Spatial Reconstruction using Microsoft HoloLens™

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Contents

1 Project Background

1.1 Project Details

This project is being worked upon as a part of the course COMP4801/CSIS0801: Final Year Project for the degree of Bachelor of Engineering in Computer Science at the University of Hong Kong. The supervisor of the project is Dr. Dirk Schneiders. The project team consists of students Aman Gupta and Waleed Zafar.

Dr. Dirk Schneiders suggested that the team leverage the highly accurate depth-sensing cameras of the Microsoft HoloLens™ to scan and reconstruct indoor environments. The team is determined to create an application that can perform spatial reconstruction of indoor spaces using the hardware, and create virtual reality ready maps of the spaces.

1.2 Motivation

The main motivation of this project is to assist in the development of 3D models of real-world indoor environments. Development of 3D models usually requires using complex modelling software to mirror a real-world indoor environment.

Existing systems trying to achieve the same objective usually exhibit accuracy and quality issues owing to hardware limitations, or cost prohibitions. Microsoft HoloLens™ provides a decent trade off between cost and hardware, and has not been previously used, in a public and commercial capacity, for indoor 3D scanning purposes.

Our approach of scanning indoor environments instead of designing them on a software is analogous to what a photograph is to a painting - we will be able to build more accurate 3D models at a much faster pace.

Following the numerous real world applications of our proposed system and the benefits the HoloLens™ provides to that extent, the team felt the need to create an application that is able to reconstruct and map indoor environments without much effort.

2 Problems to be Solved

There are a number of existing methods to generate 3D models of indoor environments. However, each of those methods presents some problems, either by being too expensive, or tedious, or simply lacking sufficient quality to be reusable for mapping purposes. By utilizing the HoloLens™, the team aims to solve three major problems plaguing the 3D reconstruction field.

2.1 Interior Visualization Problem

The team plans to build a viable solution that would help interior designers, planning commissions, and engineers visualize interiors as holograms and/or virtual environments. This will allow the user to gain a better understanding of the space for their particular use case.

2.2 Accuracy of 3D Models Problem

The proposed solution aims to improve on the accuracy of models created using scanning techniques. The team will build an application that will leverage the 4 environment sensing and 1 depth sensing cameras [1] to scan indoor environments to build wire-frames. The wire-frames will be processed to give the user a unique experience of high-precision 3D models.

2.3 Dynamic Object Filtering Problem

The team will build a solution that will filter out dynamic objects to give the user a static real-world map. Features such as moving people and obstructing objects will be sensed and removed by the HoloLens™ since they are irrelevant details in the use cases of our application.

3 Previous Works and Their Limitations

There are several hardware and software solutions in the public domain that have attempted to solve the problem: scan and reconstruct environments. However, they have been limited by hardware; sensors and processing power alike. Microsoft HoloLens™ is the first Augmented Reality device of its kind. There exist no known commercial solutions that solves this problem.

3.1 Google Tango[8]

This API provided for the Android Platform™ by Google allows applications to track the position and orientation of the device and to recognise known environments. The API makes it possible to develop an application similar to the one proposed. However, it is marred with problems due to the limited processing power that is available on a mobile device. As the project is still under development issues such as camera crashes and device calibration are common.

3.2 Microsoft Kinect™ Fusion [3][10]

Kinect Fusion 3D provides object scanning and model creation using a Microsoft Kinect ™ sensor. Capabilities of the project include the ability to simultaneously see and interact with detailed 3D models scanned using the sensor. However, Kinect Fusion™ utilizes a single depth sensing camera for tracking, which results in poor performance while scanning flat surfaces. Furthermore, the Kinect™ sensor is not wireless, hindering mobility for the project in varying indoor environments.

3.3 Laser Scanning[9]

Laser Scanning is one of the most popular methods of indoor surveying to generate 3D models, and is used in a number of commercial applications. One of the most common technologies under laser scanning utilizes LiDAR (Light Detection and Ranging) to gather 3D point cloud data. However, extracting actual building models from large datasets generated via LiDAR is a costly and time-consuming endeavor and requires experienced technicians at work. Some commercial solutions utilizing laser scanning technology include the Trimble LaserAce 1000 Rangefinder[11] and the Leica ScanStation P40[7]. However, they face similar problems as with LiDAR, and exhibiting issues such as shape distortion and angular inconsistencies in indoor environments.

Apart from the specific limitations described above, most solutions do not use mesh correction algorithms to fill in the holes, resulting in inaccurate 3D models which might not be suitable for applications that demand high precision, such as construction and industrial automation.

4 Proposed Application

There are two major use cases provided to any user within the app. A user can either load and project a hologram of an existing environment/model, or the user can record a new environment. Environments/models will be stored on our web server and cached on the device. All new users would automatically get registered via their Microsoft Credentials. Users will be sent an email to confirm registration along with a temporary password to access the web portal.

The HoloLens™ application itself will be controlled using voice commands and hand gestures. Figure 1 below outlines the cycle of interaction a user would go through while using the application.

Figure 1: Interaction on HoloLens™

Apart from the HoloLens™ application, the team will also design a web-portal for the system. Users would log into the web portal using their Microsoft Credentials. The web portal would provide, to the user, a list of all of their recorded environments, both processed and ones that are still under processing. Users would be provided with options to either directly download a selected environment to their HoloLens™ for viewing, or to export and download a rendered environment to a different format, compatible for viewing with other VR headsets.

4.1 Major Features

The major features of the application are:

1. **Streamlined UI:** A clean and simplistic User Interface that is controlled by voice commands and hand gestures. The friendly UX allows the user to record new environments or view existing holograms easily.

