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Research paper



Ilung: Interactive Holographic Medical Application for Lung CT Scans Using Hololens

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Abstract

This research aims to design a holographic medical application for lung CT scans using Microsoft HoloLens. *iLung* application offers users the possibility to interact with the actual lung of a patient in a mixed reality and 3D environment. A prototype of the *iLung* was developed based on raw CT scans data and converted into 3D model generation. This paper reports the earlier stage in designing the application. Based on the application's overview with a group of users, the findings gathered showed that *iLung* prototype facilitates interactive manipulation and exploring of the 3D lung object. Feedback and comments were recorded for future improvements such as air taping interaction method and voice command.

Keywords: *Hologram, CT scans, Microsoft HoloLens, Medical Application, 3D modeling.*

1. Introduction

Lung disease is a chronic illness that affects millions of people around the world. Currently, Computed Tomography (CT) scans are one of the technologies used at hospitals which produce multiple detailed images rather than a regular x-ray to detect and diagnose lung disease. However, current lung CT scan images are limited in their ability to convey the full three-dimensional (3D) representation of the lung.

Computed tomography images provide several successive 2D slices. This form of CT scan representation is considered difficult to read, analyze, and diagnose because only one slice can be represented at a time. Thus, developing three-dimensional objects facilitates identification of the lung structure embedded in the CT scans. This can be achieved by applying segmentation techniques on the targeted area of the CT scans to produce a 3D visual display of the lung. The segmentation can be carried out automatically or manually. Applying auto segmentation on CT scan images can be quite challenging due to its intense levels of noise and inhomogeneities. The techniques of auto segmentation might involve several phases including preliminary processing, followed by image contouring and label filtering to extract the target tissue [4]. The automatic CT scan segmentation can be enhanced using advanced 3D generating models such as Active Shape Model which allows users to display the target organ's 3D model features by leading the segmentation [5]. On the other hand, the manual segmentation can be applied using medical image processing softwares such as 3D Slicer [15]. The 3D Slicer software provides an Editor tool which increases the accuracy of segmentation by allowing volume boundaries selection of the target area.

3D modeling of the lung CT scans can benefit from the recent technologies which provide more engaging experience and natural interactions. Currently, there are several visual modalities that enable natural human computer interaction including web-interfaces, virtual reality, and holographic interfaces [10]. The hologram is described as a three-dimensional representation of an image to enhance the way the user interacts with the physical representation of an object, receives and provides information from and to the system. As one of the most advanced holographic headsets available today, the Microsoft HoloLens has a significant impact on the developing of holographic applications [7]. Furthermore, the device has many features that makes it well-suited for a variety of applications. The device has the ability to operate without depending on a remote machine.

Several applications have been developed to test the capabilities of Microsoft HoloLens [8, 12]. *HoloBee*, an augmented reality system using Microsoft HoloLens for visual analytics of bee drift data has been developed to examine the performance of Microsoft HoloLens in visualizing spatial data. [8]. The system displays the bee activity data on 3D geospatial grounds. A study was conducted to investigate the user experience and performance of *HoloBee* holographic application with a desktop application [8]. Even though participants having more knowledge interacting with a desktop application, the results showed that they were able to solve tasks at a similar speed and accuracy using *HoloBee*. The natural interactions that *HoloBee* provides received a markedly positive feedback from some participants. Several applications have been developed that demonstrate the potential of the HoloLens for the medical field.

Another important feature of Microsoft HoloLens is its ability to display high-resolution 3D objects. Garon Ma. developed a system for providing HoloLens applications with real-time and high-resolution 3D data [9]. The system consisted of another RGBD camera attached to the HoloLens, and a PC stuck to the HoloLens to stream the acquired data back to the HoloLens. The system was able to detect small objects with the high-resolution 3D data and overlay their 3D model in the HoloLens viewpoint. Besides the high-resolution 3D data that the HoloLens provides, HoloLens facilitates interactive manipulation and exploration of the 3D model.

