Boston University
Electrical & Computer Engineering
EC463 Senior Design Project

First Semester Report

Ventana

Submitted to

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Team 13
Ventana

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Executive Summary

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Technology in the home is hard to use. In modern homes, internet connected devices surround people, from smart TVs to wireless speakers. Controlling these different devices consists of multiple applications, either mobile or web, ranging even to clunky interfaces that are inconsistent between types of devices and not intuitive for the everyday user. Using Microsoft HoloLens, the team will create a platform to find, connect, track, and control these existing internet connected devices in the home. Ventana comprises of three main facets: the platform that allows these Internet of Things devices to speak to HoloLens, a target that acts as a marker for the HoloLens to track device position, and an application for the HoloLens that allows it to control the interface of our platform. In doing so, Ventana will simplify the interaction between humans and internet connected devices in the home by providing clear, customized holographic displays.

1.0 Introduction

The average modern home supports ten internet connected devices. This ranges from mobile phones, to routers, to internet connected TVs, to personal computers. According to Reuters, that number will jump to fifty by 2020. Many of the devices consumers use today have interactive displays that make it easy to control, but most of the 500 percent jump will be made up of devices that have a single purpose and are small, so they either need to have a very limited display, or none at all. This makes setting up, controlling, and maintaining these products less obvious and therefore more difficult.

This first step of creating an augmented reality interface will be for early adopters who already have dozens of internet connected devices in their home. Currently, the best solution for managing multiple devices is a mobile application. It shows a list of IoT devices on your network and you tap on each one to control it. That solution works well with 5 devices, but becomes overwhelming as you add more. Competitors suspect the solution to this problem is voice control, which initially sounds promising, but remembering the given name of each of your thirty devices and their supported functions quickly becomes just as overwhelming.

Today, the solution will require a three-thousand-dollar headset, but tomorrow that headset will look like a pair of glasses and cost a few hundred dollars. Today, this is only a solution for people who dive into new technology early and easily, but soon the average consumer will be able to empathize with the problem of controlling the dozens of smart home devices. Allowing even the smallest device to display an uncompromised interface will make technology in the home easier to use for everyone.

The team completed background research of IoT devices in the home, from interviewing customers to testing the devices themselves, in order firmly grasp the problem. From there, the team's approach has been to use an Agile development methodology. Implementing all aspects of Ventana for a single device, the Sonos speaker, allowed the team to understand how to approach continued development. Starting with one device and expanding to the next device, light bulbs supported by a Wink Hub, also represents modular development, another critical aspect of the team's approach. The more modular the project, the more scalable it becomes, in terms of having a standard sandbox hologram that can then be customized with relevant controls depending on the device. Overall, the team emphasizes Agile development methodology, modularity, and scalability for Ventana.

Figure 1, shown below, represents the overall vision for Ventana. The HoloLens user on the right side of the Figure 1 sees a custom holographic display for internet connected devices in his living room, such as his speaker, TV, and lights. The controls for each of the devices are accessible to him by simply gazing at the targeted device and tapping his finger on the desired button.

Figure 1. Ventana Project Vision for a HoloLens User in the Living Room

2.0 Concept Development

The main objective of a design project is to ensure that one is solving a problem and building a solution that fulfills the issues within the given constraints and required needs of the client. Ventana has been carefully planned and thought out to ensure that all viable options are considered and have the problem statement at the core of the development process.

As a student-proposed project, Ventana was idealized as a better interface for controlling a home's devices. The vision of the product drew from advances in the technological ability of augmented reality and the release of the Microsoft HoloLens as the team's target development device. The Microsoft HoloLens was chosen for its unique ability to overlay applications in a user's world without the need of additional devices and it's advance room mapping abilities allowing virtual objects to be placed and fixed in the physical world. These two properties combined would allow for the team to build a proposal which would add to the use cases the HoloLens supports, making Ventana more useful and marketable for the team's customer. Ventana will help shape the standard of communication and control between Internet of Things devices and augmented reality systems such as the HoloLens.

The problem specified by the proposal mentioned the complexity of controlling the constantly growing number of devices in a modern home. When interfacing with a speaker, traditionally to determine what is playing on that speaker the user would need to get his or her phone, unlock it, and find the app that's playing music. If he or she wants to interact with the speaker itself, like checking the battery level, he or she needs to go to a different app, or handle the speaker with a working knowledge of the hardware buttons and light indicators. As the number of devices increases, there are applications that support the control of many IoT devices, but these applications are simply lists or unintuitive, complex menus that make the experience of using these smart devices poor. Another solution is voice control, which requires memorizing the correct names for the devices that the hub application assigns to them and requires memorizing the proper commands to control the specific device. This led to the realization of Ventana's problem statement: technology in the home is hard to use. Most people do not have a substantial number of internet connected appliances right now, but there is an obvious growth potential and prediction for smart home devices that will require a solution for ease of use and fluidity of control. It is not only about IoT devices and the hubs, but also about the combination of different technology tools and providers which each have separate interfaces, dissimilar methods of interaction, and unclear requirements on use of the system.

