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Spatial Frequency Imaging and Mixed Reality Rendering

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ABSTRACT

The goal for this project is to provide rescue workers with an immersive interface that can give the user a more natural view of a remote environment. To solve this problem, a proof of concept system that scans the general layout of a room and superimposes the rendering of the scanned space onto a mixed reality headset will be implemented. This document will layout the plan for the design of this project, the implementation, and the all other details pertaining to the topic.

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1 Introduction

Everyday, people are placed in life threatening situations. Accidents and disasters occur at a moments notice and require a quick and timely response. We rely on our first responders to keep us safe, but at the potential expense of their lives. In situations where safety is not guaranteed, and minutes or seconds can mean life or death, we want to provide first responders with the best situational awareness and response time to increase the success of their mission. Humans rely greatly on their vision and gain the majority of their environmental awareness from visual clues. In the absence of these visual cues, whether prior to entering or upon entering a space, the risk to the responders life greatly increases. It is our desire to provide first responders with increased spatial awareness in a variety of scenarios by giving them a more informative view of their surroundings.

Current search and rescue methods either put the rescuer in direct danger or completely remove them from the setting using technology such as drones or robots. Entering into a room where the environment is unknown and the risks are unforeseen may place the rescuer and evacuee both in peril. Conversely, removing the rescuer from the environment through sole reliance on video feed prevents the rescuer from naturally visualizing the potentially dangerous environment.

Our solution is to design a proof of concept system that aims to provide the rescuer with an immersive interface to give the user a more natural view of the environment. We will complete this by using real-time room imaging technology to render images that will be viewed using an augmented reality device. We will achieve this by completing three tasks. First, we will create a deployable that will be able to scan a space and relay the data. Second, this information will be processed to create a three dimensional rendering of the area. Finally, this will be ported to a augmented reality device allowing a user in a different space to effectively see into the rendered environment regardless of any obstructions. This will provide the responder with a three dimensional view into the environment, allowing a quick response in an already time sensitive situation. Ideally, our solution will give the responder more information, increasing the probability of a successful rescue.

Our goal is to implement a proof of concept system that gives people the ability to see past physical walls and boundaries. However, the potential does not end there. The successful implementation of this project could someday lead to the visualization of phenomena picked up by our other senses as well. From air pressure to temperature, and invisible gases to sound, the possibilities are endless.

2 Ethical Context

The objective of this project is to provide first responders with increased spatial awareness in a variety of scenarios by giving them a more informative view of their surroundings. We believe this aligns us with multiple standards of ethical standards outlined in The Framework for Ethical Thinking from the Markkula Center for Applied Ethics at Santa Clara University. Our project follows the standards for a Utilitarian solution outline in the Framework. While we are creating a tool that could be used for good or ill - we believe that the potential benefits outweigh the potential disadvantages.

The initial idea for our project stemmed from two ideas: to help rescue workers by reducing their risk of injury while attempting a rescue and to create an innovative system by combining two emerging technologies. Our project has a wide array of uses, many of which are highly beneficial to human safety. However, there are some evident problems that are created.

One large issue that can occur with our project is the presence of false positives. A rescuer could be put in great danger if they enter a room that was deemed safe by the sensor but was done so in error. This false positive could cause injury to the rescue worker and possibly even death. On the other hand, we don't want our device registering a room as unsafe if there is no potential harm inside. This would advise the rescuer to not enter the room and thus put the individuals being rescued in more danger. In order to reach our group standard as to how effective our device is, we need to acknowledge that several tests need to be executed on this device to note how many times the output yields a false positive. If we disclose that information to the user we believe have done our jobs as ethical engineering students.

Another issue that needs to be noted is that our project is a tool. Tools and their functionality are dictated by their design and the end user. There are numerous ways that our project could be used for direct harm. Firstly, this project could be easily used to invade privacy on a small or large scale. This could be either stalking, or spying on the activity of a company. Both these methods would require the deployables to be setup in the rooms that are to be rendered.

