Mirror with Smart-Touch Display

ECE 4011 Senior Design Project_Final Report

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Executive Summary

As technology has evolved over the years, smart mirrors have become more popular. Smart mirrors take a traditional mirror and enhance it by using Bluetooth or WiFi to add smart capabilities. Many of the existing models include basic applications with limited functionality. The goal of Smart Look is to improve upon the existing technology and create a mirror with its own specialization.

Smart Look is a smart mirror that has 4-in-1 functionality. The first functionality is that of a normal mirror. The second functionality is the smart mirror, allowing access to information such as the weather and note taking. The third functionality is a home entertainment system, allowing videos to be cast to the mirror. Lastly, the mirror can display an image, enabling it to act as decoration. Smart Look will allow the customization of the mirror interface so that the user can personalize the product.

Some of the technical challenges include the tradeoffs between the complexity of features and size and power. A technical opportunity is that there are so many software applications that exist so there are a variety of designs and features to choose from.

In order to build the smart mirror, a full-sized mirror and display will be used along with an IR frame. The design will be compact, allowing the smart mirror to be better suited for decoration purposes. The cost of the product will vary by size, but it is expected to cost around $2,000.00.

The key performance specifications include voice control, touch commands, user layout customization, and Bluetooth or WiFi connectivity. Additionally, applications need to be integrated with the hardware. Once the hardware and software aspects are integrated, the display, voice, and touch commands will be tested as a full product. Outside of the scope of this project, some future work includes extending the target consumers from individuals to organizations. The specific applications that are implemented can also be expanded based on user feedback.

Mirror with Smart-Touch Display

1. Introduction

Smart mirrors have become more popular in recent years and can support a large range of functionality. Our team, Smart Look, is requested $1000 in funding to develop a smart mirror that extends the functionality of the traditional mirror to include additional features such as applications like the weather, news, and personal calendars along with voice and touch control capabilities. There would also be options to stream media, display a still image on the mirror, and take notes.

1.1 Objective

The smart mirror is intended to have 4-in-1functionality, depicted below in **Figure 1**.

1. The first function would be the regular mirror aspect.
2. The second function would be the smart display of information on various applications such as a to-do list, calendar appointments, the weather, and the date and time, and other touch and voice-interactive features.
3. The third function would be a home entertainment system in which apps like Hulu, Netflix, or YouTube can be streamed on the display.
4. Lastly, the mirror would be able to display a still image so it can act as a home décor piece when not in use.

All the features of the smart mirror will be controlled by touch with an IR frame or with voice control through Alexa configured into a Raspberry Pi unit. The backend to allow the smart features will be a Raspberry Pi with WiFi or Bluetooth enabled. Additionally, the user interface for the mirror will be customizable so that the user can personalize the layout of the various applications on the display.

The smart mirror designed for this project will be a full-sized mirror and display, which will allow the entire screen to display information. Additionally, there will be an IR frame overlay on the mirror so that the entire surface will be touch sensitive. As for the software aspect, the user interface will be customizable by the user and will display all the functionalities of the smart mirror.

1.2 Motivation

The idea behind smart mirrors is to make that time spent in front of a mirror productive with useful information displayed and smart mirrors are a popular do-it-yourself (DIY) project. Smart Look focuses more on an innovation aspect of this technology in hopes to take it one step further, to make it interactive. The main motivation for creating the smart mirror is that smart technology has been developed and plays a large role today. There are many smart devices ranging from smart locks to smart watches that can be connected to the internet and increase their traditional functionality [1]. Similarly, a smart mirror has potential for many advancements in functionality. Thus, a commercially available 4-in-1 mirror would be a useful device to develop because it offers many different features than existing smart mirrors.

1.3 Background

A person's appearance has an impact in social situations and because of this people are concerned with how they look [2]. Many people start off their day looking in the mirror and will continue looking at themselves throughout the day. As technology has evolved over the years, mirrors are now able to provide users with easy access to information and have added features which provide a variety of functionality and multitasking abilities. Additionally, because the 4-in-1 mirror has so many use cases, this can reduce the amount of items people need to buy. Studies have shown that millennials who have grown up with technology, are trending towards a minimalist lifestyle [3]. Therefore, the idea of a mirror having the functionality of streaming, displaying an image, and taking notes would reduce the need for a TV, white board, or other decorative pictures.

1.4 Overview

The remainder of the document will further describe the project specifications, customer requirements, goals and technical specifications. Next, the proposal will go into more details about the design approach and project demonstration. Lastly, more administrative information will be given at the end. This includes the timeline and milestones for the project, a cost analysis, the current status of the project, and leadership roles that are distributed.

2. Project Description, Customer Requirements, and Goals

The goal of Smart Look is to design a smart mirror with 4-in-1 functionality. The mirror will consist of a frame, integration components, and software applications with a user interface. The frame will include a mirror and a full screen display with touch capabilities. This frame will be integrated with the software to enable the mirror to connect with the "smart" features and display the information that it receives from the applications. Lastly, the software applications will allow the mirror to be used to display information, watch shows, take notes, and project a still image. The goals of the project are shown below:

- Full screen smart display
- Connect Raspberry Pi using WiFi or Bluetooth
- Voice control using Alexa
- Touch control enabled
- Display software applications (weather, calendar, notes, etc.)
- User customization of interface

2.1 Stakeholders

The stakeholders for the project include the material suppliers, existing smart mirror businesses and their customers, and smart mirror DIY builders. The components that are bought online will consist of the seller or manufacturer and the existing smart mirror companies will be affected by the introduction of a new product. Lastly the customers will have invested money into the mirror, so they are also stakeholders. Smart Look's direct current target audience include home and apartment owners. However, Smart Look aims to eventually market the product to companies and organizations, such as schools and universities, as a sleek multi-use display to be installed in office rooms, classrooms, and student dormitories. For now, such companies and organizations are an indirect target audience, and thus also stakeholders.

2.2 Customer Needs and Functions

The final prototype will be a smart mirror that can be used to access information, take notes, stream videos, and display pictures. The important customer requirements include the user interface, touch screen, voice control, software applications, WiFi and Bluetooth connectivity, aesthetics, ease of assembly, and costs. The information below further explains these requirements, which are also part of the QFD chart.

