the object. As shown in Figure 6, if this condition is true, the user can perform a palm-up gesture to spawn the menu option. As the user selects a button, the object spawns. To translate and rotate objects, the user could perform a pinch gesture by bringing the index and thumb fingers closer together until their colliders hit the object. Releasing the object was also possible. If the condition of the ongoing interaction is true, the user can select another object and repeat the process. The flowchart for user interaction is completed once the user exits the application.

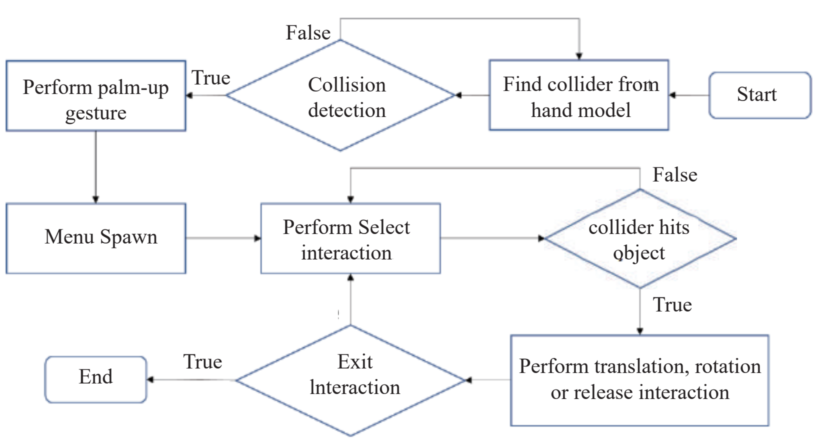


Figure 6 **Interaction flowchart.**

4 Implementation

In this study, a physical motherboard was used along with a z-hologram placed under the holographic display, because the motherboard was needed and dependent on the hologram content to create an interactive relationship between hologram objects and real-life objects. The monitor was then connected to a computer and placed on top of the *z*-hologram to display the holographic content.

4.1 User interface

The application starts after the user enters the application by selecting the start interface shown in Figure 7a. It then instantiates all the related 3D objects and buttons. Users can choose either a button for the component information or instantiate the 3D object. The user matches the component to the highlighted area on top of the motherboard, based on the given instructions. The application ends after slotting all the components in the area. The process flow of the user while interacting with an application is presented. Figure 7b shows the user interface and options for a user to assemble the motherboard components. The application has several 3D objects, such as RAM, processors, and complementary metal oxide semiconductor (CMOS) batteries. These 3D objects can be manipulated by the user while displaying the application on a hologram screen. The 3D objects in the hologram can match certain areas on top of the physical motherboard.

(a) Introduction screen to recognize the user's hand (b) Application with real-hand detection

Figure 7 Interface for PC assembly application.

Figure 8 shows a flowchart of the hologram application for CPU assembly when a user enters the application. The user can choose a select button from various components. If the user selects the button for CPU,