This project teaches us multiple aspects of being an ethical engineer, most importantly, commitment to the public good and teamwork. The successful implementation of our project will lead to better chance of rescue of civilians who find themselves in certain dangerous or life-threatening situations. These civilians could be anyone: people trapped by an earthquake, a fire, or even a tsunami. Our team has also needed to make sure that our project will work well in a team environment. Almost all search and rescue missions are done in teams, and we want our project to be used by these teams without harming their coordination as a group. This means that part of our project is making sure that the interface is clean, easy to use, and has support for multiple users working at the same time. We believe every person should have the highest possible chance of survival in the event of a natural disaster. In an event that could potentially be no fault of the person at risk, we want to provide them with the best chance of rescue.

3 Requirements

This section lays out all of the requirements for our system, both functional and non-functional, arranged in order of precedence. The requirements address what our system will do as well as how it will perform. In addition, we have included the initial design constraints. They are the limiting factors by which our final product must abide.

- Functional
  1. It will acquire distance vectors of a room.
  2. It will render to-size version of a scanned 3 cubic meter room.
  3. It will display the scanned room onto a mixed reality headset.
  4. It will allow the user to rotate the room on the headset through hand motions.
  5. It will oriented the room based on a magnetic compass that will be integrated onto the deployable device.
- Non-Functional
  1. It will have a user friendly interface.
  2. It will produce an accurate rendering of scanned room.
  3. The rendering will clearly depict important features of the room and the data will be easily discernible.
  4. It will be quick in search response time.
  5. It will be a lightweight deployable.
- Design Constraints
  1. The deployable must keep an accurate reading of the relative direction it's facing with regard to the HoloLens.
  2. The deployable must maintain an accurate distance from itself to the HoloLens.
  3. The deployable must be able to scan a room in less than 5 minutes.
  4. The deployable must take distance vectors from at least half a room.
  5. The deployable must weigh less than 2 Kilograms.
  6. The deployable must be smaller than 20 cubic centimeters

4 Use Cases

The HoloLens only has a limited number of use-cases as most of the actions our system will assist occur externally. To clarify, say a first responder uses our application to scan a potentially dangerous room, any rescue operations after the fact are not an extensions of our system, as our device is simply a tool.