The focus of this research is to assist doctors, medical field, patients and their family members in obtaining unique information about lungs in a more intuitive and natural way. This research aim

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to design a holographic medium to allow interaction and manipulation of the medical data. In our research, the Microsoft HoloLens was used as the interaction device which allow users to visualize 3D lungs in holograms projections due to its standalone ability. The HoloLens device allows users to interact with the application via eye tracking, gesture selection and voice commands. A set of CT scan data provided by the Cancer Imaging Archive (TCIA) database [1] was used in generating the 3D lung model (consisting of 230 CT images of a thoracic patient) using 3D Slicer software. After that, texture was added to the model using Blender software. The 3D iLung interactive application was designed using 3D Unity and is displayed using Microsoft HoloLens device which keeps track of the hologram object's location and rotation relative to the environment.

Unlike several holographic medical applications that use tracking systems based on external markers to set the position of the hologram, *iLung* does not require any external markers. Using Microsoft HoloLens world mapping technique, the position of the 3D hologram by default is displayed based on the user's location. Furthermore, *iLung* provides patient information including the patient ID, name, age, gender and the date of scanning. This information is gathered from the CT scans metadata records.

The paper is structured in six sections. Section 1 describes the background of the research, Section 2 presents the Microsoft HoloLens, Section 3 provides the design of the application, Section 4 and 5 report the user experience and the discussion and finally, Section 6 presents the conclusion.

2. Microsoft HoloLens

Microsoft HoloLens is a wearable holographic device that generates high-resolution, 3D holograms using advanced nano-optics. The HoloLens advanced features exceed other AR devices. These features include holographic 3D displays, gaze tracking, gesture recognition, voice commands, and spatial mapping.

In order to interact with objects, HoloLens uses gesture recognition. Gestures are specific hand movement that can be used for choosing objects or selecting buttons. HoloLens can only recognize the position of the user's hands if they are visible for the headset. Beside gesture, gaze is a fundamental way of interacting with HoloLens.

HoloLens targets the object that the user wants to interact with by tracking the user gazing [11]. A third way of interacting with HoloLens is using voice commands. It is also used in combination with gazing to know which object the user wants to interact with. Furthermore, the HoloLens uses sensors for capturing information about the user's environment. It can recognize physical spaces such as furniture around the user.

The process of deploying and running the whole holographic application is presented in Fig. 1. The application is made up of two components, the physical component and virtual component. The virtual component consists of the holographic objects. The physical component refers to the physical space acquired by the HoloLens scanning, and the physical world is mapped into the virtual world through spatial world mapping [3].

3. Designing iLung Application

This section describes the design and implementation of the iLung application.

3.1. Lung CT Scans Data

Computed Tomography imaging of the lung provides insight into the diagnosis of pulmonary diseases, such as lung cancer. The data was acquired from The Cancer Imaging Archive (TCIA) [2]. TCIA provides academia, researchers, the medical community, and industry access to different kinds of imaging archives that can be used for many purposes. One of the data collections provided by TCIA is Lung CT Segmentation data collection [1]. This collection includes CT scan images of 60 patients. These scans were acquired from three different institutions, 20 from each. The following table provides a detailed description about the database (see Table 1).

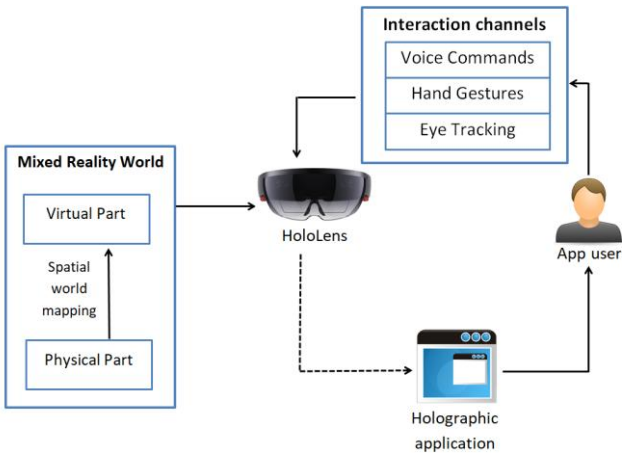


Fig 1: Holographic Application Deployment on the HoloLens.

