Mixed Reality System

Interim report
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Supervisor : Loretta Yi-King Choi

Jack Cheung Ka Kit
2013559878
Jerry Tam Chi Ho
2013510585
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Abstract
Mixed Reality is a new technology that allows users to perform physical interactions with the digital world in real time. It combines features of Virtual Reality and Augmented Reality. The project aims to explore and showcase the potential of this technology by creating a multiplayer application. The main focus of our application is interior design but there are also small minor interactive features. This report presents our technology used, methodology, milestone and future development. The team has already done a research on the feasibility of the devices and started implementing the basic functions of the application.
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Section 1 : Project Overview

1.1 Background

In Virtual Reality, a head-mounted device covering the user’s sight and hearing is used to transmit 3D computer graphics and audio. Users can therefore immerse themselves in the digital world as if they were actually in the environment. For example, users can enjoy the view of the Grand Canyon while sitting on sofa.

In Augmented Reality, the digital data is overlaid on the physical world capturing by camera to create the illusion that both aspects are in the same reality. This usually appears on smartphones or cars. For example, map instructions or information can be projected on the dashboard of a vehicle to guide the driver. Popular games such as Ingress or Pokemon GO also uses Augmented Reality.

The idea of Mixed Reality have been discussed for years, but was not realized until 2016. Google [2] and Microsoft [3] are only the 2 companies released devices for Mixed Reality development this year. This is the reason that we tried to use Microsoft Hololens and Google Tango Tablet Development Kit in the project. And there are no any products on the market yet. It is rather similar to Augmented Reality. Both digital and physical data are mixed together to form a new reality. However, digital and physical objects would have physical interactions in real time to even enhance the illusion of having both aspects in a same reality. As an example, if you throw a digital ball to a physical wall, the digital ball should be able collide with the wall and bounce back. Throughout project development, we will use Unity3D as the main editor and the official SDKs of the devices, with the help of online tutorials. More explanations of the technology we used will be introduced later.

1.2 Objective & Scope & Deliverable

The project is not aiming at providing an APP or WEB solution, it is for research purpose. Therefore the objectives are exploring Mixed Reality Applications as the cutting edge technology and the potential of mixed reality and lastly the interactivity of this technology.

Therefore the final goal is to develop an interactive multiplayer mixed reality game which can be installed on the 2 different devices (Google Tango and Microsoft HoloLens) and communicate with each other.

Jerry have been responsible for Tango Tablet in the 1st semester.

Jack have been responsible for Hololens in the 1st semester.
The idea of the game has changed several times. Details of the games will be described in Section 3: Application Design.

To achieve this, there are some sub-goals:

To build simple single player demos for each device. The demos should utilize the common functions provided by the device, to test any practical executional limitation. Then, we can focus on the functions that are only needed for our project and develop demos to test whether we can realize our claimed features and learn other limitations.

To make simple demos to test the communication with each other among the same devices. E.g demos to communicate between 2 HoloLenses and 2 Tangos respectively.

To make demos communicate with each other in a cross platform fashion.

To refine the demos into a complete game.
Section 2 : Technology used

2.1 Microsoft Hololens

It is a head-mounted display unit connected to an adjustable, cushioned inner headband, which can tilt Hololens up and down, as well as forward and backward. There are some sensors in the front and related hardware, including the cameras and processors. The visor is tinted; enclosed in the visor piece is a pair of transparent combiner lenses, in which the projected images are displayed in the lower half. Before using, the HoloLens must be calibrated to the interpupillary distance (IPD) or accustomed vision of the user.

HoloLens uses the position and orientation of user's head, not eyes, to determine their gaze vector. User can think of this vector as a laser pointer straight ahead from directly between the user's eyes. As the user looks around the room, any applications can intersect this ray, both with its own holograms and with the spatial mapping mesh to determine what virtual or real-world object user may be looking at.