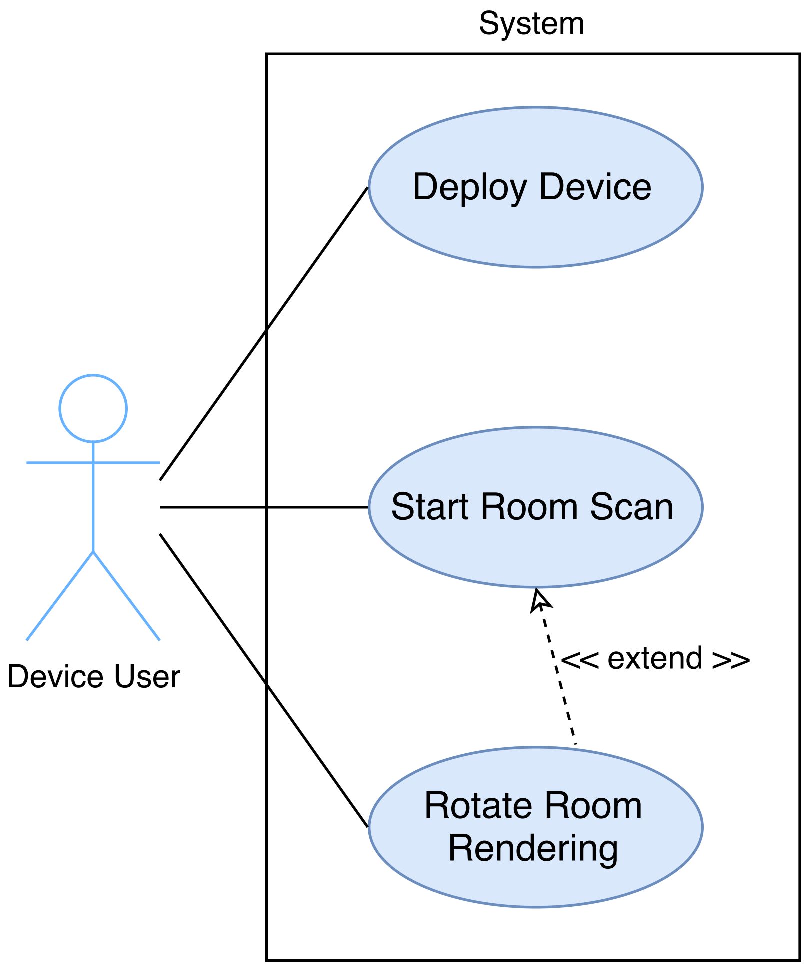


Figure 1: Use Case Diagram.

1. **Deploy Device**
   Actors: Device User
   Description: User positions device in a room.
   Pre-Conditions: Since our system is still a proof of concept, ensure device is tethered to a computer.
   Use Case Process:

   (a) User enters room with device

   (b) User places device in room

   Post-Conditions: Device is ready to start scanning.
   Exceptions: User can either stay inside or leave room after placing it.

2. **Start Room Scan**
   Actors: Device User
   Description: User initiates scan from HoloLens' application
   Pre-Conditions: HoloLens must be worn and application opened
   Use Case Process:

   (a) System displays main page
   (b) Actor selects ”Start Room Scan”
   (c) System sends message to computer and then to device to start scanning
   (d) Actor waits will device scans
   (e) Once finished, device will send data back to Unity which will render point cloud of the data
   (f) Rendered room is sent back to HoloLens

   Post-Conditions: Point cloud is now viable to user.
   Exceptions: If data is lost or corrupted in anyway, a rescan button is available.

3. **Rotate Room Rendering**
   Actors: Device User
   Description: User rotates rendered point cloud room.
   Pre-Conditions: Start Room Scan action must occur before.
   Use Case Process:

   (a) System displays point cloud room
   (b) Using HoloLens touch controls, user taps, moving their pointer finger from vertical to horizontal, and Holds this position anywhere in front of them
   (c) While holding, user moves fingers left to rotate left and right to rotate right
   (d) Actor rotates until room lines up with real room
   (e) Actor releases Hold, or relaxes fingers

   Post-Conditions: User must release Hold to perform any other actions
   Exceptions: Depending on desired result, lining up the rendered room with the real room is not essential, only suggested.

5 Block Diagrams

In Figures 2 and 3 are both our level 0 and level 1 block diagrams outlining the principal functions of our system. The Level 0 Diagram explains a higher level design process of our inital project model. The Level 1 Diagram delves deeper into the processes of our design and depcits the intricacies of our implementation.

1. **Level 0 Diagram**
   This diagram shows the direct chain of data starting from the Lidar up until it is rendered in the HoloLens.

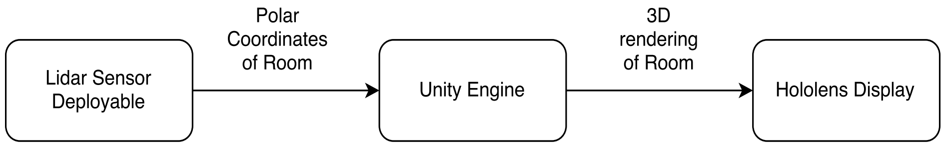


Figure 2: Level 0 Block Diagram.