With Ventana, the solution is simple. By returning to the familiarity of physical interfaces such as a switch, slider, info dialog, or button and ensure that within a familiar yet flexible interface, users can interact and control their devices with localization context, the best UI possible, and without the need to memorize special keywords or navigate intricate lists. The team plans to deliver a standard and a Universal Windows Platform application that presents a method of interaction with devices in the home through augmented reality. The two components of the solution are the HoloLens application written with Unity and C# and a hardware or software tracker that will be used to track objects based on the user's gaze. To narrow down the scope of the problem statement, the team focused on simplifying the smart device entertainment experience in the home.

Tasked with the challenge of developing an interface and a standard that will make interaction with entertainment technology in the home simpler to use, the team went ahead and conducted customer development questions to validate the problem statement and establish an approximate market size. These customer interviews helped the team to understand the client's problem and to develop an approach to begin solving this problem. The direct opportunity to talk to potential users of the system provided valuable insights, such as how users work with IoT devices daily and the popularity of internet connected devices within the chosen demographic of users. This demographic is best represented by young professionals, often with families, that adopt new technologies at an above average pace — either being innovators or early adopters as based on Roger's Adoption curve (Summary of Innovation Adoption Curve). The team also learned the most common type of IoT device in the home are entertainment devices followed by the Nest Thermostat.

The customer discovery findings and the additional research on a wide array of IoT devices available on the market helped determine what would be the first device that Ventana would support. The client required a solution that would be able to be deployed by the end of November with support for at least one device, and a holographic interface that would aid in the control of entertainment devices at home. Given this requirement, the Ventana team explored the base requirements to interface with a device to meet those standards. This involved exploring televisions, speakers, lights, and music equipment. For the HoloLens, this would involve determining a positional tracker, an augmented reality standard development kit, a network interface path such as to be able to interact and relay data to and from the HoloLens and the device, and lastly, to be relatively available both in the consumer market, as well as the team's lab environment. These search criterions helped narrow down the scope of supported IoT devices to speakers as an initial target. Researching the APIs and available third party developer accessibility tools on each speaker device, it was determined the Sonos Speaker has the widest range of compatibility and interoperability for third party expandability. Two alternatives explored that did not successfully pass all compatibility tests included the Amazon Alexa Connected Speaker and Google Chromecast. Both of these devices connect to the internet, but the Alexa has a limited developer-facing APIs which wouldn’t allow us to add control to the device, and the Google Chromecast lacked an API to interface with it.

Another major requirement, outside of the IoT device, is how the HoloLens would identify the device in the context of a real-world location. Ventana needs a positional tracker to track of what devices are available in the current view frame, and needs to be able to recognize which interface should control that particular, specific device. Research efforts in this spectrum relied heavily on try and test. A niche prototype test, determined if the HoloLens could identify an object, such as a face, and place a textual marker under it. This involved complex linear algebra and computer vision, which would add significant time to the development efforts requiring to build a scalable solution. The next test came out of recommendation from the MIT Media Lab Hackathon, and involved utilizing an augmented reality framework called Vuforia that uses VuMarks, physical symbols placed on a real device, to tag and place a holographic object based on the seen VuMarks. This proved to be fast to deploy, effective for the recognition requirements, and served as a stable solution to build into the code of Ventana.

The Wink Hub is the next IoT device selected to build development support. This hub maintains an open API endpoint for multi device control from lights to home sensors satisfying the need to facilitate interaction with IoT devices through holographic interfaces and allows Ventana to quickly scale to multiple IoT device under one common shared interface. This design decision opened the ability to turn from a one-device mixed reality interface to a consumer-facing, in-market application that can be used in homes today. Ventana will modularize these API endpoints into use cases, such as music, lighting, security, and give the last and final requirement traction, a common standard for interfacing with IoT devices through augmented reality.

With Ventana, the team introduces not solely a device to control Sonos or Wink Hub connected devices, but also opens up the door for IoT device manufacturers to leverage mixed reality interfaces into a common, user-friendly, and intuitive approach simply by linking existing APIs with Ventana’s platform.