The core interactions on HoloLens are press, release, and bloom. The primary way in which user will select or activate holograms in user’s world is the air-tap gesture, which consists of a press followed by a release.
To air-tap, user makes a fist in front of himself, with the back of his hand facing him. User’s elbow should be bent at his side in a comfortable position. Next, user raises the index finger to the sky and then tap, by flexing his index finger down (the press) and then back up (the release).

Bloom is a gesture that is used to go back to the Start Menu from within a holographic application. It is similar to pressing the Windows key on a keyboard. To do the bloom gesture, user holds out his hand, palm up, with his fingertips together. Then open his hand.

2.2 Tango Tablet Development Kit

The Tango Tablet Development Kit is a device that uses computer vision to learn about the world around it. It is equipped with multiple sensors that enable application developers to perform motion tracking, area learning and depth sensing.
2.3 Unity3D Editor

It is a free cross-platform 3D engine and development environment developed by Unity Technologies and used to develop video games for PC, consoles, mobile devices and websites. It is in fact the only officially supported application IDE for the 2 mixed reality devices.

2.4 Tango SDK

The Tango SDK is a free unity package enabling us to communicate with the Tango Tablet Development Kit in Unity using developed functions. It also contains core source codes, documentations and demos adapting to Unity3D.

2.5 Hololens SDK

There is no separate SDK for HoloLens. Development tools are also free, and consist of

1. Visual Studio 2015 ( integrated development environment developed by Microsoft ) Update 3 with the Windows 10 SDK.

2. HoloLens Emulator, which allows users to run apps on Windows Holographic in a virtual machine without a HoloLens device. This is an optional special tool provided by Microsoft, other than ordinary API and SDKs, is the “HoloLens emulator”. We only need the emulator, when we want to carry out the development process without the Hololens device. Although CS department bought 2 sets Hololens, they may be needed by other students anytime for their needs, and therefore we cannot always keep the devices ourselves. Even we have the device, we do not need to carry the devices wherever and whenever we want to develop and test, if we installed the emulator. The emulator is good for a convenient development.

3. Unity HoloLens Technical Preview. In order not to cause confusion, note that this is just the Unity3D engine itself. But it is a custom version of the engine that already integrated with Runtime for Hololens as well as offline documentation and more supports from Hololens forum.
2.6 Photon Networking Framework SDK

This is a free package developed by Exit Games on the Unity platform allowing users to develop realtime multiplayer games. All the server-client interactions are well developed and the implementation is simple. The package also includes a fully authoritative backend server or access to the cloud servers hosted by Exit Games.
Section 3 : Application Design

In the final application, all users would be able to see virtual objects created on both devices but they cannot perform the features provided on the other type of device. Among the 3 main objectives, interactivity is the most difficult and important component.

Note that the design of the project has been modifying with the progress of study of the devices, documentations of the devices and the development. Since we can discover better ideas by learning various kinds of limitation and utilize the concept of Mixed Reality under the limitations. And since the change of design is part of the process of our project, we will describe the designs in this section and describe reasons and the changes in Section 5 : Current Progress.

3.1 Block Building system - Hololens & Tango Tablet

The building system allowed users to build different virtual objects on top of the real world. Users could choose to add simple shapes such as cubes or spheres or some realistic 3D models like buildings or bridges. It was similar to playing lego or minecraft but it involves a lot of mixed reality features. After selecting an object from user menu, the user could tap on a flat surface through the device (Tango) or perform an air-tap (Hololens) to indicate where he wants to place the object. Once the object was added on top of the surface, the scale of the object can be modified by the user. Other than using pre-installed models, users could also upload their own 3D models to the application. Users could achieve this by using the various scanners on the tablet to scan a real object. The user had to circle around the real object holding the device to conduct the scan. Once all the surfaces of the object were covered, a 3D model could be generated by the device. Users with Hololens & Tango Tablet can build and manipulate the blocks simultaneously.
3.2 3D drawing of Art gallery - Hololens only