The user interface refers to the degree to which the user can customize their own layout and organize the content however they want. The mirror should additionally have touch capabilities. The precision and accuracy of this can vary and will be determined by the applications implemented and how sensitive this needs to be. Next, voice control through Alexa will be another way in which the mirror can be controlled. The number of applications may also be varied. With more applications, the user can do more with the smart mirror. The last technical aspect is the WiFi or Bluetooth capabilities which allow the mirror to provide news, weather, or other information from a user's phone. The aesthetics, ease of assembly, and costs are also important to the customer and need to be considered throughout the prototype's design.

The target price for the smart mirror will be $2,000.00. The targeted user will be individual people that will use the mirror in a home. It will be most suited for a bedroom or common area. The types of applications implemented will be personalized by the user but not include sensitive information. Because the mirrors are intended to be used in personal and secure spaces and connect with applications that do not contain a lot of personal data, there is not a need to implement many additional privacy or security measures. Since our end user focus was individuals who are engaging in DIY projects, we made it a primary objective to use open-source softwares and cost-effective hardware tools so that our users are not restricted by any licensing and registration access and expenses. In the future, as the functionality and uses expand to larger and more public settings, this may be a bigger concern and something worth implementing.

2.3 QFD

Customer Requirements	Engineering Requirements: Component Price	Size of Mirror	Storage Capacity	Power	Thermal Maintainance	Functionality
Customer Requirements	-	+	+	-	+	+
User Interface		+				+
Touch Screen	+			-	+	+
Voice Control				-	+	+
Software Applications			-	-	+	+
WiFi / Bluetooth Connectivity	+			+	-	+
Asethetic	+					-
Ease of Assembly		-				-
Cost	+	+	+	+	+	+

2.4 Constraints

Referencing the QDF diagram above, the constraints for the project include the component price, size of the mirror, storage capacity, power, thermal maintenance, and the complexity of added functionality. The component price of the mirror is affected by the quality and size of the mirror's components and, in turn, will affect the customer cost. The size of the mirror is also important because a larger mirror can enable more functionality and visibility, however it will be more expensive and will take more energy to power. As far as the storage capacity, most Raspberry Pi units are only equipped with 1 GB of RAM, which would be enough to handle simple smart mirror operations. However, the project aims to incorporate touch-frames, touch enabled features, casting video playback, and other features, which all require more memory capacity to be able to sufficiently operate multiple features simultaneously. Purchasing a more expensive Raspberry Pi with more storage could enable more advanced functionality and a greater number of features. The additional capabilities, especially touch features, also affect the product's power usage. The Raspberry Pi needs to be able to maintain and distribute enough power while dispersing heat efficiently and effectively so that a thermal overload does not cause hardware malfunction. The precision and accuracy of the touch screen will be determined by the hardware and functionality chosen to incorporate into the mirror. Greater precision and accuracy can be achieved by using a more advanced touch screen overlay, as different types of touch screen overlays use different methods of collecting and processing touch data. Lastly, the added functionality will be limited by the complexity of the code required for implementation, which affects how much time it takes to be completed. The amount of time needed for development will limit the number of added functions that are able to be implemented.

3. Technical Specifications

The core components behind Smart look include the following: a dielectric mirror, a display unit, Raspberry Pi unit, WiFi/Bluetooth adapters if not already integrated with the Raspberry Pi unit, and an IR Touch panel.

Table 1. WiFi and Bluetooth external USB adapters (required if not integrated with raspberry pi unit) [4]

Features	Specification
Wireless Network	· Dual band 802.11b/g/n/ac WiFi (2.4 and 5.0 GHz) o Minimum 35-meter range
Bluetooth	· Minimum Bluetooth 4.0 version o Minimum 30-feet range o Minimum 20 Mbps bandwidth

Table 2. Dielectric mirror [5] * A one-way mirror film was used to substitute but specs remain the same

Features	Specification
Reflectivity Ratio (Reflective:Transparent)	Ratio(reflective < transparent) · 20:80 · 30:70 (preferred) · 35:65 · 40:60 · 45:55

NOTE: Reflectivity should be less than transparency to ensure maximum brightness and quality of display visuals. However, extreme ratios or a 1:1 ratio will negatively affect visual presentation. Size will depend on the size of the IR touch panel. Cost increases with size.

Table 3. Raspberry Pi Specification (minimum requirements and quantity)

Features	Specification
Processor	Cortex-A53 64-bit Quad-core ARM v8 – OS.Mbed enabled
Processor speed	1.5 GHz
Memory	4 GB LPDDR4-3200 SDRAM
Peripheral types	· USB 3.0 or 3.1 preferred (over USB 2.0) (2) · USB-Type C (power supply) (1) · HDMI (1) or micro HDMI (1) · Class 8 SD Card support (1) o Minimum bandwidth 50Mbps r/w o DDR50 UHS transfer · Aux OUT port (optional)
I/O peripherals Voltage level	3-4 V
Power Supply	5V USB-Type C
Network (wifi/Bluetooth optional)	· 10/100 MBPS Ethernet · Dual band 802.11b/g/n/ac WiFi (2.4 and 5.0 GHz) · Bluetooth 5.0

Table 6. Mini Microphone [7]

Features	Specification
I/O	USB 2.0 (data and power)
Power	20-50mW depending on unit “plug-in power”

NOTE: Negligible power, very little power required to operate. The Raspberry Pi is capable of supplying more than enough power.

Table 4. IR Touch Panel [6]

Features	Specification
Ratio	16:9
Touch Point	Minimum 2 point touch
Interface	USB, no driver (plug ‘n play)
Size possible	32/35/40/42/46/50/55/60/65/70/75/80/84/85
Power supply (plug-in power)	Operating voltage: DC 5V Power: < 2W < 250mW on standby
Operating system	Windows XP/7/8/8.1/10, Linux,
Data	USB

NOTE: Diagonal dimensions of IR touch panels will determine equal size of display unit and mirror. Lowest dimensions found start at 32” panels. Cost increase with size.