Table 1: Database Detailed Description

Collection Statistics	Quantity
Modalities	CT, RT
Number of images	9569
Number of series	96
Number of patients	60
Number of studies	60
Image size (GB)	4.8

The dataset was divided into three categories, 36 scans for training datasets, 12 scans for off-site test dataset, and 12 scans for live test datasets. For each dataset, four organs were scanned in the CT images, including the esophagus, heart, left and right lungs, and spinal cord. Some data was excluded from the lung CT scans including tumors, hilary airways and vessels greater than 5 mm (+/- 2 mm), main bronchi and secondary bronchi. In some scans, small vessels near hilum and collapsed lungs may be excluded or included.

TCIA Download Manager software has been used to download the entire database collection. Using the filter option, scans from the training dataset were used for the application development. To build the Lung hologram, 230 CT images of a thoracic patient have been used.

3.2. Generating the 3D Hologram

The 3D hologram was generated from the row of CT scans using 3D Slicer software. 3D Slicer is an open source software used for medical purposes. 3D Slicer provides advanced functionality including informatics of medical image, visualization of three dimensional objects, and image processing. The first step in generating the lung hologram was to perform volume rendering. Volume rendering is a technique used to display the 2D CT scans as 3D object. 3D Slicer provides an automatic volume rendering technique. The process of volume rendering requires aligning all the slices of the CT scans and then adding 3D texture to produce the final 3D display of the Lung. The Fig. 2 below shows the final result of the volume rendering which provides a pre-presentation of the targeted model.

The final result of the volume rendering model included many organs besides the lung. As a result, the cropping tool was used to eliminate the irrelevant parts. The 3D model was generated using the fast marching segmentation method. Fast marching method uses *Dijkstra* style propagation to estimate the shape quickly and

accurately [14]. Once the CT scan images are cropped at the volume rendering stage, the targeted area (the lung) can be selected from the CT scan view using the selection tool (see Fig. 3b). After applying the fast marching segmentation technique (see Fig. 3c), the 3D model was generated using the module rendering (see Fig. 3d) [6].

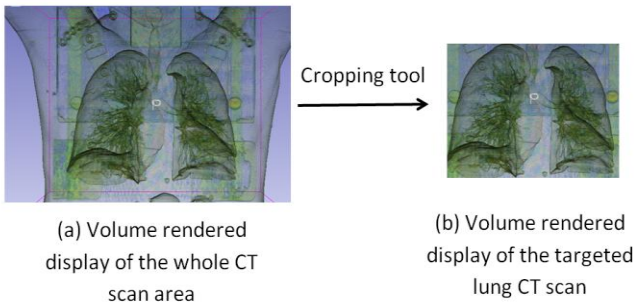


Fig 2: Volume Rendering of the Lung CT Scans (A) Volume Rendered of the Whole CT Scan Area; (B) Volume Rendered of the Targeted Lung CT Scan.

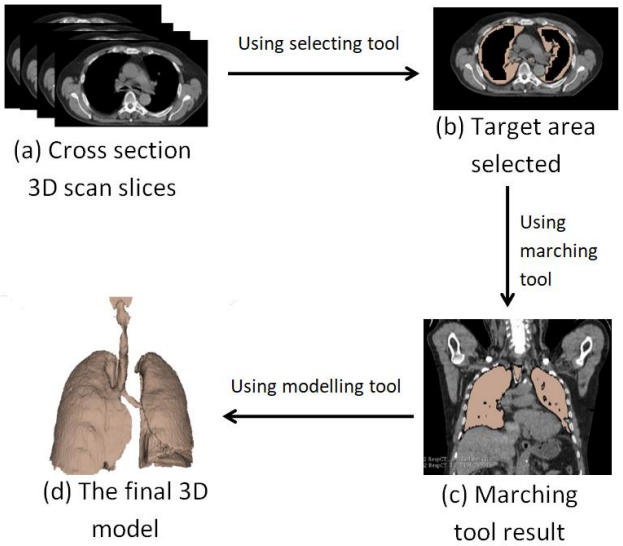


Fig 3: Generating the 3D Lung Model (A) Cross Section 3D Scan Slices; (B) Target Area Selected; (C) Marching Tool Result; (D) The Final 3D Model.