What was influenced in this idea is Hololens. Works of Tango of Jerry remains on building system. Users could do the air-tap gesture, as if holding the left mouse button to draw anything in MS windows paint or photoshop, and drag the fingers in real world to draw 3D objects into the world. Those 3D objects could be cubes, spheres or cylinders. Based on these simple base 3D models, we can still achieve variation by applying different colours and shapes. We would also allow 2 different types of objects to be draw, either behaving as Rigidbody that bind to real world physics or non-Rigidbody that floating in the mid-air. We would also allow users to switch to shooting mode upon a selection on an UI panel. Shooting mode allowed users to shoot a 3D object to the drawn objects set by an air-tap, as if a mouse click. Tango users could see what users with Hololens drawn.

3.3 Interactive Table tennis - Hololens & Tango Tablet

The Tango device would be replaced by Oculus Rift, a VR headset. Hololens remained in the idea. Both users would use real rackets and real table, while the ball was a 3D object, which was going to be shared across Hololens and computer. Note the Oculus is only responsible for conveying the graphics from games running on computer to user, it is not a computer as Hololens. The game in this idea was a cross-platform application between Hololens and computer. Moreover, a camera would be paired with Oculus such that to let user see the real world, since the game was supposed to run accompanied by reality. The moving rackets should be mapped by hololens into 3D word to interact with the 3D ball, such that users wearing Hololens and the Oculus headset could play table tennis. The game was very dynamic and interactive.
3.4 Interior Design - Hololens & Hololens

This is the final design with only Hololens involved. **Jerry will be switching from Tango to Hololens.** Series of furniture 3D models will be used in the design. Users can drag them from user menu into a room environment, such as sticking to wall or lying on a table, for room design purpose. The reality surface will be scanned into computer, such that 3D objects can only be placed on an available surface, for example, a 3D computer object cannot be placed on a real small chair if the area of the seat was too small. Additionally, users can drag to rotate and resize the 3D object by user menu button.

Other than the main interior design feature, there is also a small interactive feature where a robot would exist in mixed reality to guide and interact with the user.
Section 4 : Project Methodology

4.1 Configured the hardware and Installed the tool

All the development tools required for Hololens can be downloaded from:

We chose Microsoft Hololens SDK for our development, since it is the only SDKs available at the time being. We can only trigger the devices to run the software by using the SDK. Furthermore, it is an official release to support Unity3D Editor, the most compatible SDK for our development.

4.2 Feasibility Research and Study

Before development, we should know

1. The limitation and capability of the device, such as virtual object positioning, depth camera distances, such that we can know how far the device can detect the real world environment, how far we can place the virtual objects in the 3D world from our device and how great the visibility of the virtual objects.

2. The structure and components of the SDKs and function of each components.

3. How the sample demo within the SDKs function, and what do they look like.

Next, we can

1. decide and design the scope and scale of our project, and improve the idea of which.

2. know how to position the virtual objects to let user have the best experience

3. modify the correct source code files and define our own methods without breaking the Hololens system by knowing how the components cooperate to realise the corresponding functions,

We need to study the details of tutorials and documentation provided by Microsoft from:
4.3 Single player applications for individual devices

After learning about the devices, the team will develop a single player application for each device individually. Two members will work on Microsoft HoloLens and the remaining two will work on Tango Tablet Development Kit.

As for the development engine, Unreal Engine and Unity are currently the only two open source game development software supporting mixed reality. However, Unity has a larger user base, better documentations and cheaper packages. This means searching for resources and problem solving on Unity would be a lot easier comparing to Unreal Engine. Therefore the team chooses Unity as the development engine.

4.4 Multiplayer

After completing single player applications for individual devices, the team will start transferring the applications to a multiplayer platform. First, a multiplayer player server would be built using the Photon Networking SDK. The team chooses to set up a fully authoritative backend server rather than using the cloud servers provided by Exit Games. This is to prevent any potential problems in the connection to occur since cloud servers require the use of the internet but a local server can be host in a Local Area Network (LAN). Then, the team will merge the applications from Tango Tablet Development Kit and HoloLens into one so two different types of devices can run the same application and communicate with each other.