3.0 System Description

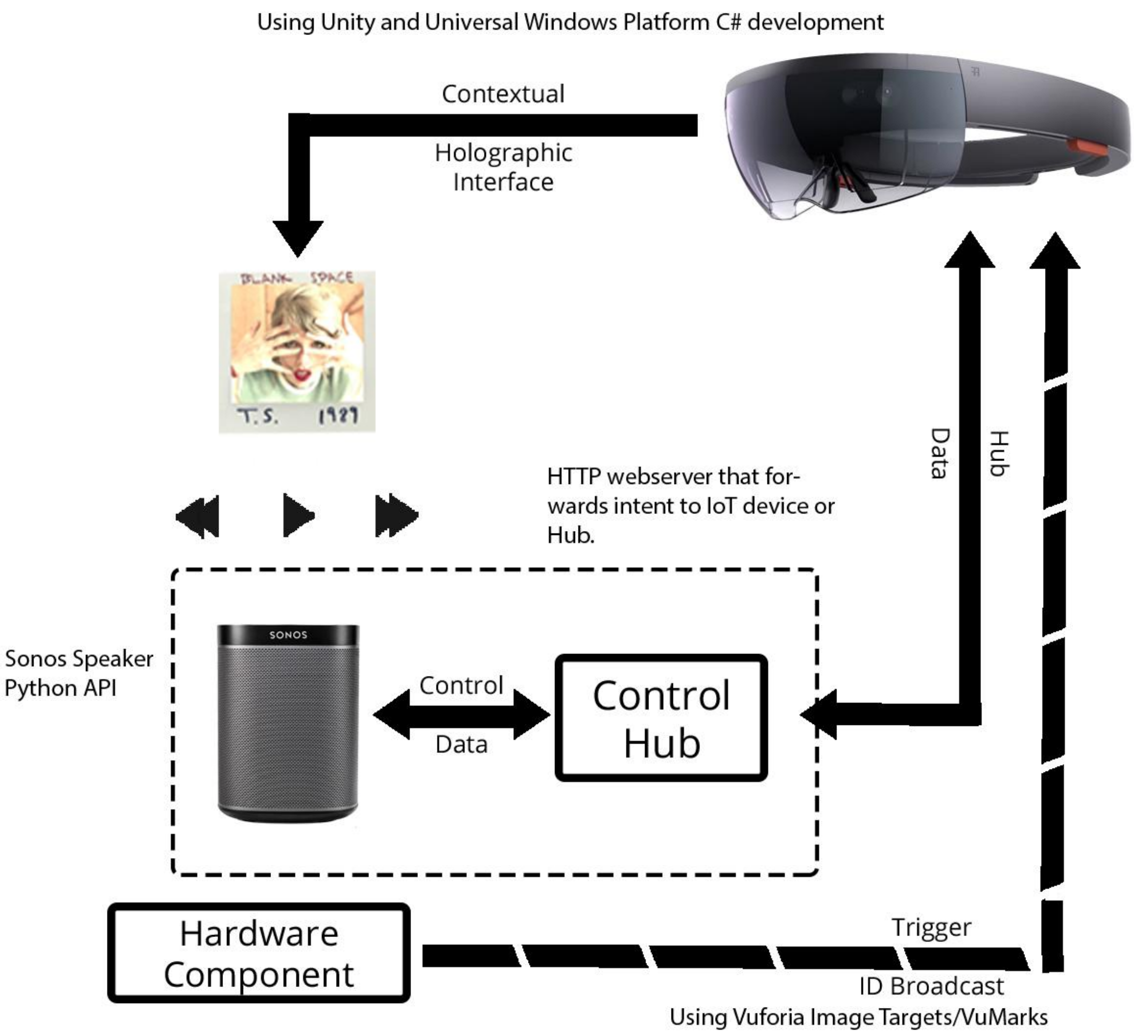


Figure 2. Ventana System Overview

The main system is defined in Figure 2. The team decided that having a control hub would abstract away the need for the HoloLens to be both a control server and in charge of managing where holograms get placed in the world. This control hub would allow the HoloLens to talk to it through simple HTTP requests that are easy to fabricate. A side effect of setting up this control hub is that more modules for different IoT devices can be added, as will be described later. Once the control is set up and working, Ventana only needs a way to spatially tell where to place a Hologram. This part of the functionality is done with the Hardware component (right now a Vuforia image marker) as it will trigger HoloLens to display a hologram at a specific location in the user's field of vision. Together, all these parts will encompass the basic implementation of Ventana.