Table 5. Display unit (monitor)

Features	Specification
Size	32” or greater
I/O	HDMI
Panel	LCD LED (preferred)
Power	Operating voltage: Varies with unit Power: varies with unit

NOTE: Size of monitor will be determined by IR touch panel dimensions. Cost increases with size, panel type, manufacturer, etc.

4. Design Approach and Details

This section outlines the details of the design approach for Project Smart Look, as far as they are known at this time.

4.1 Design Concept Ideation, Constraints, Alternatives, and Tradeoffs

4.1.1 Concept Creation

Building a smart mirror is a popular Do-It-Yourself (DIY) project and there are many existing builds that have many common features [2]. The first elements considered are features and generic layouts that are currently available with existing builds, which include but are not limited to:

- Time and date and weather
- News updates
- Email
- Use of virtual voice AI assistant, such as Alexa

Current smart mirrors allow the functionality mentioned above, but Smart Look aims to be an innovative enhancement to improving smart mirror technology. This involves creating a way to multi-purpose a mirror, make it more interactive by combining touch-interactive technology, and allowing users to customize their own unique layout and features. The next step is to limit the target audience scope and determine additional feasible features to incorporate that the target audience will find both interesting and useful and that can be implemented given the time frame. After several brainstorming sessions, it was decided that Smart Look would mimic a home décor piece in a living room or bedroom. Additional feasible features included:

- Multi-mode: regular mirror, smart mirror, TV for entertainment, wall-hung mural
- Touch-enabled features, i.e writing notes, widget and application interactions, task organization
- Home automation using touch or voice assistance

4.1.2 Design fabrication

Refer to the materials used for the fabrication of Smart Look under “Technical Specifications” (Section 3). *Figure 1* below represents Smart Look’s layout of the final product. This design incorporates touch screen capabilities using IR touch overlays, commonly referred to as IR frames. IR touch overlays are a patented device that has many light-emitting diodes and photoelectric sensors on opposite sides chained together embedded on a frame [6]. The diodes emit a grid of infrared beams in a XY-direction. Any interruptions, via any object, like a finger, between the beams of light and the sensors will be interpreted as touch on that interrupted location. IR frames also support multi-touch capabilities and have a fast response time of 1ms. It does not require a driver installation, just a simple USB plug-n-play.

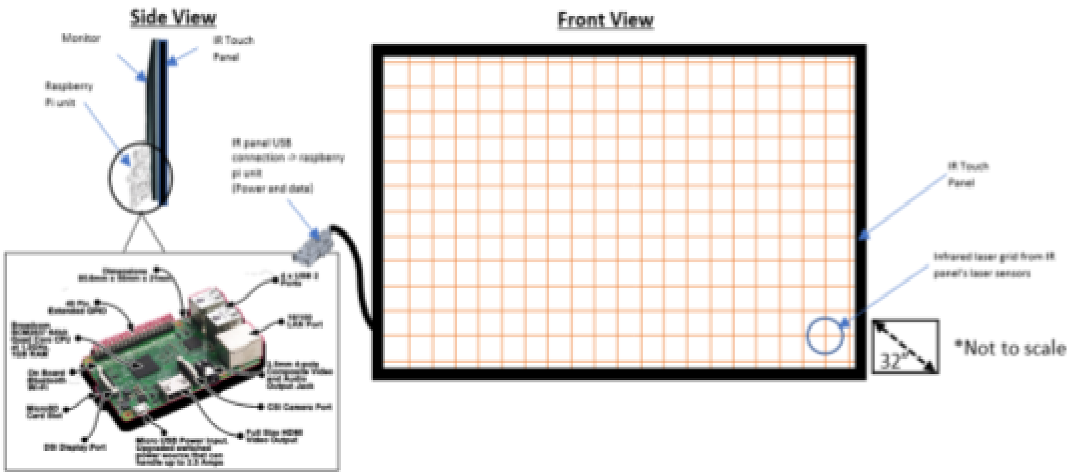

Figure 1: Smart Look build layout. *Note that a finished border frame is not shown in the layout above. Also note that the 32" diagonal dimensions indicated is not finalized but an example*

4.1.3 Constraints and Alternatives

The primary limitation comes from the SBC used for the project. When considering which board to use, we noticed that the Raspberry Pi 4 was the best choice. Other alternatives lack the memory capacity that the Raspberry Pi has, uses an older CPU than the latest generation of Raspberry Pi units, and lacks the flexibility of operating systems. Additionally some of the alternatives are much more expensive than the latest generation Raspberry Pi model. [100] An alternative we considered was the Orange Pi 3, which has a comparable cost to the Raspberry Pi 4. While it is affordable and includes 2GB memory with an option 8GB flash, it runs on a limited number of operating systems (Linux), which reduces our flexibility in implementing the software design. [101] After assessing our alternatives, we decided to use the Raspberry Pi 4. However, even the Raspberry Pi 4 provides some constraints and limitations to the project. Smart Look aims to include additional features like touch and voice interaction, so with an increase in capability requirements, it is mandatory that a unit with more capable in-built specs be considered, such as faster CPU, latest GPU, 4GB RAM memory, upgraded latest generation ports for stable and fast connectivity, and equipped with a power supply capable of supporting the IR panel. However, there are not many Raspberry Pi models that would be capable of handling the workload. The ones that are capable are expensive, approximately $100-$120 before tax, which would further restrict the size of the finished product.

With the current design route, it is necessary that the IR panel, display unit, and the mirror, or in our case a one-way mirror film, itself all have the same diagonal dimension. The size of the mirror, display unit, and IR panel will be limited by both cost and power. It is possible to build a small-scale prototype, like a 27” or below 16:9 dimension. As far as power is concerned, a smaller display and IR panel would require less than 500mW of power support each, which would reduce strain placed on the Raspberry Pi and the risk of overheating [8]. Considering the tradeoffs for this project, we would ideally build a mirror display that is 40-50 inches. However, for financial reasons, our prototype was finalized with a 32” display, IR frame, and a mirror film traced out to match the screen size.