4.5 Fine tuning of parameter

After multiplayer prototype being accomplished, we will start to refine the parameters, details and user interface, and finally to present the final product.
Section 5: Current Progress

In this chapter, our team will conclude milestones we achieved in previous phases.

5.1 Feasibility Research

5.1.1 Microsoft Hololens

The table is the results of feasibility research of Hololens, related to hololens spatial mapping and hologram range. By learning the numbers, we can make an appropriate game design about how far from the hololens the objects can be placed, moved, and created.

<table>
<thead>
<tr>
<th>Range Name</th>
<th>Minimum Distance</th>
<th>Maximum Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth Camera</td>
<td>0.85 m (2.8 ft)</td>
<td>3.1 m (10 ft)</td>
</tr>
<tr>
<td>Hologram Placement</td>
<td>0.1 m (4 inches)</td>
<td>infinity</td>
</tr>
<tr>
<td>Optimal Zone</td>
<td>1.25 m (4 ft)</td>
<td>5 m (16 ft)</td>
</tr>
<tr>
<td>Comfort Zone</td>
<td>1.0 m (3 ft)</td>
<td>infinity</td>
</tr>
</tbody>
</table>

The table[4] is going to be explained in the following. Note that Holograms is the terminology refers to virtual objects in Hololens constructed virtual world.

1st Row. Depth spatial mapping cameras is from 0.85 meters to 3.1 meters. This means a plane put in front of the hololens less than 0.85 meters would not be remembered by the devices, but only blocking the camera sight. And in an open area that the closest surface to the hololens farther than 3.1 meters would neither be remembered. The virtual world where holograms to be put into is constructed by depth camera capture [4]. This feature will not influence our project goal, since open area spatial mapping is not required for our the project.

2nd Row. When users use finger pinch gesture to place any holograms, the closest distance between which and the hololens is 0.1 meters. Holograms can also be put to infinite distance from the hololens. The infinity means holograms will be shrunk into very small size, therefore users feel the holograms are being moved to infinitely away from them [4]. Note that though theoretically holograms can be put 0.1 meters from hololens, users can not perceive it. Because holograms will appear in users’ eyes only 0.85 meters away from hololens. No matter users move too close to or too far away from the holograms, they...
will disappear. This is due to the concern of eye comfort, that Microsoft want to prevent the focus of each eye from being too great. Thus, the closest distance of the virtual object to the display lens should be 0.85m [5]. This feature reminded us when users create holograms in our game, the objects should not be generated less than 0.85m from the hololens.

3rd Row. Optimal Zone is referring to optimal hologram placement distance range. It indicates holograms placing between 1.25 meters and 5 meters from the hololens look better to players [4]. Because the objects users see in the 2 display lenses overlap relatively better in this range of distance. If objects were placed beyond this range, situation that objects being seen in one eye while not in another will occur [5]. This feature reminds us that holograms should not be generated less than 1.25m from the hololens.

4th Row. Comfort Zone means our eyes and hands will be comfortable when holograms placed within such distance range from the device. Microsoft suggest that application designers should structure content to encourage users to interact with holograms at least 1 meter away from hololens. The “interact” means users to perform the tap gesture to select holograms. The 1 meter minimum distance here is to prevent users’ arms from passing through holograms, which may ruin user experience. This may relate to object starting to disappear in less than 0.85m distance. Since we have concluded that holograms should not be generated less than 1.25m from the hololens, the comfort zone will not influence our project.

Besides the above table, there are other limitations for hololens. HoloLens is a standalone, mobile computer, so the available storage and memory are a real concern. The hard limit of the memory allocation to each single hololens app and games are 900MB, which is small in nowadays. However, we have decided to focus in user interactivity and cross-platform multiplayer, so sophisticated computer graphic and complex game system are not our objective. The project will stay simple.