2. **Level 1 Diagram**
   This diagram shows the direct chain of data starting from the Lidar up until it is rendered in the HoloLens, as well as more specific functionality of the lidar deployable

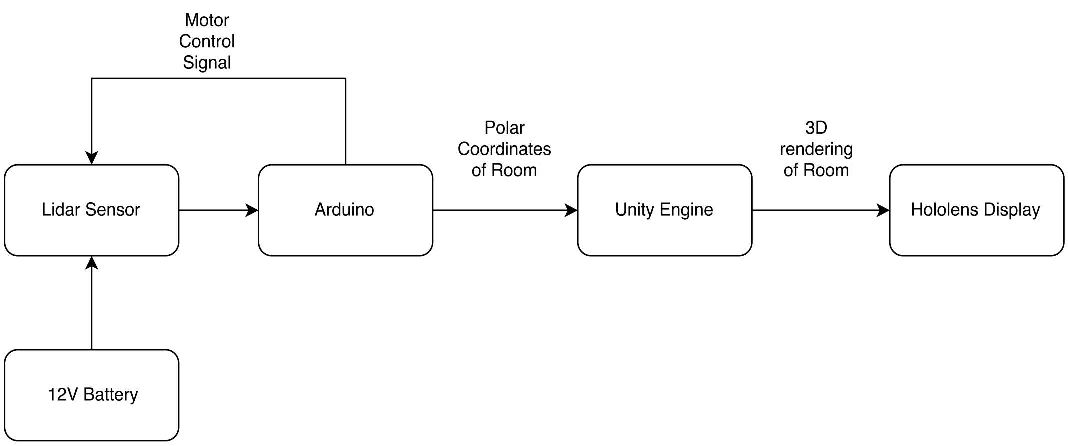


Figure 3: Level 1 Block Diagram.

6 Activity Diagrams

The activity diagram depicted in Figure 4 lays out the process flow for using the application. The device user will start by deploying the device in the desired room and opening up our application in the HoloLens. They will then be presented with an option to start the room scan, which will send a message from the HoloLens to our computer and finally to the device.