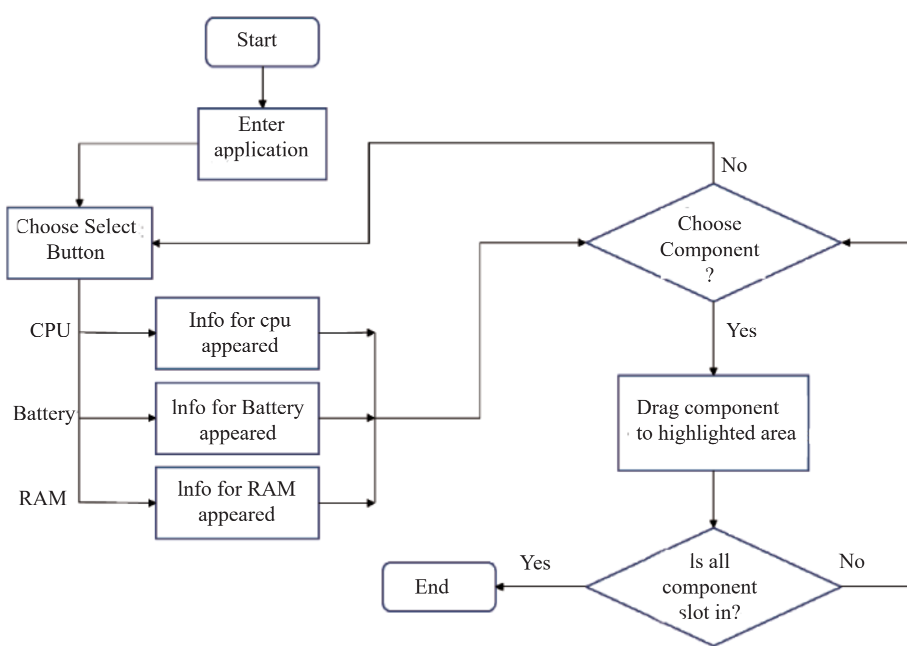


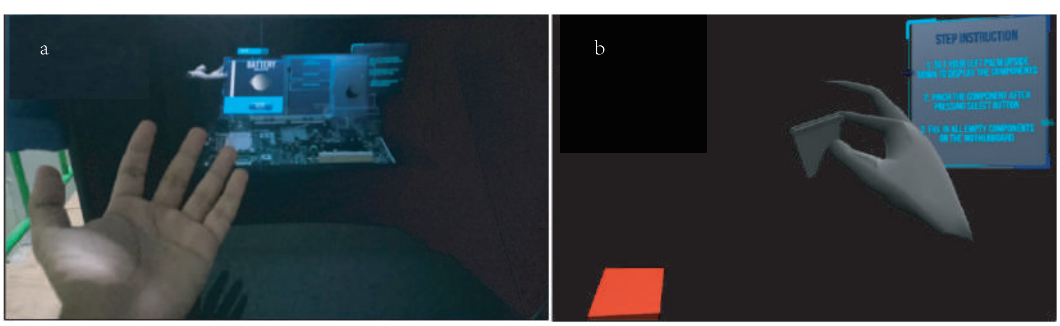
Figure 8 Application flowchart.

information about the CPU and its 3D object components appear. If the user selects the button for battery, information about the battery and its 3D object components appear. If the user selects a button for the RAM, information regarding the RAM and its 3D object component appears. After selecting one of the buttons (e.g., CPU), the user can choose the corresponding 3D object component and drag the component to the highlighted area in the hologram. The process is recursive because the user must drag all the three PC components (CPU, battery, and RAM) consecutively in the highlighted area. The application ends after all the components have been successfully slotted into the highlighted area.

4.2 Integration of a real hand interaction with the hologram

The process of integration involved importing Leap Motion to the project folder of the hologram application. As the device was already connected to the computer with a ready configuration, the related hand prefabs were placed in the application scene. The tag names for the index and thumb fingers were assigned to the collider trigger to detect the collision that occurred during the pinch gesture for each of the 3D motherboard components. All collision conditions were enabled by a pinch detector. The process was completed, and the application was displayed on the screen monitor before being transmitted to the holographic display *Z*-hologram setting.

Figure 9a shows the result of the desktop motherboard assembly application using natural hand gestures in a hologram. Figure 9b shows the gesture of pinching between the two fingers. Translation occurs when two fingers, the thumb and index finger, collide. The distance between the thumb and index finger is measured in each frame to determine whether a pinch gesture is being performed. When two points are closer to each other, the pinch gesture collides with the desired object. The object follows the transformation along with hand movement. This behavior also triggers rotation; if the user's hand rotates, the object will correspond to the palm movement. The application was then projected using a hologram screen with an inverted horizontal view, as mentioned earlier.

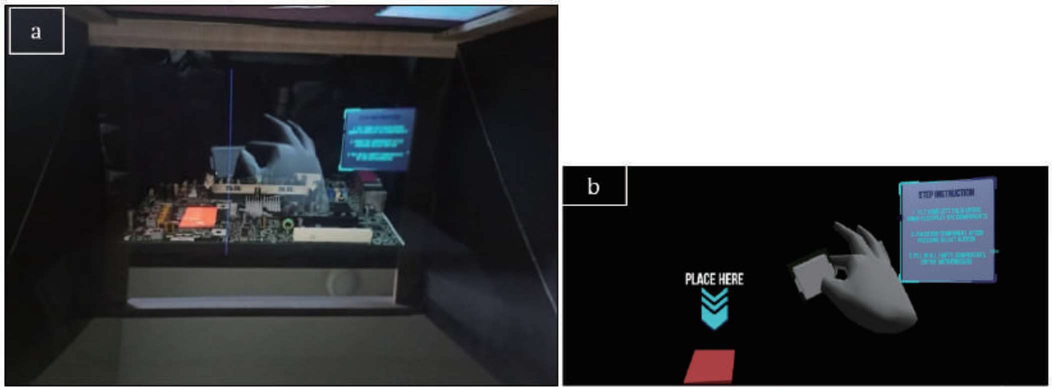


(a) Palm up gesture with the first interface (b) Gesture of pinching between two fingers

Figure 9 Pinching between two fingers collided to trigger selection.