5.1.2 Tango Tablet Development Kit

The team discovered three core functions of the device which are motion tracking, area learning and depth perception. Motion tracking enables the tablet to tracks it own position and orientation in a 3D environment. The data is returned in two parts: a vector with the xyz coordinates of the device and a quaternion with the rotation of the device. Area learning gives the device the ability to identify and memorise significant key features in a 3D space. For example, edges and corners can be recognized and stored as a mathematical description. This allows the device to learn the surrounding area and memorises it. Lastly, depth perception is the ability to understand distance to objects or surfaces in a real world. This is the basic requirement for implementing mixed reality. Many depth sensing technologies such as Structured Light, Time of Flight and Stereo are implemented in the device. However, the accuracy of sensors would be affected in high Infra-Red areas and works best indoor at a moderate distance (0.5 - 4 meters).
5.2 History of application design

Note that the change of design is concurrent with the study of the devices, documentations and tutorial, and with the development.

The first idea was 3.1 Block Building system. However, after discussion, the gameplay might not sufficiently utilize the concept of MR and might be slightly dull. Users may feel bored soon, therefore the design was extended to our second idea 3.2 Art gallery.

The idea consisted of “3D Drawing” on Hololens and “Photo Gallery” on Tango. Note that the “Photo Gallery” was assigned to another student in another group. The Tango task on our group remained as building system. In the idea of 3D Drawing, We expected a different gameplay experience than only dropping objects to build, and user could make full use of their creativity by drawing their own imagination.

In early December, we thought that Art gallery was not fun enough to attract users, since the pace is slow and the interactivity between users was still low. Then we came up with the third idea, 3.3 Interactive Sport game : Table tennis. The description of the idea is on the above section. This idea was fully dynamic and thus full interactivity between users was required and less boring. However, there were several difficulties.

1. we could not pair the the camera with Oculus VR headset to transform Oculus into transparent glass as Hololens.
2. Hololens at this stage could not detect fast moving small real world objects into 3D world. The spatial mapping power was limited.
3. 3D objects 0.85 meters or closer from the Hololens would not display on the lens, which means users could not see the 3D objects even if they exist in the 3D world. This is the hardware limit of Hololens, stated in the above “Feasibility Research” section.

Thus the idea was changed again.

The final design is 3.4 Interior Design. The path changed from interactivity and dynamism to practicality. We have been focusing on making a game and providing fun, however, after discussing with supervisor, the better idea to respond to “Innovation of HKU Department of CS” is a practical application. Although the design appear to be boring since users only drag and then stand to observe the 3D objects existing in reality. The design is more useful and constructive to society and business in the future, and it is also extendable. It could be applied further to Architecture upon further development. Thus the idea will have greater potential.
5.3 Single player application

5.3.1 Microsoft HoloLens

The first demo was tap to instantiate objects in the environment with gravity to free fall upon instantiation. The objects were held by reality surfaces, such as sofa and table. One important note here was that the objects looked not as 3D and seemed dull. In the final product, we have to use more sophisticated model and beautiful texture to convey the 3D graphical effect. One more problem was found that when the total number of 3D objects such as spheres or cylinders is over 300, the frame rate of Hololens drop drastically, serious lagging occurs. This is the hardware limit.

Some small features such as gazing at an object changing its colour or tapping to move objects were also tested on the demo. Then I thought if more physics effect and dynamics could be added into the game, more fun could be provided to user, and at the same time, 3D drawing was being developed by another student, I changed my direction on trying to do a shooting demo.

Problems arose during development. Objects after instantiation still dropped as free falling, not performed a projectile as expected. Some answers from official forum gave hints. The codes were modified and placed in another new script file; movement of objects were triggered by accessing the velocity parameters directly rather than applying Unity embedded physics methods.