1. **Activity Diagram**

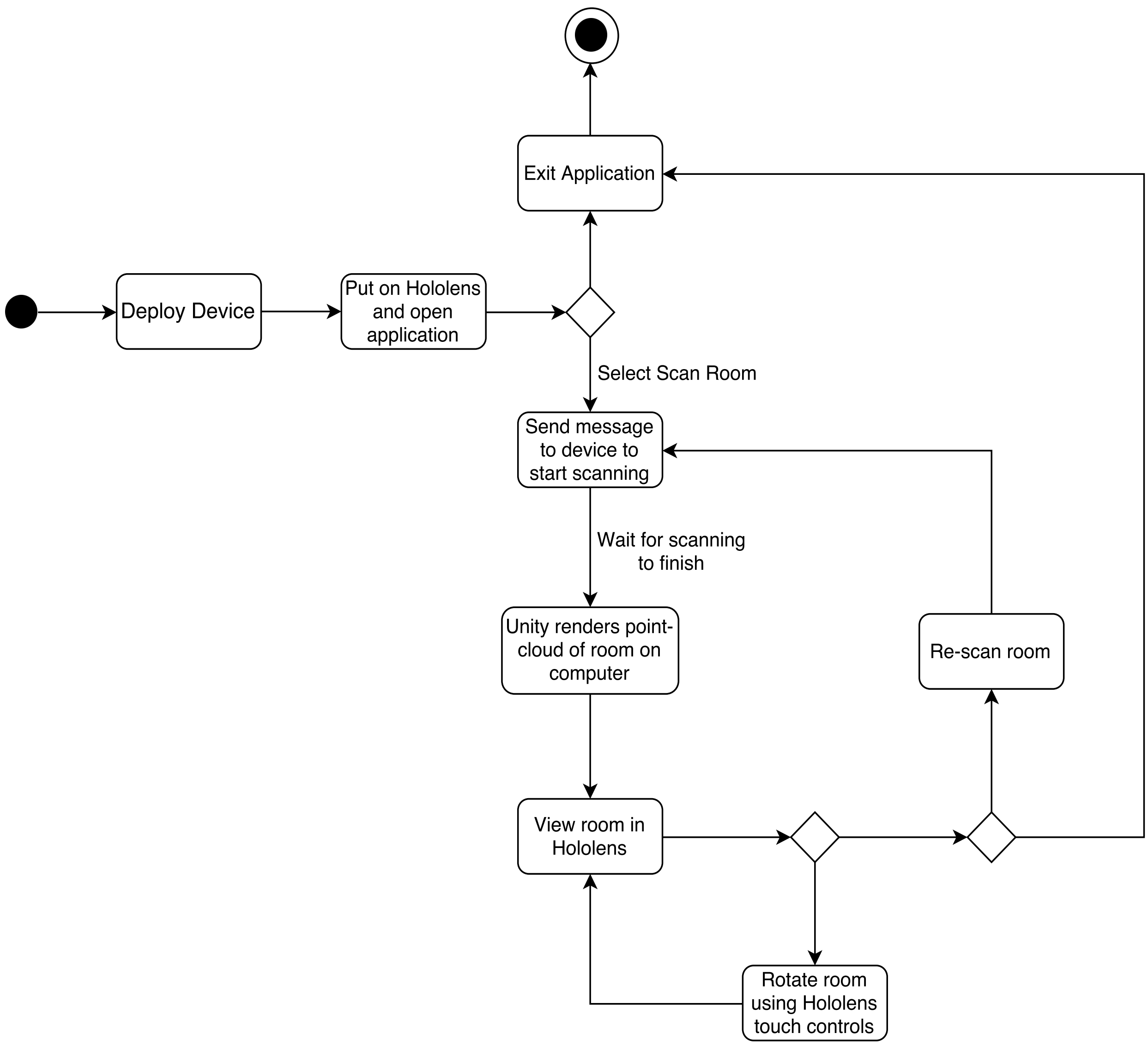


Figure 4: Activity diagram for the Device User.

7 Conceptual Models

In order to illustrate what our HoloLens application may eventually look like, we have made mock-ups of the proposed systems graphical user interface. The first one, found in Figure 5, depicts the button the Device User will select to initiate room scan. This will then lead the deployable to begin scanning - the HoloLens will show that the scan is underway by a loading message shown in Figure 6a. Finally the user will have the point cloud/mesh of the room on the HoloLens as shown in Figure 6b.

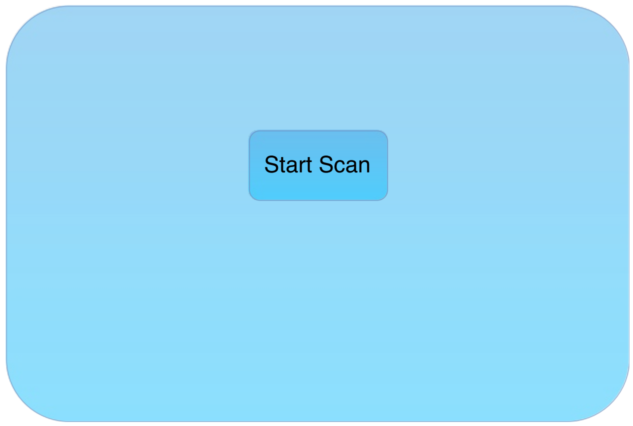
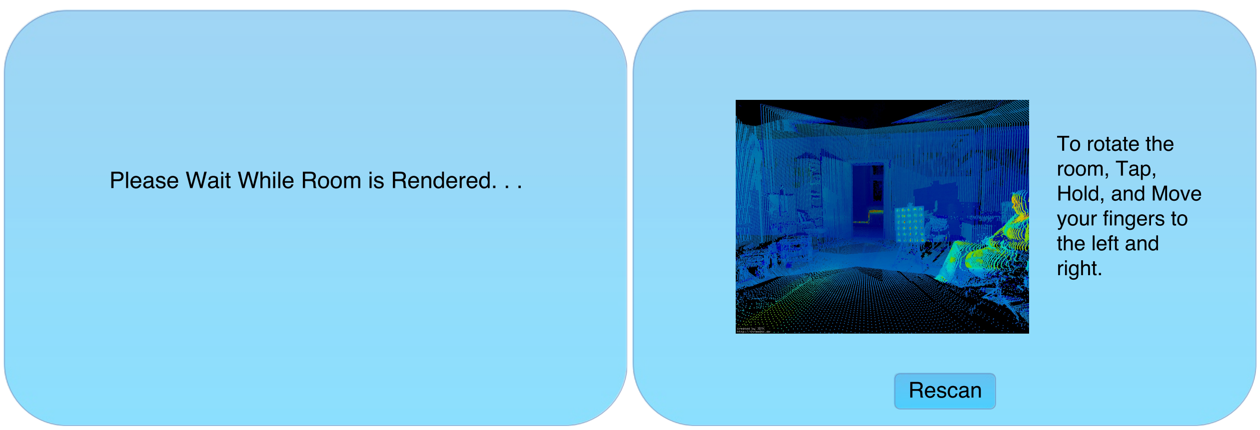