2. **Record New Environment:** This is the core feature of the project. The team plans to use the depth-sensing camera and existing APIs of the Microsoft HoloLens™ to create 3D mappings of surrounding environments. The HoloLens™ provides hardware and software that is already capable of stitching together surface meshes as a user moves around in an indoor environment.

3. **Environment as Hologram:** The proposed application will have the ability to project holographic representations of 3D models scanned via the application, and span, zoom, and rotate the holograms on the surface it is projected.

4. **Streamlined Web Application:** A simplistic web application that allows the user to manage their recorded environments on the web.

5. **Export Environment for VR Headset:** The web portal would also provide an option to export the scanned 3D models (after post processing on the server) to formats compatible with VR headsets such as Oculus Rift™ and HTC Vive™, to be used as virtual indoor maps.

4.2 Technology to be Used

The main structure of the application would be built using the Microsoft Visual Studio Development Environment along with Unity Framework [2]. This requires the knowledge of programming languages including C#.

A major challenge for our project would be the post-processing required on our back-end server. We are aiming to utilize volumetric integration[6] methods for mesh processing, while utilizing tools from Microsoft's Mixed Reality Toolkit[5][4] where necessary. We will modify the algorithms to suit our project should the need arise based on the quality of processed output we obtain from the HoloLens™.

The back-end will use technologies such as Firebase to maintain the database. Ruby on Rails or Web2py framework will be used to host the server. All user data will be encrypted using AES-256 encryption during network transmission. The team is exploring front-end technologies such as React and Angular to create our web portal.

5 Development

5.1 Timeline

Following is the timeline for the project

Date	Deliverable
October 1	Deliverable of Phase 1 - Detailed Project Scheme - Project Web Page
January 8-12	First Presentation
January 21	Deliverable of Phase 2 - Preliminary Implementation - Detailed Interim Report
April 15	Deliverable of Phase 3 - Finalized Tested Implementation - Detailed Final Report
April 16-20	Final Presentation
May 2	Project Exhibition

The team will be adhering strictly to the time-line. From the completion of Phase 1, the total duration of time available is 196 days. The duration of time that has been allocated to each stage of the project is as follows:

1. Determining the scope of the project - 20 days
2. Analysis of the hardware, and software such as APIs and frameworks - 20 days
3. Design and Development of a functional prototype with basic scanning and visualization features - 30 days
4. Development of web application - 10 days
5. Development of final product - 80 days
6. Integration Testing - 10 days
7. Documentation - 30 days (documentation has been allotted 30 days as it would be a continuous process running in parallel with other tasks)
8. Deployment of web application and publishing of application on Windows™ Store - 10 days
9. Final Report based on continuous documentation - 5 days

5.2 Methodology

The team will follow the Agile Development Methodology throughout the project. Agile Development allows iterative, incremental development which will help our team to divide the project into phases.

The team members have unique expertise and will divide the work accordingly. Mr. Aman Gupta has a strong web-development and app-development background; therefore he will focus on the HoloLens™ application UI as well as the development of the web platform. Whereas, Mr. Waleed Zafar will focus on the development of the back-end server and the mesh processing algorithms.

By phasing the development process, the team will adhere to the strict timeline of the Final Year Project as well as have an integrated application ready at the end of each sprint.

6 Feasibility

6.1 Risk Analysis

As the HoloLens™ is a technology under development, the project is surrounded by significant risks. The dependence on external APIs and limited support from the developers community also add to the challenges. The major risks include:

1. **Time sharing for Microsoft HoloLens:** The Department of Computer Science has only one HoloLens™ device. In the academic year 2017-2018 there are two undergraduate Final Year Projects that will be using the Microsoft HoloLens™

   Mitigation Strategy: Having a regular communication channel with the other teams is essential. Our team has had an initial meeting with the respective students and are in the process of formalizing a schedule to share the device. While the team has possession of the device, it will focus on the development of the user interface for the HoloLens™ application. When the device is booked by other teams, our team will continue work on developing the back-end server and mesh processing algorithms.

2. **Performance of Mesh Correction Algorithms:** Several proprietary correction algorithms and software do exist however, their performance with the HoloLens™ mesh are untested.

   Mitigation Strategy: This risk is of a high magnitude and our team plans to leverage the expertise of our supervisor as well as other researchers to overcome the problem. The alternative of constructing our own algorithm is also under consideration.

3. **Ability to import the 3D mesh in third party software:** The HoloLens™ creates a 3D mesh of the environment it has scanned. For our plane recognition and hole-filling algorithms to work, it is essential that we can upload the mesh onto our server and process the same using third party software.

Mitigation Strategy: This risk is of a very high magnitude and our team needs to quickly overcome the same. In case of roadblocks, our team can also explore using the Unity Engine to process the 3D mesh. This will limit the scope of the project significantly.

6.2 Applications of Project

The project has a wide array of applications in diverse fields. Indoor mapping and visualization can be useful to Engineers, Designers, and Planners alike. Some of the applications include:

1. **Civil Engineering and Interior Designing Applications:** Engineers and Designers have a diverse use cases for 3D models of indoor environments. As our team's technology boosts accuracy and speed of modelling, the productivity of such users will improve. Moreover visualization of the models as holograms and VR environments will help users gain a new perspective of the environment that is missing in existing technologies.

2. **Military and Disaster Relief Applications:** The HoloLens™ could be tethered to a remotely controlled vehicle, or a drone and traversed through an indoor environment that is unsafe for humans. The device will be able to capture the environment to render a 3D mapping while also delivering a live camera feed. Disaster zones such as the Fukushima Radioactive Zone and hostage situations are prime examples of domains that the technology could be used to introspect the setting before taking action.

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