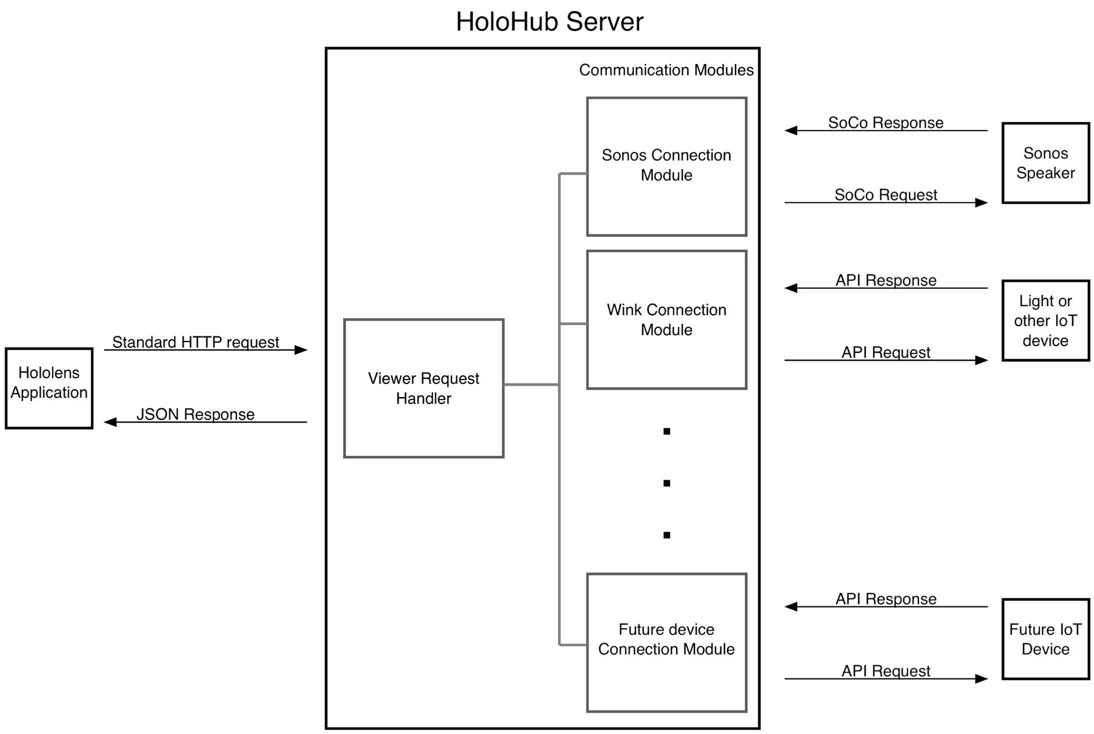


Figure 3. HoloHub Server System Overview

The HoloHub server is the brains of the entire system. Its job is to receive requests from the HoloLens via HTTP requests to a URL that can be specified. After the HTTP request is received by the HoloHub Server, it then gets processed so that the corresponding module for an IoT device can send out another HTTP request to control the correct device. This design is smart because it allows Ventana to possibly migrate to the cloud in the future, as all the code would just need to be uploaded to a cloud service provider like Microsoft Azure or Amazon Web Services. The guts of the HoloHub server code is currently written in Python using the Flask microframework, which was chosen because it allows for a quickly set-up, efficient web server that has no vestigial parts that would slow it down. To further increase the efficiency of use, this server is hosted on a Raspberry Pi 2 that the team has set up to run our code on launch. Currently, it is equipped to handle talking to a Sonos Speaker, but the HoloHub server will be able to exponentially add devices due to the extensibility of the design that can be seen in Figure 3.