Figure 5: A mock-up for the system's login page.



(a) Loading screen displayed in HoloLens.

(b) A point cloud rendering of a room.

Figure 6: Diagrams for the user's interface on the HoloLens.

8 Implementation Possibilities

Our solution to give first responders more information about their environment can be implemented in several ways. We wanted a solution that minimizes the danger to the user and gives them information without being too invasive on their natural flow of searching through the building. We could have implemented a deployable that uses a camera to scan an image of the room and relay that but we felt that this does not give the user as much supplementary data than distance measurements.

We also recognize that this deployable could be mounted on a robot or drone.However, this would require another user to be piloting the robot or drone. We do not want to add the requirement of another user to pilot each robot and we believe that creating a robot to mount our sensor on would greatly increase our workload in our very limited timeframe. This led to us creating a mobile deployable that can be easily tossed into the room which will measure the distance from the deployable.

Our next step was to present these distance vectors to the rescuer in a way that is easy to understand, and minimally intrusive to their natural senses. We could have created a mapping displayed on a screen they could interact with but we felt this takes them away from the room and doesn't allow them to smoothly canvas a room at the same time they are inquiring with the data. This led us to implement our solution through a mixed reality headset which will display the room rendering in a heads up display which still allows for the person to interact with their environment while working with the data provided by the deployable.

9 Technologies Used

We will be integrating a number of technologies into our system to improve the accuracy and functionality of the system as a whole. In addition to the main devices, we intend to include a few accessory devices to supplement the deployable. We are also utilizing very comprehensive software tools to reduce the number of dependencies of our software.

1. Hardware
   - Microsoft HoloLens
   - Arduino Uno Rev3 Microcontroller
   - Lidar-Lite V3
   - HS-422 Servo
   - Lynxmotion Servo Mount
   - Bluefruit Bluetooth Serial Link
   - SparkFun HMC6343 Breakout Electronic Compass
   - Ethernet Cable
   - Microsoft Surface (Carls computer for now)
2. Software
   - Unity v2.0.03f
   - Visual Studio 2015/2017
   - OpenGL
   - HoloToolKit

10 Design Rationale

The initial design of the system was created to produce a base level proof of concept model. The design decisions were made to ensure that we could create a working model for both the hardware and software.

- Hardware
  - The lidar scanner will rotate 90 degrees in azimuth and 180 degrees and take 270 samples per second to acquire a sufficient number of sample points without taking too much time.

- Software
  - From the file of data points, we will create a point cloud to generate a mesh. The mesh will create a better approximation of the objects in the room a simple point cloud.
  - We will allow the user to rotate the rendered room on their own accord to remove any errors that might result from hardcoding the rooms orientation.