Blender software was used to add texture to the resulted 3D model using texture mapping technique to make it more realistic (see Fig. 4) [13].

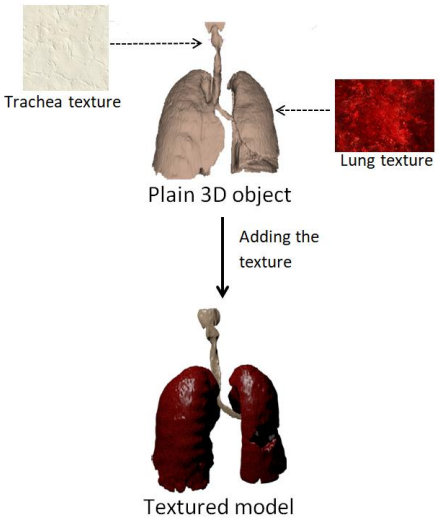


Fig 4: Adding Texture to the 3D Model using Blender Software.

3.3. Application Design and Implementation

The *iLung* application was designed and developed taking into consideration the limitations and features of the Microsoft HoloLens. The application provides three ways of interaction including voice commands, hand gestures, and eye tracking. Fig. 5 shows the logic diagram of the interaction methods. Initially, the user position is used as an input to set the default location of the hologram using the spatial mapping.

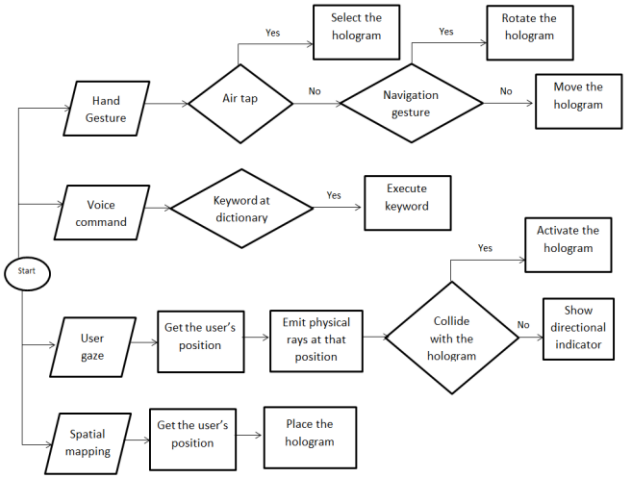


Fig 5: The Logic Diagram of the Interaction Methods.

The application responds to the user's hand gesture by tracking the user's hand position and interpreting the equivalent action of a specific gesture. iLung recognizes three hand gestures including air-tapping, rotation gesture, and moving gesture. The air-tap triggers selecting the hologram event. The rotation gesture is the default mode of navigation through the hologram. It is used to rotate the hologram around the x-axis. A specific voice command is used to change the mode of navigation from rotation the hologram to control the movement of the hologram.

Besides aforementioned hand gesture interaction method, iLung application provides the user with the ability to interact with the application via voice commands by using predefined keywords. All the keywords used in the application are stored in a dictionary. A hash table is used to match each keyword with its corresponding behavior. As a result, when the user says a keyword, the previously installed act in the application is performed. Some rules have to be followed in the designing of voice commands including creating concise commands, using simple vocabulary, and avoiding using the HoloLens default system commands.

The user's gaze is used to obtain the interaction between the user and the application by tracking the holographic objects. The gazing method consists of two parts: tracking the user's sight location and providing visual feedback to the user. The implementation of the gazing method is based on the location of the hologram and the direction of the user's sight. After colliding with the hologram, the location of the collision point is used to provide visual information feedback to the user. The feedback includes a visual symbol indicating the navigation mode and a course indicator of the position of the hologram.

Spatial mapping is used to place the hologram in the most convenient location in the real world based on the user's position. This is implemented in Microsoft HoloLens by using the embedded 3D camera to examine the target's physical location. Through surface mapping, the HoloLens builds triangulation of the scanned data to accomplish digitization and modeling of the real world.

3.4. Application Implementation

The iLung was developed for Microsoft HoloLens using Unity3D game engine platform and C# programming language. This application also utilizes the Holotoolkit Software Development Kit

(SDK). The Holotoolkit SDK provides the basic class libraries that allow users to accomplished a natural interaction between the user and the 3D holographic models.