Moving on to software constraints, cost is not as much of an issue as feasibility of time and compatibility of the operating system with the Raspberry Pi unit. It is not possible to configure a Raspberry Pi unit with multiple operating systems. Therefore, the operating system that will be installed on the Raspberry Pi will be determined by the chosen desktop application tool. The primary desktop customization tool currently under consideration is Rainmeter, which is compatible with Windows architectures [9]. However, current Raspberry Pi models are not capable of supporting the Windows OS that comes standard on most personal computers. However, some Raspberry Pi models do come pre-installed with NOOBS, or New Out Of Box Software [10]. NOOBS is an operating system installer primarily for single board computers, or SBCs, such as Raspberry Pi, and has several operating systems a user can choose to install the unit with. One of the offered OS's is Windows 10 IoT Core, which is the smallest version of Windows 10 common core architecture that enables building low-cost devices with fewer resources, such as Raspberry Pi and other SBCs, commonly used for development purposes [10][11].

4.2 Preliminary Concept Selection and Justification

4.2.1 Design Concepts

The chosen design is a full-size display unit matching the dimensions of the mirror, visualized in *Figure 1*. Having an extended display size for smart features allows for more space for adding features, widgets, and more personalization options for the user. This design option revolves around a 4-in-1 concept, where Smart Look can be used as a plain mirror, a smart mirror, a cast-enabled TV, or a home decor wall-piece. However, a larger display size will result in more power usage. Using power values taken from electronic components found in the technical specifications and if a large 50" display unit that has a typical power consumption of 105 watts, the final prototype is estimated to use a total of 125.5 watts [15]. All the features and customizability will require more power and memory storage to maintain all the systems being controlled by the Raspberry Pi unit, which might be an overload and could risk causing thermal damage or runoff. At the time of design research, it was unknown whether or if 4GB memory size of the new Raspberry Pi units will be sufficient or not without having a prototype ready for integration testing, but it is possible that 4GB will not be enough. However, with further analysis, the hardware lead predicted that 4GB will be enough to support the desired features for our product (see Section 4.2.4).

4.2.2 Component Justification and Project Map

Smart Look depends on the success of the integration of both hardware and software. The critical path of the timeline, as depicted in red in *Figure 2* begins with the fundamental design, like *Figure 1* above. The hardware and software components can be worked on simultaneously and independently. The software aspect, including user-interface design and feature modules, will undergo testing as needed using a laptop, while the hardware team will order materials and will conduct thermal, power transference, and performance testing on the Raspberry Pi unit once they are delivered. Before the assembly stage, hardware and software components will be integrated. Continuous testing and error checks will be done in preparation of assembly and presentation of the final product. *Figure 2* maps the steps and critical path necessary from the start to finish. For more details on the critical steps see Section 4.3.

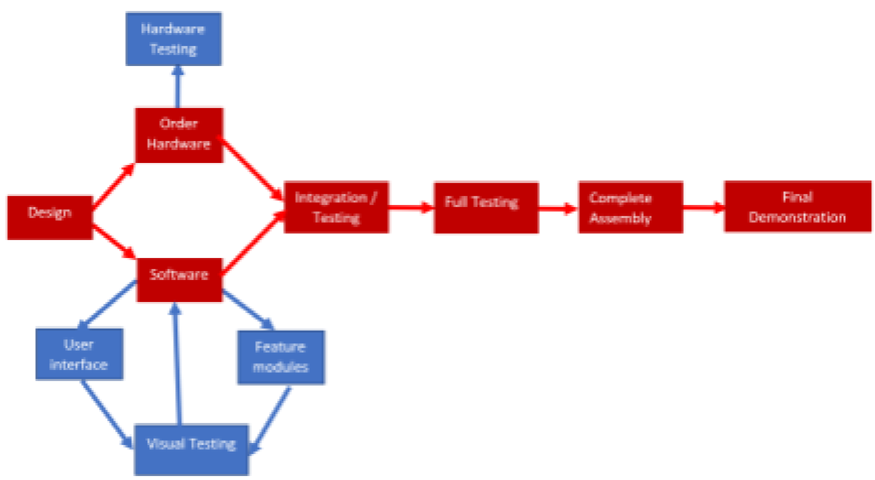

Figure 2: Smart Look project map where critical path is indicated in red

There was not an opportunity to have a hands-on demo session with different Raspberry Pi devices or any of the other hardware required to initiate this project. Regarding hardware, the Smart Look team has only been able to research the list of available Raspberry Pi models, TV and monitor models, mirror types and their manufacturers, and variations of touch panel and manufacturers. After comparing the top 7 Raspberry Pi models (the comparison chart can be located in the Appendix C), it was decided that the Canakit Raspberry Pi 4 Model B was the best choice [18][19][20][21][22][23]. This model has an updated 64-bit quad-core processor chip that is 50% faster than the second and third-generation models used in the other smart mirror builds [23]. The model is equipped with 8GB LPDDR4 SDRAM so it will be able handle the more tasks faster and simultaneously. The LPDDR4 has a two-way 16-bit channel which reduces stray capacitance and has a shorter data path. It has a higher I/O data rate and its memory architecture uses lower voltage, thereby saving more power and increasing thermal profile and battery life [23][24]. Chances of thermal runoff from the unit are low. The unit has high-performance and high-power thermal delivery that comes equipped with a dedicated fan and three copper heat sinks to dissipate heat quickly. This model also comes equipped with 5.1V 3A USB Type-C power adapter, rather than a standard than a USB 2.0 or micro-USB power supply [23]. A USB Type-C is the superior choice for several reasons: higher data transfer speeds, higher power handling and distribution, and is overclock-compatible [25]. This particular model also supports Power over Ethernet, otherwise known as PoE This unit is equipped with built-in Bluetooth 5.0 and dual-band 802.11b/g/n/ac Wi-Fi, which doubles the speed, quadruples the range, has less interference, and has better connectivity than previous generation raspberry pi units [23].

For the purpose of full-screen video-casting, having a mirror with low-reflective and high-transparent ratios is imperative for maximum display brightness. Dielectric mirrors have several layers of transparent optical materials designed to minimize reflectivity [5]. In this project, it is ideal to reduce any reflections or glare on the mirror and maximize displayed content brightness when viewing content from any angle. Exact pricing is unknown, where a team member will need to contact manufactures, like Guardian Industries, for quotes [26].