An 3D object could finally after weeks of trying by the air-tap gesture, projectile motion was performed and bouncing can be applied to the object. What users will see is that they can tap to shoot a projectile cube to hit other existing 3D objects in the scene, the objects being hit will bounce as well. If the shooting cube hit spatial mapping surface, which means the reality surface remembered by the computer, the cube
will also bounce. Thus users will have experience that the 3D cube has interaction with the real wall or table or something else.

The link to the video demo is
https://drive.google.com/file/d/0B49TxTEydDtRNFJXWmp5VkpOZEk/view?usp=sharing

5.3.2 Tango Tablet Development Kit

The team has successfully developed a simple application with some fundamental features. A basic user interface is created and users are able to select virtual objects and add them to the mixed reality world by tapping on the screen.

The objects will only be placed if the destination of the tap is a horizontal plane with an incline or decline of no more than 30 degrees. If the destination does not fulfil the requirements, the application is smart enough to detect that objects cannot be placed on the targeted area. Other than that, objects can also be stacked on top of each other by tapping directly on any object. Below are pictures of some cubes and spheres placed on the floor in different angles.

As shown above, the blocks have a fixed location in space. However, there are still many details to be tackled. The blocks do not have any collision mechanism so they will merge together when placed nearby each other.
The team is now working on the collision mechanism to solve this problem. Currently, the approach is to add the object and run an immediate detection function to check whether the object is colliding with anything else and declare whether the object is safe to be placed. If the targeted area is occupied by other virtual objects, the newly created object will be declared unsafe and immediately removed from the scene. All the computation will occur in a very short amount of time so users will not notice any difference it occurs.

Other than that, we have also tried modifying the light effects on objects according to the surrounding environment so the virtual objects look more realistic.

As you can see, the car models on the left have a lower brightness and a more realistic texture. This is the result of modifications in the texture, brightness and shader of the objects.
### Section 6: Future Development

<table>
<thead>
<tr>
<th>Scheduled Time of Completion</th>
<th>Task</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>Researched on Tango Tablet Development Kit feasibility</td>
<td>Completed</td>
</tr>
<tr>
<td></td>
<td>Researched on Hololens feasibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Determined the project goal</td>
<td></td>
</tr>
<tr>
<td>November - December</td>
<td>Tango Tablet Development Kit single player demo</td>
<td>Completed</td>
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<tr>
<td></td>
<td>Hololens single player demo</td>
<td>Completed</td>
</tr>
<tr>
<td>December - January Mid</td>
<td>Adapting Photon Unity3D Networking SDK</td>
<td>Terminated</td>
</tr>
<tr>
<td></td>
<td>Tango Tablet Development Kit multiplayer development</td>
<td>Was developing and Terminated</td>
</tr>
<tr>
<td></td>
<td>Hololens multiplayer development</td>
<td>Was developing and halted</td>
</tr>
<tr>
<td>January Mid - February</td>
<td>Hololens UI</td>
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<td>UI linking to resize, rotate and move objects</td>
<td></td>
</tr>
<tr>
<td>February - April</td>
<td>Hololens UI</td>
<td>Planed</td>
</tr>
<tr>
<td></td>
<td>UI linking to resize, rotate and move objects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AI Non player character</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>Project refinement, Optimization</td>
<td>Planed</td>
</tr>
</tbody>
</table>
Section 7 : Conclusion

The goal of the project is to develop an interactive multiplayer mixed reality game which installed on the 2 different devices (Google Tango and Microsoft HoloLens) can communicate with each other. We learnt the limitations of the devices after the feasibility research. The Depth Camera capability is basically satisfied for ordinary mixed reality experience, but one crucial imperfection is that the optimal zone and comfort zone minimum distances. The limitations prevent users from a close examination of fine details of some sophisticated 3D objects. The research is crucial as a starting point of this project. Because we need them to decide our actual scope and know our project limitation, and most importantly, we will know what can still be designed to achieve our goal and what should be careful when we are designing more details and developing the game. Although there are changes on the project design and difficulties, the process is as an iterative model of software engineering in commercial development out of school. Thus it is part of the valuable learning experience.
Section 8 : Reference