4. iLung User Experience

4.1. The Study

The aim of this evaluation is to observe user's experience while interacting with the *iLung* application using the Microsoft HoloLens. Two hypotheses were defined for the study as the holographic interface presents a natural way for the user to interact with the hologram through hands gestures and voice commands:
H1 It is easier to apply voice commands than hand gestures in using the application.
H2 It takes less effort and time for the users to perform a task that requires one action than the task that requires combined actions.

4.1.1. Participants

Twenty users (7 experts and 13 normal users) aged from 15 to 50 (mean 24.7) were recruited in this experiment. Only three of them have used the Microsoft HoloLens before taking part in the experiment. Ten participants were students in computer science and software engineering. The experts included one medical doctor and six PHD holders in the field of computer science and human computer interaction.

4.1.2. Study Design

The user experience session was conducted with a group of users to evaluate task performance of iLung for about 10 minutes each. The experiment was set up in a living room with white walls and enough space for the users to walk around the hologram when using the HoloLens. For the holographic evaluation session, the iLung application used the Microsoft HoloLens Development Edition. The holographic screen performance was captured and recorded for analysis purposes. The researcher observed and took note of the users' interactions and behaviours during the sessions.

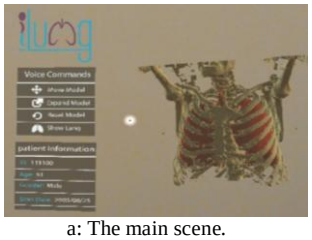
4.1.3. Materials

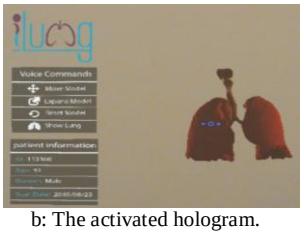
A 3D holographic patient's lung was used in the study. The structure of iLung is provided below:

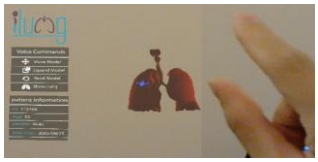
- Microsoft HoloLens starts the application and activates the camera displaying the main scene (see Fig. 6a).
- When ready, the user can interact with the hologram by using hand gesture or voice commands.
- Once the user gazes on the hologram, the hologram will be activated (see Fig. 6b) and the user can select it using air tap hand gesture (see Fig. 6c).
- After selecting the hologram, the user can rotate the hologram around the x-axis using the sliding hand gesture.
- Using the voice command "Move model", the navigation mode changes to movement control mode (see Fig. 6d).
- The user can display an expanded view of the hologram using the voice command "Expand Model" (see Fig. 6e).
- The hologram can be reconstituted to its original display using the voice command "Reset Model".
- The user can view the lung hologram separately using the voice command "Display Lung".

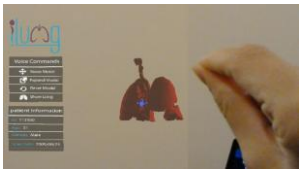
4.1.4. Procedure

At the beginning of the evaluation session, the researcher explained what the participant was required to perform throughout the session. During the session, participants were required to explore the iLung such as using the voice commands. Participants also were asked to rotate and move the model using hand gestures. The tasks were arranged based on level of difficulty (see Table 2). Task T1 - task T3 involved only voice commands, while task T4 involved applying two hand gestures (air tap and sliding), and task T5 involves using voice commands and hand gestures.


a: The main scene.


b: The activated hologram.


c: The air tap gesture.


d: The moving gesture.

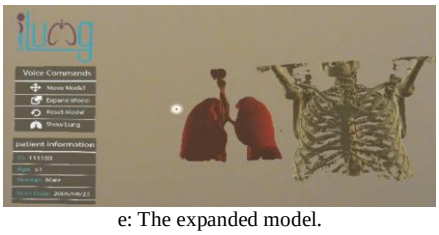

e: The expanded model.

Fig. 6: Screenshots of the iLung Holographic Application.

Table 2: The Tasks That the Users Needed to Perform.