However, to prevent delivery delays during the COVID pandemic and limit financial expenditure, we decided to use a one-way mirror film instead as a substitute. Though its reflectivity is subpar to an actual dielectric mirror, it does a satisfactory job to give a mirror-like experience.

4.2.3 Choice of Desktop Customization Tool - Rainmeter

The user interface of our prototype will be developed with Rainmeter, which is an easy-to-use open-source customization tool which users can use to display customizable skins on their device, from hardware usage meters to fully functional audio visualizers or productive applications to entertainment. It also is able to display time and weather graphics on screen, however all of its displayed tools provides flexibility for users to personalize their layout from thousands of pre-existing templates or create their own [9]. Rainmeter operates on a Windows OS on both 32-bit and 64-bit architecture, has a very minimal 1.66KB to 2.5KB of memory usage, and uses a maximum of 4% of CPU usage [27]. Rainmeter is a safe application that is proven to be free of harmful viruses from the test results with 50 antivirus software [28]. Lastly, Rainmeter allows functional support of external software through its application. **Figure 3** below shows a visual example of two different personalization layouts with external applications and widgets created by two different users [29]. Unlike most customization tools, Rainmeter is only limited by your imagination and creativity. Rainmeter is currently only compatible with windows architecture. For that reason, our raspberry pi 4 is running on a beta version of Windows architecture for SBCs. A Windows OS with Rainmeter can bring your imagination to the smart mirror. Your perfect user interface you envisioned can be as simple as you want or as complex as you want. Our team used some existing Rainmeter skins and further customized them to produce

2 demo skins, which we will show later.

Figure 3. Two different Rainmeter personalization layouts by two different users [29].

4.2.4 Contingency

At the time of the initial design phase, there were several factors that were unknown and could potentially cause failure for certain aspects of the project. Potential risks include out-of-the-box hardware or port failure. If the Raspberry Pi unit has any damaged ports, then it is possible to get I/O port add-ons using the 48 pin GPIO header and adapter that the CanaKit RB4B comes equipped with [30]. This should not require any additional power as previously required because the ports would be dead and would not be supplied any power, so the power would be transferred directly to the adapter ports from the GPIO header pins. Other risks include delayed arrival of ordered materials, which would delay the integration steps. Fortunately, the software aspect can be implemented and tested independently on another device during this time.

Smart Look aims to integrate touch-sensitive applications to a smart mirror using an IR touch overlay. IR overlays are a plug'n play product that do not require a driver installation on an intended device. However, it was uncertain whether the Raspberry Pi unit will support this plug'n play feature and there are not any prior examples of any implementation to get confirmation. Learning of incompatibility, especially if the delivery of the overlay is delayed, could have been very problematic. A team member can confirm IR overlay's compatibility with

Raspberry Pi from the IR overlay manufacturer before getting the material's cost quotation. If it is still unknown, then this is an acceptable risk that can only be determined during the hardware testing phase. The worst-case scenario is that the overlay is not compatible with the Raspberry Pi, and if this occurs then the Raspberry Pi unit can be replaced with a low-end laptop or similar Windows compatible and the Raspberry Pi can function as an external I/O hub for additional port access. Since the software team will develop all the software elements on a laptop, which can be set on a display-only mode, it will act the same as a Raspberry Pi would have.

4.2.5 Design Aspects

The layout samples of the user interface was left to the discretion of the software team upon implementation and testing. The selected Labist RP4B comes equipped with 8GB of memory with the latest and fastest processor among any Raspberry Pi models [23]. The 8GB of memory is more than sufficient to handle the workload that will be exerted by the final prototype. It is estimated that Windows 10 IoT OS will take up approximately 4% of the CPU operations and 256MB of memory [11][31]. Rainmeter is a rather light application, where it will fluctuate between 2-4% of CPU and 30MB of memory on a laptop, which has a significantly better CPU, GPU, more memory, and other relevant specifications than a Raspberry P [27]. Therefore, the hardware lead estimated Rainmeter's usage workload on the Raspberry Pi unit's specifications to fluctuate between 10-15% of CPU and 30MB of memory. Rainmeter's CPU usage is estimated higher for the Raspberry Pi than a laptop to account for the difference in the processor chips.

4.3 Engineering Analyses and Experiment

While developing Smart Look, the prototype went through testing procedures to ensure the nominal operation. Testing procedures included software testing, hardware testing, and integration testing. Software and hardware testing were done separately, and integration testing will ensure successful collaboration of software components and hardware devices.

4.3.1 Software Testing

Software elements include using HTML and JavaScript to design sample user layouts, integrate internet-based applications and ensure their compatibility, and configure widgets using live RSS feed [32]. When conducting software testing, the software team will be using a Windows-OS laptop. The Windows-OS laptop will mimic the Windows 10 IoT OS that will be used in the Raspberry Pi. Testing procedures include visual corrections of displayed layout, testing internet-based applications, and comparing RSS-encoded widgets with websites for accuracy. Internet-based applications for testing and final prototype include, but are not limited to, Spotify, mail, messaging platforms, etc. RSS-encoded widgets testing includes Weather Channel for weather widgets, MarketWatch for stock widgets, Taskbar Clock for accurate time and date, news websites used for RSS-encoded news widgets, etc. [32]. While conducting all software testing, the software leads uses the benchmarking tool, determined by the hardware lead, and records all CPU usage and memory usage data. The hardware lead used this data to initially predict if the Raspberry Pi has sufficient RAM space for smooth operation of the prototype.

4.3.2 Hardware Testing

Hardware elements include the Raspberry Pi unit, display unit, dielectric mirror, and IR frame. The display unit will be connected to power to ensure it turns on properly. Then, heat emission will be monitored while remaining on for 30 minutes and then while streaming movies or videos on an entertainment platform for another 30 minutes. To ensure that the display unit's I/O ports and speakers are working properly, external devices will be connected using respective cables, like HDMI connection with laptop and video playback for sound. During the testing of the display unit, the dielectric mirror will be attached in front of the display unit to ensure visibility of the displayed material from the unit when in use and then become a plain mirror when the display unit is turned off. The frame overlay will be attached to the display unit and connected to one of the USB inputs of the laptop and the laptop will be connected to the display unit via HDMI or necessary adapters as required. To test that the IR touch overlay is working properly, the tester will interact with the display unit, which will mimic actions done on a touch screen laptop.