- Technologies Used
  - We will use the Microsoft HoloLens mixed reality device because:
    * There is a significant amount of support and documentation available.
    * It is the most advanced mixed reality device available.
  - We will use the Arduino Uno microcontroller because:
    * It is cost effective.
    * It can efficiently perform all the tasks we require in a microcontroller.
  - We will use lidar sensors because:
    * The maximum error we can expect from Lidar is only 2.5cm.
    * They able to take multiple samples at a fast rate because samples are taken at the speed of light.
  - We will use the HS-422 Servo and its accompanying Lynxmotion Servo Mount they interface easily the Arduino and are reliable.
  - We will use Bluefruit Bluetooth Serial Link because it is a low budget and commonly used bluetooth device that integrates well with the Arduino.
  - We will use SparkFun HMC6343 Breakout Electronic Compass it is a cost effective and commonly used compass that integrates well with the Arduino.
  - We will use Unity to render our room scans because:
    * It is reliable.
    * It ports easily into Visual Studio.
  - We will use Visual Studio 2015 to develop the HoloLens application because:
    * It has OpenGL build-in.
    * It easily ports to the HoloLens.

- Technologies Not Used
  - We chose to not use sonar sensors because:
    * Interference of reflecting waves complicates the mapping of the room.
    * The accuracy of sonar is not nearly where we believe it needs to be for search and rescue applications.

11 Budget

We established a budget early in the development process to establish our financial constraints. Based on the funding that we acquired we have constructed a budget plan, depicted in Table 1. This budget table provides a breakdown of all purchases, quantities, and costs.

Device	Quantity	Cost
Lidar-Lite V3	2	$300
Arduino Uno Rev3	2	$51
HS-422 Servo & Lynxmotion	2	$30
Bluefruit Bluetooth Serial Link	2	$60
SparkFun HMC6343 Breakout Electronic Compass	2	$300
Ethernet Cable	1	$10
Total Price		$751

Table 1: Itemized budget table.

12 Test Plan

In order to ensure the development of a high quality device we intend to use a number of different testing styles. Below we have laid out the types of testing we will use in the order that we intend to use them, based on our current development plan.

- Unit Testing: Performed on individual tasks to ensure correct execution.
  - Hardware
    - Verify the accuracy of all Lidar measurements.
    - Verify the functionality of hardware level code.
    - Verify the correct performance of all tasks coded to the hardware.
  - Software
    - Read and parse files containing scan results.
    - Render file data into point cloud/mesh objects in Unity.
    - Export objects in Unity to HoloLens application.
    - Display object in HoloLens application.
    - Manipulate and interact with object through the HoloLens.

- Integration Testing: Performed when unit testing is complete on connected portions of both the hardware and software.
  - Perform one room scan, export to the main computer, render and display all as one function.

- Functional Testing: Results of this testing will be checked against our requirements to verify that they are being completed.

- Usability Testing: This will receive special attention, since the user interface is so crucial in any immersive reality experience.
  - Performed to ensure easy user interaction with the rendered room.
  - Performed to optimize the menus and options present in the display.

- Regression Testing: Since out design is proof of concept, it will undergo many changes and additions depending on the success of each step we take.
  - Performed when any additions or replacements are made to the hardware (motors specifically).
  - Performed when new additions are made to user capabilities and backend functionality.

13 Risk Analysis

Knowing the risks associated with completing a functional product is an important part of the design process. By laying out the potential impact of each risk as well as the probability of its occurrence, we will be able to take preventive steps to avoid encountering them. Below is a risk analysis table that highlights our potential risks.

Risk Analysis					
Risk Name	Consequence	Probability	Severity	Impact	Mitigation Strategy
Hardware Failure	Unable to run tests and take scans	0.01	9	0.09	Purchase backup hardware implements
Loss of Member	Reduction in work speed or halting of work	0.001	6	0.006	Remain healthy and take care of ourselves
Time Constraints	Create a backlog in workload and reduce quality of deliverables	0.3	4	1.2	Utilize good time management by following our schedule and accomplishing checkpoints on time.
Loss of Data/Invalid Data Collection	Slow down development time due to a lack of testable data. Require regathering of data	0.01	3	0.03	Use source control to manage all code and data
Compatibility Complications	Will have to find other tools with wider compatibility or reevaluate the structure of project to circumnavigate compatibility issues	0.2	6	1.2	Do research in advance and select our tools carefully to avoid conflict of platforms. Start all development from the same platform for all team members.
Significant Software Bugs	Slow down development time	0.3	4	1.2	Plan out software development details and follow good programming strategies

Table 2: Risk analysis table.