Selection was implemented in this study for tapping of the button or object while the spawn interaction was enabled after the selection process. The selected interaction occurs when the collider from the tip of the index finger collides with the collider of the 3D object, as shown in Figure 10a. The object is selected, and a user feedback animation is used to indicate the location for dropping the object, as shown in Figure 10b. If the tag names from both colliders collide, the 3D object of the RAM spawns after tapping the button. Spawning an object implies that the visibility of the object is activated. The checking process evaluates whether the other object's collider has collided with the current object.

Figure 11 shows the test application before and after the user places the hand on the platform. Figure 11a shows the state of the application before it starts, while Figure 11b shows the user entering the application by performing a palm movement. The palm-up gesture spawns the menu display for the motherboard component.



(a) Pinch gesture in the hologram view (b) User feedback "PLACE HERE"

Figure 10 Pinch gesture for interaction in the hologram using a real hand.

Figure 11c shows that the user has hit the virtual button and that the information pop-up panel is displayed on the hologram. Figure 11d shows the user pinching the CPU component and placing it in the highlighted area.

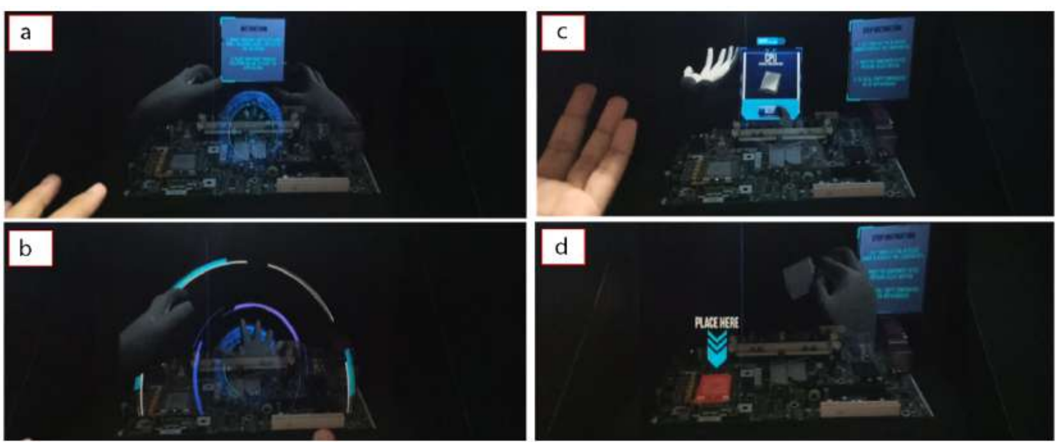


Figure 11 Tested application (a) both hands detection on hologram, (b) the palm up gesture appears on hologram, (c) user hits the virtual button and (d) the highlighted area where user needs to drop the object.

5 Evaluation results

Twelve undergraduate and postgraduate students who had computer science background performed the user testing. The respondents were 21 to 28 years old. Each respondent conducted only one session. The time to complete the tasks was 10 min. User testing was performed along with a consent form, questionnaire, and Nasa task load index (TLX) form distribution. Each respondent was given 10 min to try the application. The user task performance of each respondent was recorded for evaluation. After completing the application, the respondents were requested to complete the questionnaire and Nasa TLX form. The Nasa TLX in this project was based on a testing[17], which obtained the subjective workload estimates for the Leap Motion device. The evaluation process was modified from a previous study[18].

Figure 12 shows the ratings from 1 (bad) to 5 (good) for pinch, selection, spawn, rotation, and translation gestures. Users were asked for the degree of difficulty to drop or place the 3D object component in the highlighted area. In total, 16.7% of the respondents with a score of 3/5 felt neutral. 33.3% of the respondents with a score of 4/5 easily placed the object in the highlighted area of the hologram, whereas the other 50% with a score of 5/5 stated that it was very easy to place the 3D object in the highlighted area.