Smart Look is assembled using 3 main components, the first being an IR frame, which allows for the touchscreen experience. As mentioned, IR touch overlays are a patented device that has many light-emitting diodes and photoelectric sensors on opposite sides chained together embedded on a frame [6]. The diodes emit a grid of infrared beams in a XY-direction. Any interruptions, via any object, like a finger, between the beams of light and the sensors will be interpreted as touch on that interrupted location. IR frames also support multi-touch capabilities and have a fast response time of 1ms. It does not require a driver installation, just a simple USB plug-n-play. Next, the display unit, in our case we used a TV, size of 32” to match the dimensions of the 32” IR frame for proportional and accurate touch experience.

In place of an expensive mirror, an inexpensive mirror film was used for financial concerns as a substitute to mimic the mirror-like resemblance. Installation steps for mirror film can be found in the assembly manual created by the Hardware Lead

4.3.3 Raspberry Pi Testing

The Raspberry Pi, being the core component of the project, will undergo independent testing. The hardware lead will run the Raspbian self-diagnostic tool to check that all there are no faults with the Raspberry Pi unit or ports. Then, a USB 2.0 microphone will be inserted into one of the USB 2.0 slots of the Raspberry Pi and the unit will be configured to enable Cortana voice enabling Microsoft voice recognition. After successful configuration, the voice-recognition feature will be tested using various voice commands. Then, Windows 10 IoT OS will be installed onto the Raspberry Pi unit, along with several Windows-based applications and hardware-testing benchmark tools, which will be determined by the hardware lead at the time of testing. Installation of Windows IoT OS and rainmeter can be found in the Assembly Transcript documentation created by the hardware lead. Multiple applications were opened and used simultaneously, and the benchmark tool was used to monitor thermal temperature status, nominal CPU and RAM usage, and the unit's power distribution. This test was done on five different intervals, where each test is a longer duration of testing and monitoring than the previous test to ensure the consistency of the data. The duration of each test will be determined by the hardware lead at the time of testing. The final test's primary objective was to monitor any thermal leakage while maintaining smooth operations without crashing the system. As mentioned earlier, for the prototype to maintain its functionality, the unit must be equipped to support all power usage of the hardware components while maintaining thermal output. The raspberry pi unit was equipped with heatsinks on the three modules, the Broadcom CPU, the memory module, and the USB controller module, that were determined to produce the highest heat runoff. A kit fan was installed via the raspberry pi's GPIO pins 4 and 6 to exhaust hot air trapped inside the case and replenish with cool air. Placing the heatsinks and the fan are to absorb thermal runoff and prevent damage on the other modules and system

It is difficult to estimate the standards that classify as optimal values without proper testing of the applications' CPU and RAM usage and testing of the prototype integration. However, as mentioned earlier, the known variables, Windows 10 IoT Core OS and Rainmeter, should not take up more than 20% CPU usage and 300MB RAM usage, leaving plenty of operating capacity for any other integrated applications, like the IR overlay. The Cortana virtual assistance feature will once again be tested to ensure compatibility with the Window 10 IoT OS. A latest gen Raspberry Pi 4 unit, with 8GB ram installed with the beta WoR OS, which is compatible with the desktop customization tool, Rainmeter.

4.3.4 Integration Testing

Integration testing will consist of first assembling all the physical components together. The Smart Look team will strip the exterior casing of the display unit to secure the dielectric mirror onto the front of the display screen and attach the IR overlay around the display screen. The IR overlay will connect to the Raspberry Pi unit through USB, which is used to power the overlay and transmit touch-sensor data simultaneously. The display unit will be powered using an external surge-protected power strip and connected to the Raspberry Pi unit using a micro-HDMI-to-HDMI or HDMI-to-HDMI adapter cable. The Raspberry Pi will also be powered through the external surge-protected power strip and will be loaded with the software elements designed by the software team. The Smart Look team will test the integration with the criteria found in the project demonstration section below. The team will continue to fix any error checks and retest as necessary.

The overall integration came together successfully. We were able to boot the raspberry pi through the WoR OS, launch rainmeter, test several skin layouts, get a 10-point touch functionality through the IR frame, install a mirror-film to close to mirror-like resemblance.

However, our prototype wasn't flawless, there were obstacles hindering progress. During the start of our project, an official version Windows OS was not available for single-board computers (SBCs for short). We used a WoR, a windows os version still in beta and testing, and in doing so disabled drivers and all the onboard I/O peripheral ports. Additionally, using WoR noticeably slowed the performance of our raspberry pi unit. Our hardware lead created an instruction manual documenting problems, solutions guidelines, fixing the peripherals, system performance enhancement tips, and step-by-step assembly and installation process. This manual can be found on our projects website.

4.4 Codes and Standards

4.4.1 IEEE 802.11 standards and FCC Part 15

IEEE 802.11 is the standard for wireless local area connection. It will be used to provide wireless network access to the Raspberry Pi device that supports bandwidths 802.11b/g/n/ac at frequencies 2.4GHz and an optional 5GHz channel. Any device that uses Bluetooth or enables Bluetooth via adapter must adhere to FCC Testing and Guidelines. The current unit model consists of an integrated Bluetooth 5.0 and a wireless WiFi adapter that supports 802.11b/g/n/ac operating under both 2.4GHz and 5.0GHz frequencies and conforms to both, 802.11 and FCC Part 15, standards.

4.4.2 Microsoft Cortana Configuration Standards

Amazon enables product development and Alexa assistant configurability for any compatible non-Amazon product, including Raspberry Pi devices and other SBCs. Users must acknowledge and adhere to Amazon Developer Services Agreement when using Amazon Developer Tools.

4.4.3 Modular Connections

SBCs, including Raspberry Pi devices, contain one or more of the following: PCI, audio/visual I/O, SD storage, USB connections. If the unit does not contain an integrated IEEE 802.11 wireless controller, then one of the USB interfaces to provide wireless functionality via an adapter.