14 Development Time Line

In order to organize the design and implementation of our project, we have developed a timeline, shown in Figure 7. This timeline outlines our main tasks throughout fall, winter, and spring quarters. The colors are used to show each groups tasks.

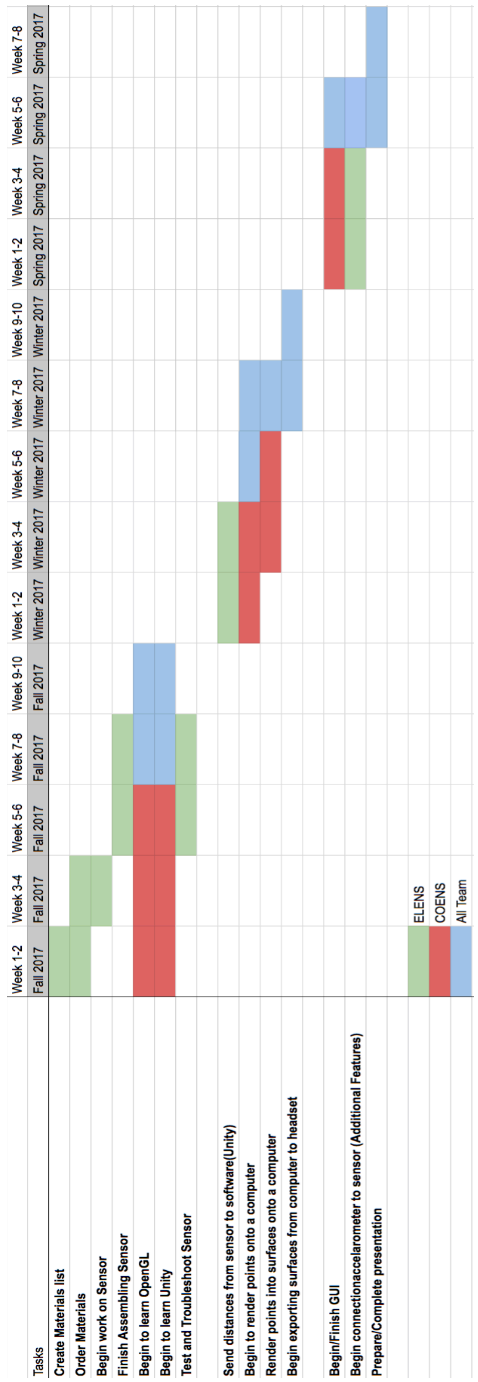


Figure 7: A layout of the breakdown of tasks and their completion time lines.

15 Results of Preliminary Work

As of December 9th 2017, we have constructed a functional Lidar room scanner by securing a servo pair to a base and mounting a Lidar on top. This scanner has 180 degrees of freedom horizontally, and 90 degrees of freedom vertically. This means our device can only currently scan half a room, the bottom servo may be upgraded in the future to allow for an accurate 360 degrees.

This device is being controlled and interfaced with through the use of an Arduino which is wired to a computer via USB. Data is currently processed by the connected computer and then manually dropped into Unity. Currently in Unity we are able to render a point-cloud room based on the data.

16 Expected Results of Finished Product

By the end of the school year we hope to have a lidar deployable with a full 360 degrees of motion in the horizontal direction. We also aim to have the scanner be controlled by the user wearing the HoloLens. This means we will need to create an application to run within the HoloLens.We will be able to output an accurate point cloud of our room through Unity. Finally the HoloLens will create a rendering of the room on its screen allowing a user to get distances to objects that they may otherwise not see.