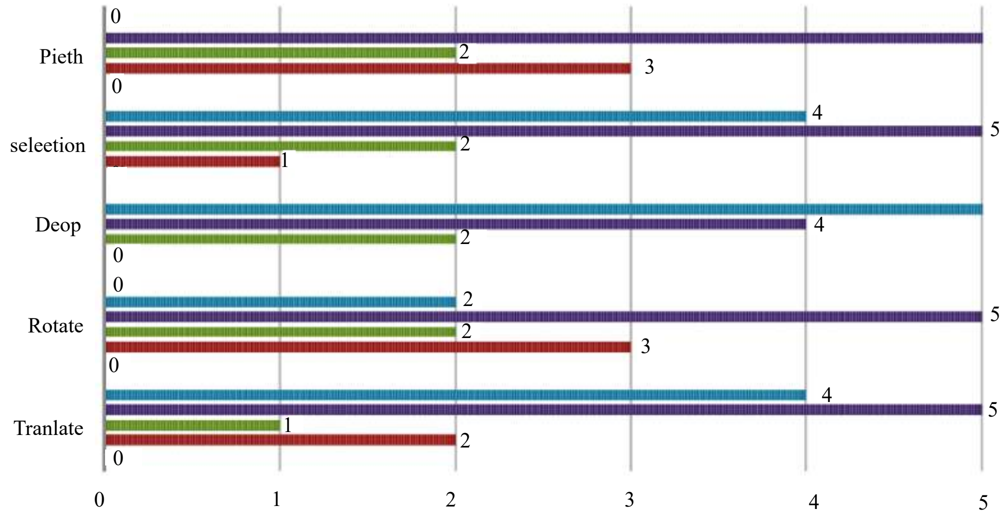
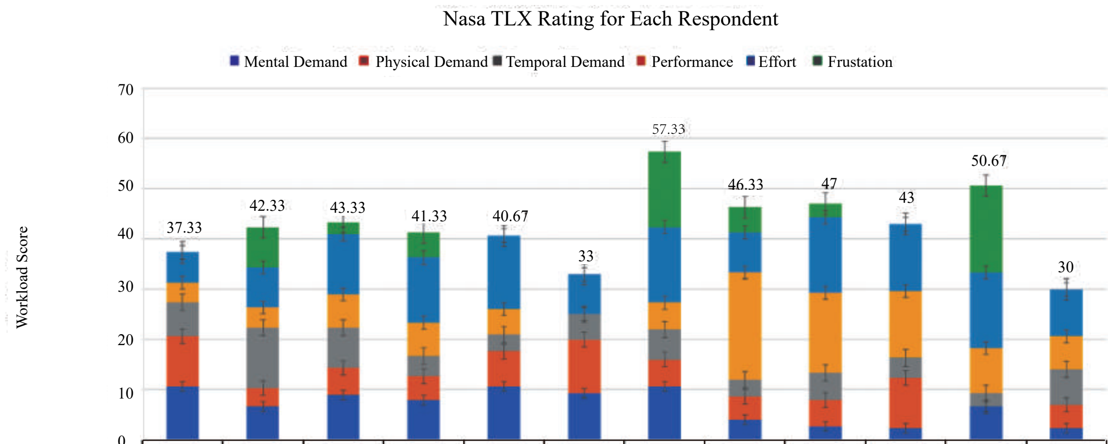


Figure 12 **Nasa TLX testing results for each subscale.**

Regarding the rotation, the 3D object component was rotated. 25% of the respondents with a score of 2/5 stated that it was difficult to move the 3D object component in the hologram. 16.7% of the respondents with a score of 3/5 felt neutral while moving a 3D object. 41.7% of the respondents with a score of 4/5 felt that it was easy to move the 3D object, whereas 16.7% of the respondents with a score of 5/5 stated that it was very easy to move the 3D object component in the hologram. As shown in Figure 12, the 3D object component was translated. 16.7% of the respondent with a score of 3/5 stated that it was difficult to move the 3D object component around the hologram, whereas 8.3% with a score of 4/5 chose a neutral answer to the question. 41.7% of the respondents with a score of 4/5 easily moved the 3D object, while 33.3% of the remaining respondents with a score of 5/5 stated that it was considerably easy to move the 3D object component in the hologram. Regarding the selection of the button in the hologram, 8.3% of the respondents with a score of 2/5 stated that it was difficult to select the button, whereas 16.7% of the respondents with a score of 3/5 were neutral in their answer for selection of the button. 41.7% of the respondents stated that was easy to select the button, whereas 33.3% of the respondents stated that it was considerably easy to select the button in the hologram. Figure 11 shows results for pinching of the 3D object component. 25% of the respondents with a score of 2/5 stated that it was difficult to pinch the 3D object component, whereas 16.7% with a score of 3/5 had a neutral answer to the question. The other 58.3% of the respondents with a score of 4/5 stated that it was easy to pinch the 3D object component in the hologram.