4.4.4 Windows 10 IoT Core

Microsoft enables product development and OS installation for any compatible computing device, including Raspberry Pi devices and other SBCs. Users must acknowledge and adhere to Microsoft Developer Agreement when installing any version of their Windows operating system, including Windows 10 IoT Core.

5. Project Demonstration

The demonstration of this prototype will take place at the Senior Design lab for evaluation by the faculty. It will also be demonstrated at the Georgia Tech Capstone Expo. The Smart Mirror will be connected to an immobile power source, such as a wall outlet. It will also be connected to a Raspberry Pi, which will be controlling the display and reading from the touch screen and voice input. A user can demonstrate the various functionalities by interacting with the Smart Mirror and showing the different applications on it.

5.1 Touchscreen Interface

The touchscreen will be demonstrated by having a user interact with it. The user will be able to show various applications on the Smart Mirror by controlling them via touch. These features include:

- Pulling up applications such as weather or news
- Messaging to show ability to type on the screen
- Drawing and writing on the display

5.2 Voice Commands

The Raspberry Pi will be configured to enable voice recognition and Amazon Alexa virtual assistance. Voice commands are enabled and will be an operational demonstration by having a user speak to provide verbal input to the system. They will be able to tell the Smart Mirror to turn on, open applications, search the Internet, record information, and message contacts.

5.3 Display Customization

The visual customization of the display will be demonstrated by showing that the user can modify the layout of the screen. The user will demonstrate a couple of design layouts to show how the Smart Mirror can be personalized. They will also show how the mirror can toggle between the 4 modes (mirror, smart mirror, television, and wall decor).

5.4 Internet and Bluetooth

The internet will be demonstrated in the following ways:

- Show successful connection to the web (Google)
- Be able to send messages on WiFi based messaging applications
- Show weather and news data, which will be taken from live Rich Site Summary (RSS) feeds

Bluetooth will be demonstrated in the following ways:

- Connect Spotify to a Bluetooth speaker
- Show collected data or statistics from a Bluetooth watch

6. Schedule, Tasks, and Milestones:

The GANTT chart in Appendix A shows the tasks that must be completed, including dates, duration, and assigned team members for each. It also includes milestones such as demonstrations and presentations. The durations are scaled to represent the estimated difficulty of each task.

A PERT chart is shown in Appendix B. The critical path is shaded in red, and its estimated duration is 96 days with a standard deviation of 4 days. Based on the estimation for task durations, the probability of completing the project one week before GT Capstone Expo (98 days) is 68%.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

Smart Mirrors are not a brand-new idea; there are many DIY models that can be found on the internet. In early 2016, a Google software engineer, Max Braun, was the first to develop a working prototype of a voice-enabled smart mirror that displayed weather, time, and featured news. Michael Teeuw later built a similar version and started an open source smart mirror platform, MagicMirror2, where people can upload or download modules to display [38][39][40][41]. Since then, many people have been building their own smart mirrors as a popular DIY project [40][42]. If you search "smart mirrors" on YouTube or Google, there are hundreds of videos and guides you can look at. There are open source modules, guides, and videos of ones integrated with smart capabilities and can visually and audibly display common information, like weather forecast, to-do lists, calendar events, email notifications, and even traffic information [39][42][43].

In general, the current builds are quite simple and need only a few items: a raspberry pi unit, necessary power supply and display-connection wires, a display unit, a mirror that you will lay in front of the display, HTML-based program for each display function, and an optional frame. Braun and Teeuw's prototypes were upwards of $500 [40][41][44]. There are some builds that cost over $3000. The cost will vary in terms of hardware and materials only. As the size, quality, and hardware requirements increases, the build's durability and professional aesthetic will also increase with higher capabilities and functionalities. However, the tradeoff is, the cost will also increase proportionally.

Ideally, the Smart Look team will be using a large display unit, preferably 32" or up, with a dielectric mirror with matching dimensions. The vision is that this product would be wall-mounted in a bedroom, living room, or maybe even an office room setting. Unlike the smart mirrors seen on the internet, this project aims to multi-purpose a smart mirror with touch-interactive features. Our mirror will serve four primary functionalities: A regular mirror, smart mirror, a cast-enabled TV, or a painting décor screen. A cast-enabled TV will allow the user to display videos, shows, or movies on the mirror. The additional smart mirror aspect will include interactive layout and commands in addition to common features that you would see on other smart mirrors and include touch-friendly features such as writing notes. A painting décor screen is a feature that you can activate if you are ever wanting to change the vibe of the room or to enable a security setting, almost like a screen lock, when leaving the room to go somewhere else. Additionally, this product has a customizability feature where the user can modify the screen layout as they desire.

Future goal of the Smart Look project is that it could eventually be produced and sold commercially, rather than being another DIY project. While the current target audience are home/apartment owners, this product could eventually be marketed towards companies and organizations, such as schools and universities, as a sleek multi-use display to be installed in classrooms and student dorms.

7.2 Cost Analysis

7.2.1 Component Costs

The parts and materials needed for this project are a Raspberry Pi, a WiFi and Bluetooth adapter for the Raspberry Pi unless already pre-equipped on the unit, dielectric mirror, touch-interactive IR panel, display unit, and a wooden frame. The cost of materials depends on the size of the mirror. We consider three sizes - 32”, 40”, and 50”. See **Table 8** below for cost estimates.

Table 8. Component Costs

	Costs (based on various display sizes)		
Item Name	32”	40”	50”
LABISRS Raspberry Pi 4 Model B Board Kit [45]	$99.97		
Wifi/Bluetooth Adapter	Not needed since Raspberry Pi has wireless LAN and Bluetooth		
Dielectric Mirror [46](shipping not included)	$302.21	$448.17	$1477.39
Touch-Interactive IR Panel [47]	$163	$185.00	$209.00
Display Unit (Monitor)[48][49][50]	$99.99	$174.99	$189.99
Wood for Frame: 2 in. x 4 in. x 96 in [51]	Unit Price: $2.94		
Quantity:	1	2	2
Cost:	$2.94	$5.88	$5.88

Total	**$668.09**	**$913.98**	**$1982.2**

7.2.2 Development Costs

The costs for labor hours are shown below. These are based on an assumed salary of $55,000 per engineer, which gives an hourly wage of $26.44/hr.