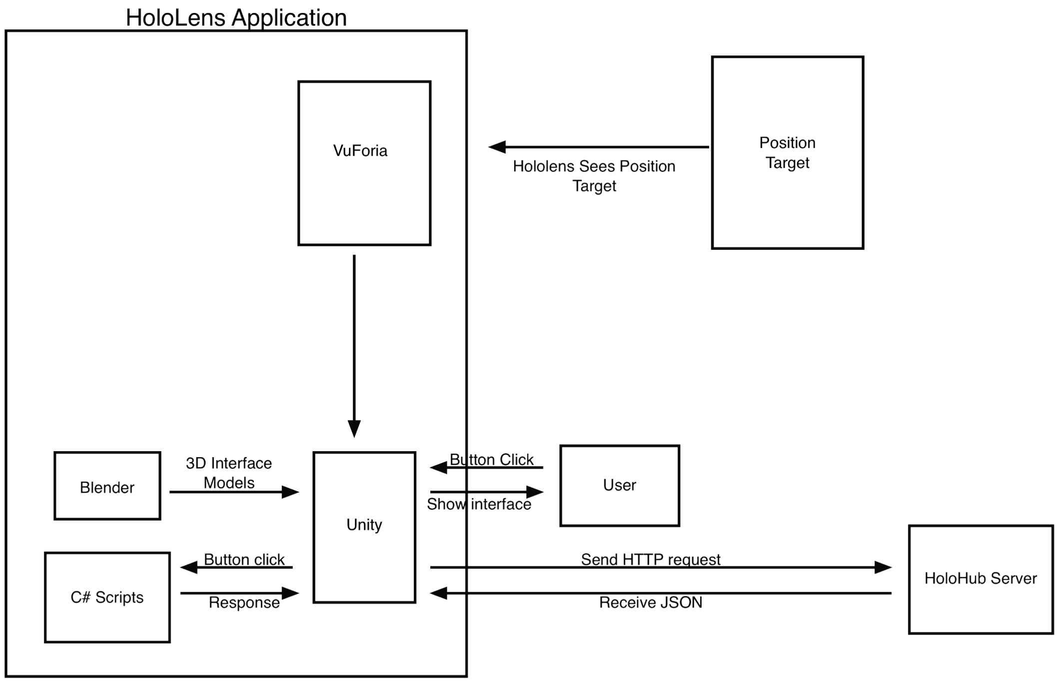


Figure 4. HoloLens Application

The HoloLens application serves as the viewport of our entire application, running on the Unity3D engine, which is compatible with the HoloLens. Ventana's Unity component is responsible for receiving a cue from the positional target, in order to display a Hologram inside the user's field of view via the positional tracking implementation. Currently, this is done using a Vuforia image marker that informs the HoloLens that the target is at a current coordinate. When the positional tracker signals the HoloLens to display a control for an IoT device, Ventana searches its 3D model database for the right control to show to the user. This identification is currently done by binding a specific image target to a specific 3D control, so that the application can display a context aware user interface to the viewer. The 3D meshes that are being used are all made in a free application called Blender, which allows the team to create more robust 3D models than could have been created with Unity. Blender conveniently also allows the team to choose to seamlessly texture Ventana controllers, in either Blender or Unity.

Moving on the the actual methodology behind the software that drives the Holographic User Interface of Ventana is the tried and true approach of Model-View-Controller. In this case, the Controller is the Unity game object that serves as the base parent of a controller object. Within this Unity game object, a subclass of a custom class called ‘VentanaInteractible’ is in charge of sending messages to child Unity game objects within its respective 3D model, while also receiving call backs from HTTP requests to HoloHub server. This architecture was chosen to take advantage of Polymorphism, so that when more IoT controllers begin getting introduced into the application they will not require a major refactor of the Unity project.

The Model is the JSON representation of our IoT device that Ventana receives from the Raspberry Pi, which allows Ventana to update the information of its controllers in real time through the music controller’s base parent script mentioned above.

Finally, the View is done by Unity displaying the 3D objects with the right context-aware controls that enable users to have multiple sessions of the Application running at once and interact with the same IoT device, without any latency or race conditions.

Below are two snippets of how this is currently achieved in Ventana.

RequestScript.cs

```
public IEnumerator callToAPI(string request, string parameters = null)
   {
      string newUrl = url;
      if (parameters != null)
      {
         newUrl += "?" + parameters;
      }

      newUrl += request;
      UnityWebRequest www = UnityWebRequest.Get(newUrl);
      yield return www.Send();

      // check for errors
      if (!www.isError)
      {
            //Debug.Log("WWW Ok!: " + responseString);

            if (newUrl == url + "status" ) {
               VentanaInteractable myVentana =
SonosInfo.CreateFromJSON(www.downloadHandler.text);
          //Sends message to child objects of this game controller.
               gameObject.BroadcastMessage("OnURLSent", myVentana);
            }
      }
```

```
        else
        {
            Debug.Log("WWW Error: " + www.error);
        }
    }
```

MusicController.cs

```
public void OnURLSent(VentanaInteractable ventana) {
        SonosInfo info = ventana as SonosInfo; //checks to see if this call pertains to this
controller.
        if (info != null ) {
            isMusicPlaying = !info.isPaused;
            songName = info.title;
            artistName = info.artist;
        }
}
```

4.0 First Semester Progress

At the beginning of the semester, the team came together and began to define the project. The team met with George for project brainstorm sessions. Afterwards, the team completed a customer screening, in order to gauge if and how they used IoT in their homes. Screening took place around MIT's campus, outside of the Apple Store on Boylston, and in the Prudential Tower, as well as asking personally known customers. The screened customers represented a variety of ages, but the results showed young families as some of the most prominent home users of IoT. They valued the technology for purposes like entertainment and security. The team themselves also tested common IoT devices in the home to further understand what interacting with IoT devices feels like. The team used store demos at City Target, Verizon, and Apple, for technology such as Philips hue lights, Canary security system, Nest thermostat and camera, Homekit, and Belkin WeMo. Upon completing the project definition and requirements, the team moved forward with the problem statement that technology in the home is hard to use.