According to Figure 13, at higher ratings, the workload felt by the respondent while testing the application was higher. After summing all the adjusted ratings for each subscale, the overall rating for each respondent was obtained. Respondents 1, 6, and 12 had overall workload ratings under 40 (37.33, 33, and 30, respectively). Respondents 2, 3, 4, 5, 8, 9, and 10 had overall workload ratings below 50 (42.33, 43.33, 41.33, 40.67, 46.33, 47, and 43, respectively). Respondent 7 had the highest overall rating in the Nasa TLX testing of 57.33, while respondent 11 had an overall rating of 50.67. The highest frustration rating was achieved by respondent 11, with a score of 17.33. Some respondents achieved a rating of 0 for frustration (respondents 1, 5, 6, 10, and 12). The highest effort rating obtained in the testing was 15 for respondents 7, 9, and 11, while the lowest effort rating was 6 for respondent 1. The highest performance rating was 21.33 for respondent 8, while the lowest rating for the performance subscale was 0 for respondent 6. The highest temporal demand rating was 12 for respondent 2, whereas the lowest rating for temporal demand was 2.67 for respondent 11. The highest physical demand rating was 10.67 for respondent 6, while the lowest physical demand rating was 0 for respondent 11. The highest mental demand rating was 10.67 for respondents 1, 5, and 7, while the lowest rating for mental



	1	2	3	4	5	6	7	8	9	10	11	12
Frustation	0	8	2.33	5	0	0	15	5	2.67	0	17.33	0
Effort	6	8	12	13	14.67	8	15	8	15	13.33	15	9.3
Performance	4	4	6.67	6.67	5	0	5.33	21.3	16	13.33	9	6.67
Temporal Demand	6.67	12	8	4	3.33	5	6	3.33	5.33	4	2.67	7
Physical Demand	10	3.67	5.33	4.67	7	10.67	5.33	4.67	5.33	10	0	4.67
Mental Demand	10.67	6.67	9	8	10.67	9.33	10.67	4	2.67	2.33	6.67	2.33

Respondents

Figure 13 Nasa TLX testing results for each subscale.

demand was 2.33 for respondents 10 and 12.

We discussed the implementation of the integration between a hologram application and natural hand gesture. A hologram is a projection of the light. Common interactions use mouse clicks, keyboards, or other tools. However, finding better user interactions using natural hand gestures in holograms or holographic projections is very challenging. Therefore, we provided initial results for the implementation of gestures in hologram applications. Gesture interaction allows the user to use their bare hands to interact directly with the hologram. We discussed how real hand gestures can be well suited to hologram applications.

6 Conclusion

Based on the development process and implementation of 3D object manipulation using natural hand gestures in the hologram, user interaction with the hologram content can be enhanced. However, a limitation was encountered throughout the development process; the light emitted from the monitor was not sufficiently bright for the user to observe the hologram content in real time. To address this issue, a previous research has proposed methods for selecting the optimal coherence of the light source for holographic displays[19] and avoiding direct illumination of the sensor by the light reflected from the surface[20]. To avoid this limitation, using a monitor with a brightness of at least 500nt is recommended. Additionally, we recommend the use of an organic light-emitting diode monitor to produce a better display on the hologram.

For future studies, a few suggestions are presented to improve existing applications. First, more computer component options can be provided to the user. In addition, this application could animate the process of placing the components on the motherboard so that the user can observe how the real process slots into the motherboard. Further, it would be of interest to allow the user to scale the size of the information displayed once the user selects the button. Finally, an undo button can also be placed on the interface so that the user can undo the previous activity.

Declaration of competing interest

We declare that we have no conflict of interest

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