ID	Task	Possible response
T1	Expand the hologram	Use voice command "Expand Model"
T2	Reset the hologram	Use voice command "Reset Model"
T3	Display the lung hologram	Use voice command "Display Lung"
T4	Rotate the hologram	Apply air tap hand gesture then slide hand gesture
T5	Move the hologram	Use voice command "Move Model, then apply moving hand gesture

Each session consisted of an introductory explanation of the application idea followed by the evaluation session. Each session consisted of instructions, user's actions, and feedback from the user. The purpose of the study was explained to the participants at the beginning of the session. Following that, a training session about the holographic interface was explained. The users were required to give their feedback on their experiences by answering a questionnaire at the end of the session. The questionnaire focused on the users' experiences [8] and their opinions about interacting with the application.

4.1.5. Performance Evaluation

For the evaluation of the application, the tasks performances were measured through completion time. The completion time of each task was noted from the moment the users started the task until the end of the task.

4.2. Results

4.2.1. Completion Time

The type of tasks (i.e voice commands and gestures) as an independent variable could influence the completion time. Fig. 7 shows that tasks involving only voice commands (task T1 - T3)

were easier to complete than compared to tasks involving hand gestures (task T4 - T5).

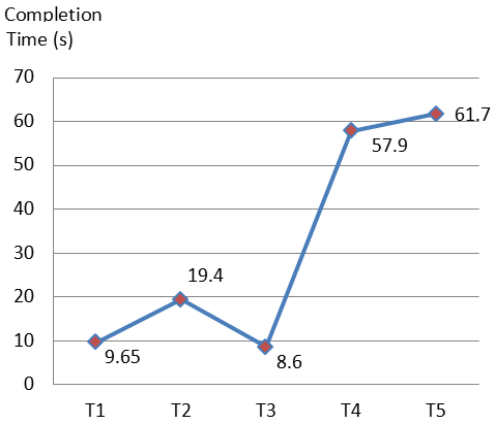


Fig 7: Mean Completion Time of the Five Tasks.

Ideally, task T1 requires 4 seconds to be performed. However, in average, it took almost 9 seconds for the users to finish it. The completion time of task T2 almost doubled with an average of 19.4 seconds. Some participants faced difficulties gazing at the model in order to activate it after being expanded. As a result, it took longer time for them to perform the task.

Since the participants had built some experience with the voice commands, there was a drop in the completion time of task T3 to 8.6 seconds. However, there was a sharp increase in the completion time of task T4 where users spent seven times more than the duration required to finish the voice commands tasks. The increase of complexity level was reflected by the amount of time required to complete task T5.

4.2.2. Questionnaire

A five-point rating scale was analyzed and its results are represented in the graph below (see Fig. 8). It can be observed that most of the participants agreed or strongly agreed that iLung application is easy and comfortable to use, natural and efficient [8].

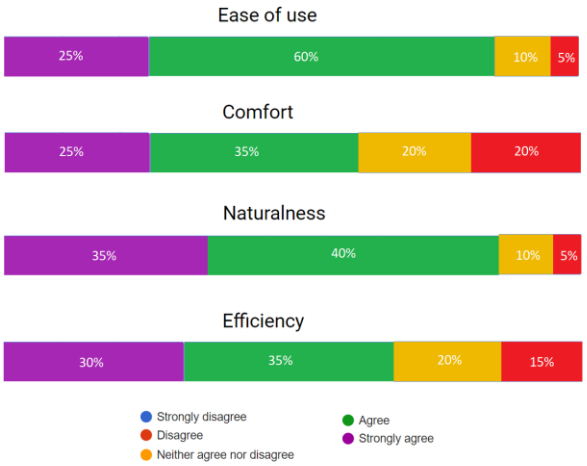


Fig 8: Questionnaire Results Displaying the Percentage Distribution Ratings on a 5-point Likert scale.

5. Discussion

A user evaluation session was conducted to evaluate the user experience of iLung. Overall, participants were pleased with the design of the application. However, some of them experienced difficulties in applying the hand gesture which required more practice of using the device.