Based on the results of the customer screening, the team selected a Sonos speaker as the first device to be supported by Ventana. During Shark Tank, the team had a chance to pitch the project to multiple BU alums, and receive feedback about the concept. In October, the team starting working in Unity and developing a Universal Windows Platform application for the HoloLens, after attending HackHarvard 2016.

For first deliverable testing in mid-November, the team examined Ventana's overall functionality for its first device, including the local server, positional tracking, and controlling an external device. The test demonstrated that a HoloLens user has the ability to interact with another internet-connected device, a Sonos speaker. This proved that the HoloLens can, in fact, control other internet-connected devices in the home, thereby facilitating a simplified experience between humans and smart devices. The first step in testing involved powering on the HoloLens and Sonos speaker, then verifying the connectivity of both devices to the local server. Then, the test ensured the compilation and deployment of Ventana to the HoloLens, when the user opened the program. Finally, the HoloLens user gazed at the Sonos speaker, saw the holographic display of album artwork, and controlled the device by pressing buttons on the hologram.

Successfully completing first deliverable testing allows for expansion of the Ventana platform to other IoT devices, such as lights supported by a Wink hub, to begin. Since first deliverable testing, the team completed an array of different assignments, including a team contract, a video overview of Ventana, a PDR powerpoint presentation, and individual semester reports. As the semester draws to a close, the team will finalize their plan for next semester, in order to continue working on Ventana.

5.0 Technical Plan

Moving forward, the team plans to integrate at least two more devices, one of which will be a smart light. The other device has not been determined, so the research and decision making process for choosing that device has been factored into the team's plan. The structure of the team's timeline is largely affected by the Agile development methodology. The team is developing Ventana in scheduled sprints, which allows the product to be tested in an iterative and consistent way.

Task 1: Interface Development

Development of the interfaces that correspond to different devices and the Ventana HoloLens application will be completed by the middle of March, at which point there will be a finalized, deployable version of the Universal Windows Platform application. There will be diverse interfaces for different internet of things devices that are interactive and intuitive. This task requires the team to make design decisions, collect feedback about user experience, and iterate on the design of the interfaces until they are clean, simple and useful. Due to the novelty of these user interfaces, this task will encompass trying different design choices for the interfaces until one is found that works well within the mixed reality world of HoloLens.

Lead: Johan Ospina; Assisting: Tess Gauthier

Task 2: Positional Tracker Design

A positional tracker will be designed and finalized by the middle of January. It will allow the Ventana HoloLens application to differentiate between types of devices and locate them within a user's space. The final design of the positional tracker has to be small, as to not affect the aesthetic of a user's home. Interacting with the positional tracker must work successfully on the HoloLens so this task will require extensive functional testing in order to ensure the users will be able to interact easily with their devices. The choice of positional tracker will encompass doing research in areas of embedded systems, computer vision, and human computer interaction in order to ascertain what is the most effective way to perform the novel task of real time positional tracking with Microsoft HoloLens.
Lead: Tess Gauthier; Assisting: EJ Fitzpatrick

Task 3: Infrastructure Deployment

The Ventana server infrastructure deployment be completed by the middle of February. This will involve picking and configuring the correct instances of cloud services, determining to what extent the server architecture is going to be deployed on a cloud platform and making changes to the API integration as needed to work in the designed infrastructure.
Lead: Santiago Beltran; Assisting: Allison Durkan

Task 4: Integration of Wink Hub

This task is the integration of wink hub into Ventana which includes the design of an interface, building the Wink API into the Ventana server and testing the functionality of different Wink devices with the server controls. This will require testing of the methods in the API to determine the extent of the control it can give to the Ventana server. It will also require adding server methods for the different functionalities of the Wink devices.
Lead: Santiago Beltran; Assisting: Allison Durkan

Task 5: Lighting Control

Control of a lighting apparatus, like a GE Link Light Bulb, will be completed by the end of February. This particular bulb is supported by Wink, so from here it would be easy to then implement other devices supported by Wink. This task involves research of the Wink API and integrating the correct functionality into the Ventana server so the HoloLens control application is able to send commands to control the bulb.
Lead: Allison Durkan; Assisting: EJ Fitzpatrick

Task 6: Determine a Third IoT Device

For a final deliverable, Ventana will be able to support at least three IoT devices: a Sonos speaker, a GE Link Light Bulb and a third device. This task involves researching and deciding what the third device Ventana will support is going to be. This will be done by early February in order to implement and add that device before functional testing. An ideal third IoT device would be one that has a supported API from the manufacturer, one that consumers are interested in and a device that has a user experience that would be improved by incorporating it into the Ventana experience.