5.1.1. Completion Time

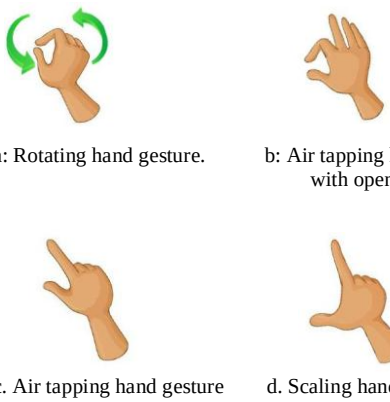
The completion time indicated the various levels of task difficulty, which as a result required different lengths of time to complete. Some users took a bit longer to perform the task T1 due to some noise that affected the voice recognition or the user's lake of experience with the HoloLens.

The statistical analysis of the task performance showed that the completion time of tasks T4 and T5 significantly increased by approximately 50 seconds in comparison to tasks T1, T2 and T3. It can be concluded that the tasks that involved only voice commands provided an easier and more natural approach of interaction than the tasks that involved hand gestures. Therefore, hypothesis **H1** can be accepted. On the other hand, no definitive conclusion can be drawn on the statistical analysis of the performing tasks that involved combined actions since the completion time of tasks T4 and T5 were not significantly affected. Due to this limitation, hypothesis **H2** cannot be accepted.

5.1.2. Observations

Some observations were recorded while participants were performed their tasks.

- Some participants faced issues with the voice command "Reset Model". After analyzing the experiments video records, most of the users were not gazing at the hologram after expanding the model. This resulted in hologram deactivation since the users were not gazing at it.
- It was complicated to use two ways of interactions to perform an action such as, moving the hologram action, which requires using the voice command then applying the hand gesture.
- When users were asked to rotate the hologram, some participants tried to rotate it by rotating their hands rather than using the sliding hand gesture (see Fig. 9a).
- While performing the expanding hologram task, some users tried to scale it using their hands rather than using the voice command "Expand Model" (see Fig. 9d).
- In some cases, the participants were performing air tapping hand gesture while opening their fingers (see Fig. 9b). As a result, they had to repeat the air tapping several times. The optimum way of applying air tapping hand gesture was striking the air with one finger lightly while bending the rest of the fingers (see Fig. 9c).
- There were issues for participants who were wearing glasses.



a: Rotating hand gesture. b: Air tapping hand gesture with open fingers.

c. Air tapping hand gesture with one finger. d. Scaling hand gesture.

Fig 9: Different Observed Hand Gestures.

5.1.3. User Feedback

Participants gave positive and negative feedback. The majority of the positive feedback was about the user experience. Participants found it convenient to use the voice commands as an input modality. As the first time using a holographic application, many of them described the application as a realistic, unique, friendly user

interface and a fast response application. On the other hand, the negative feedback focused on the ambiguity of the application. Some participants recommended adding a Help menu, more details and the reason of iLung. Others highlighted some issues related to the wearable device, as it was rather heavy and it didn't quite properly fit their heads.

6. Conclusion

In this paper, iLung is a mixed reality application for exploring the human lung in natural way. It allows the users to view, interact and explore the lung using a mixed reality device (Microsoft HoloLens). The 3D holograms were generated from the row data of CT scans using 3D Slicer software. In order, to enhance the display of the hologram, a texture was added using Blender software. Finally, the application has been implemented using Unity platform.

A user evaluation session was conducted to examine the user experience of the holographic application. The results showed that the completion time was affected by the type of the task. Opinions of the participants, as the statistical analysis showed, reflect the effectiveness, comfort, naturalness and ease of use of iLung. Suggestions from experts focused on providing guidance for the new users, increasing the voice commands and offering other alternatives to hand gesture inputs. The holographic application can be easily expanded to include more parts of the chest area and new voice commands.

Our future work will focus on expanding this application by creating a website that will allow users to upload their CT scans to order their hologram lung model. Furthermore, the holographic application can be enhanced by adding animation to the holograms. This animation might include different status of breathing settings such as normal, fast, and slow breathing. To improve the user experience for learning purposes, a simulation of the breathing process might be added. Besides the lung and chest holograms, more holograms can be added to the application including bronchial tubes, alveoli, and trachea.

Acknowledgment

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