Lead: EJ Fitzpatrick; Assisting: Johan Ospina

Task 7: Integration of Third Device

Ventana will be able to support the third IoT device by the middle of March, giving the team ample time to do final integration testing and deployment with our customer. This task requires the design of an interface that would make sense for the device, gathering feedback on iterations of the design, integrating support for the device into the Ventana server and testing the extent of the functionality Ventana would be able to provide.

Lead: EJ Fitzpatrick; Assisting: Santiago Beltran

Throughout the coming semester, the Ventana team will work in sprints to iterate, improve and create a product that exceeds the expectations of our customer and solves his problem. By following the Agile methodology, the team will be able to fully test every component as they are built and integrated into the project, creating a fluid, end-to-end, bug-free product with a user experience that is intuitive, exciting and simple.

6.0 Budget Estimate

Item	Description	Cost
1	Microsoft HoloLens	$3000
2	Sonos Play 1: Compact Smart Speaker	$169
3	Wink Hub	$50
4	GE Link Light Bulb	$20
5	Third Device	TBD
	Total Cost	$3239

The HoloLens represents a major component of the budget, and will be provided by the customer, as needed. Since a HoloLens emulator that runs on Windows 10 exists, it is possible to test some features of Ventana without the HoloLens. The HoloLens will be provided for other crucial testing, as well as presentations.

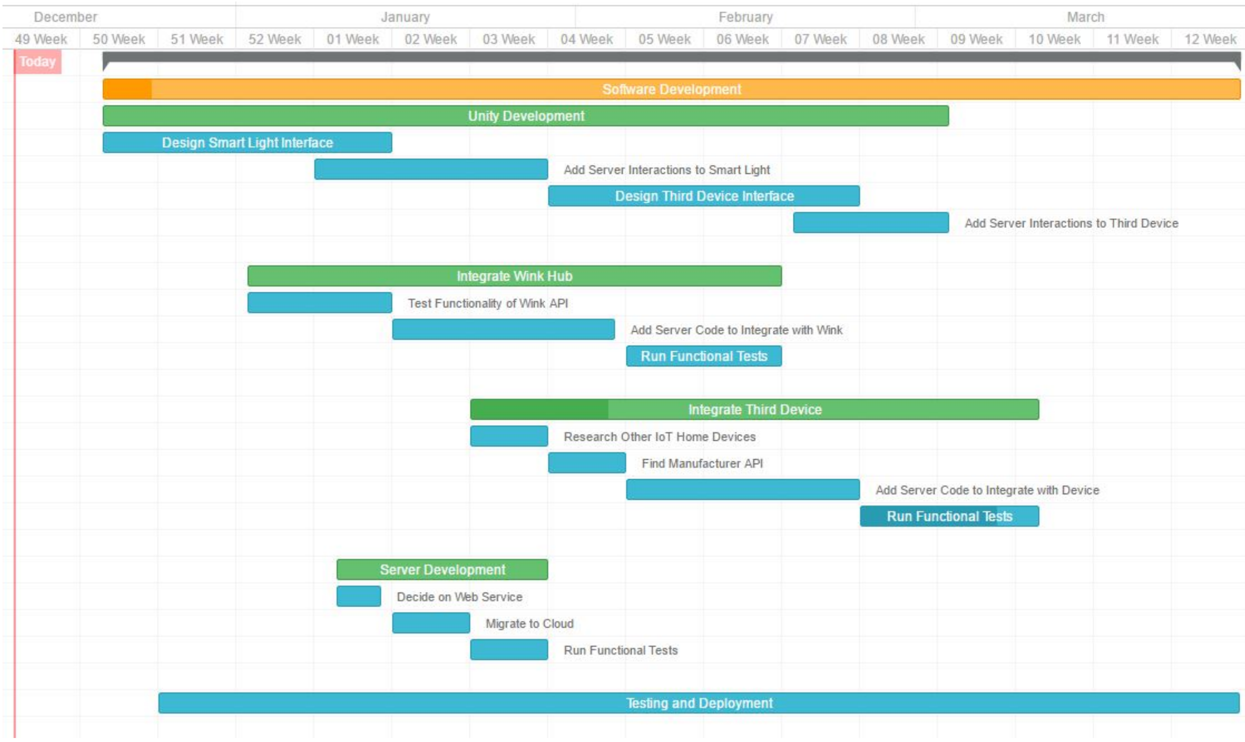
The Sonos Play 1 speaker is the first IoT device supported by Ventana, therefore, it is necessary to have one for testing purposes. Since a light bulb will be the next device supported by Ventana, it is necessary to obtain a light bulb and a Wink Hub. Since the Wink Hub supports not only light bulbs, but many other smart home devices, it makes sense economically to start with these devices, and then expand. The third device, if time permits, has yet to be determined, but would most likely be in the range of a $50-100 range. Most of the budget simply represents the total cost of buying the devices that Ventana intends to support, in order to successfully develop and test the platform.

7.0 Attachments

7.1 Appendix 1 – Eng. Requirements

Requirement	Value, range, tolerance, units
Recognize IoT devices in a room	Constellation ID Tracker via static image, global marker, or hardware identification emitter.
Establish connections with the IoT devices	API-based controller with support for local networks and cloud based networks. Must connect online from inside the home NAT network.
Communicate with IoT devices	Network protocols to send data to a specified device. This involves communication to a hub device that can handle cross-network type conversation from PAN devices to LAN and LAN to WAN communication across an internet channel. The application must be flexible enough to communicate on a LAN-only network or via LAN-to-WAN system. The hub must be able to communicate to LAN-to-PAN and LAN-to-LAN devices. There shall be no direct communication between the HoloLens and individual IoT devices.
Recognize the spatial location of an IoT device	HoloLens Spatial Mapping. Must be able to store HoloLens mapping data and correctly reassociate it to the correct room so to allow for global markers.
Display information through AR about the IoT device	Using Unity and UWP. The interface must be uniform across devices, and modular such to allow adding support for new devices without need to pre-build fully custom image assets.
Synchronize AR display with IoT device position	Combining the spatial location and display. This system must coordinate in real-time and error check to ensure that the data received from the positional tracker and the displayed holographic interface is correctly positioned and tracked in relation to the physical device.

7.2 Appendix 2 – Gantt Chart



Tasks:
Unity Development (Dec. 11, 2016 - March 15, 2017) ➢ Design Smart Light Interface ➢ Add Server Interactions to Smart Light ➢ Design Third Device Interface ➢ Add Server Interactions to Third Device
Integrate Wink Hub (Jan. 1, 2017 - Feb. 15, 2017) ➢ Test Functionality of Wink API ➢ Add Server Code to Integrate with Wink ➢ Run Functional Tests
Integrate Third Device (Jan. 26, 2017 - March 15, 2017) ➢ Research Other IoT Home Devices ➢ Find Manufacturer API ➢ Add Server Code to Integrate with Device ➢ Run Functional Tests
Server Development (Dec. 11, 2016 - Jan. 26, 2017) ➢ Decide on Web Service ➢ Migrate to Cloud ➢ Run Functional Tests
Testing and Deployment (Ongoing)

7.3 Appendix 3 – Technical References

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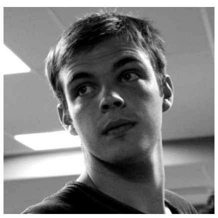
7.4 Appendix 4 – Team Information

★ Santiago Beltran: sbeltran@bu.edu, 919-889-2940
Following my passion for technology and innovation, I have worked to take advantage of every opportunity, and maximize the impact of turning ideas into actions in both nonprofit and for-profit ventures. Currently, pursuing a Bachelors of Science in Computer Engineering at Boston University.

★ Allison Durkan: azulad7@bu.edu, 978-602-4156
"Be fearless in the pursuit of what sets your soul on fire." I am a senior studying Computer Engineering at Boston University. My interests include software engineering, hardware engineering and water polo. If I can spend the rest of my life playing with computers and making the impossible an everyday possibility, I will consider it a success.



★ EJ Fitzpatrick: ejfitz@bu.edu, 781-439-3978
I am a senior studying Computer Engineering at Boston University. I am interested in new technology and the business models that arise from innovation. I am passionate about up-and-coming products, and always keep updated on the newest technologies. As a a car enthusiast, and I enjoy spending a lot of my free time looking and driving different cars.

★ Tess Gauthier: tgauth@bu.edu, 413-885-0634
Student at Boston University working towards a degree in Electrical Engineering, with a minor in Computer Engineering. Involved on campus as a member of the Technology Innovation Scholars Program in the College of Engineering, and the Conference Chair of the Society of Women Engineers.

★ Johan Ospina: johanos@bu.edu, 919-339-8132
I am Senior Computer Engineering Student at Boston University seeking admission into a graduate program or full time position that will further my career interests in Human Computer Interaction and Internet of things research. My end goal is to receive a PhD and work to develop new technologies to help redefine how people interact with their environment.