Table 9. Development Hours

Task	Labor Hours	Labor Cost
Software		
Design User Interface	20	$528.80
Implement Software Application	120	$3,172.80
Code Debugging	50	$1,322.00
Hardware		
Assemble Components	10	$264.40
Cable and Wire Management	5	$132.20
Integration		
Hardware/Software Integration	60	$1,586.40
Individual Components Testing	40	$,1057.60
Full Product Testing	40	$1,057.60
Deliverables/Team Management		
Team Meetings	20	$528.80
Research	10	$264.40
Reports	20	$528.80
Demonstration	5	$132.20
Design Expo	10	$264.40
Total	**410**	**$10,840.40**

Using the fringe benefit as 30% of total labor and overhead as 120% of material and labor, the total development cost for the Smart Mirror is $33,231.01, as shown in **Table 10**.

Table 10. Total Development Costs

Development Component	Cost
Parts	$651.14
Labor	$10,840.40
Fringe Benefits, % of Labor	$3,613.47
Subtotal	$15,105.01
Overhead, % of Material, Labor, and Fringe Benefits	$18,126.01
Total Development Cost	**$33,231.01**

NOTE: The parts cost is based on the 40" display size.

7.2.3 Profit

The production will consist of 5000 units sold over a 5-year period at a cost of $2,000.00 per unit. Assembly and testing workers will be employed at $20 an hour to assemble the parts and test the product. We assume there will be a 1 labor hour for assembly and 0.5 labor hours for testing. The sales expense in the form of advertising will be 5% of the total price, which will be $100. If the Smart Mirror is sold for $2,000.00, there will be a $348.46 profit, which is a 17% profit per unit. The expected revenue over 5 years would be $1,742,300.

Table 11. Selling Price and Profit Per Unit

Expense or Income Component	Dollar Amount
Parts Cost	$651.14
Assembly Labor	$20.00
Testing Labor	$10.00
Labor Cost	$30.00
Fringe Benefits, % of Labor	$9.00

Subtotal	$690.14
Overhead, % of Material, Labor, and Fringe Benefits	$828.168
Subtotal, Input Costs	$1518.308
Sales Expense	$100.00
Amortized Development Costs	$33.23
Subtotal, All Costs	$1651.54
Profit	$348.46
Selling Price	**$2000.00**

NOTE: The parts cost is based on the 40” display size.

8. Current Status and Future work

Currently, the prototype is fully functional, except there are several drivers are disabled. However, there are alternatives to enable functional drivers through USB adapters. Currently For DIY users looking to replicate our prototype and/or further improve our prototype, we have made a detailed instruction manual indicating steps for prototype assembly, raspberry pi configuration with WoR boot, getting functional I/O ports, and getting started with Rainmeter. Our prototype is not a perfect product and there is no such thing as a perfect prototype. However, our hope is that Smart Look can be the foundation for any future work and upgrades, enhancing user experience and product performance. During the start of our project, SBCs with windows-compatible architecture was not available. However, a new SBC called, Rock Pi X, was released recently November 2020, with a windows x86 architecture microprocessor. Replacing the Raspberry Pi 4 with Rock Pi X, is a good start for improvements, and could eliminate some of the hardware restrictions, including functional audio/wifi/bluetooth drivers, and enhance the performance for a more fluid response.

9. Leadership Roles

Leadership roles within the team include Team Coordinator, Software Lead, Hardware Lead, and Integration Lead, Webmaster, Expo Coordinator, and Documentation Coordinator, and Communications Lead.

9.1 Project Manager – Rahul

This role involves planning and facilitating meetings with group members and faculty advisors. Additionally, the Team Coordinator makes sure the team is on track with the planned schedule and is prepared for any deadlines and milestones. Lastly, they delegate leadership roles to other team members and make sure that everyone is contributing fairly to the project.

9.2 Software Lead – Madeline, Tara

The Software Lead oversees all software tasks, such as designing the customization aspect and user interface of the Smart Mirror. Other tasks are the implementation of software features, including those related to Alexa and Chromecast. Other team members may consult with this person when difficult software issues arise, such as coding bugs, or when important software decisions need to be made, like what coding language to use.

9.3 Hardware Lead – Rahul || Hardware support - Caleb

This role involves overseeing all hardware tasks, such as ordering hardware parts, assembling the frame, display, and touchscreen overlay. This person is also in charge of cable and wire management for connecting the devices, like the Raspberry Pi, and making sure all elements are properly connected to power sources. The Hardware Lead can relegate related tasks to other members and is the point person for hardware issues and significant hardware decisions. In addition, the hardware lead will be responsible for supporting with any software testing as necessary and oversee all hardware-related testing, including thermal testing, power testing, virtual assistant configuration and testing, and integration testing.

9.4 Integration Lead – Rahul || Integration support - Jake & Caleb

This position involves overseeing the integration of hardware and software for the Smart Mirror. Relevant tasks include connecting the touchscreen, so it provides input to the system and making sure the software is compatible and functions on the Raspberry Pi's hardware platform and operating system. This person also oversees the testing of individual components, once connected, and then full testing afterward.

9.5 Webmaster - Rahul

This person manages the team's website. They make sure relevant and accurate information about the project is presented in an organized manner and update the site when needed.

9.6 Expo Coordinator - Tara

This role involves overseeing all preparations for the Capstone Expo at the end of the semester. They make sure that the crucial features of the project are implemented and that it can be demonstrated smoothly. This person is also responsible for any logistics involving the Expo such as keeping track of important dates, locations, and contacts.

9.7 Documentation Coordinator - Rahul

This involves making sure that all team meetings are documented in an organized manner. They decide which team member documents each meeting and makes sure that the notes are submitted.

9.8 Communications Lead - Madeline

This person is responsible for communicating with the faculty advisor and Senior Design professors about meetings and any questions or issues the team may have. They also oversee important project deliverables such as the project summary and proposal and make sure that the team is communicating their idea well through these means.

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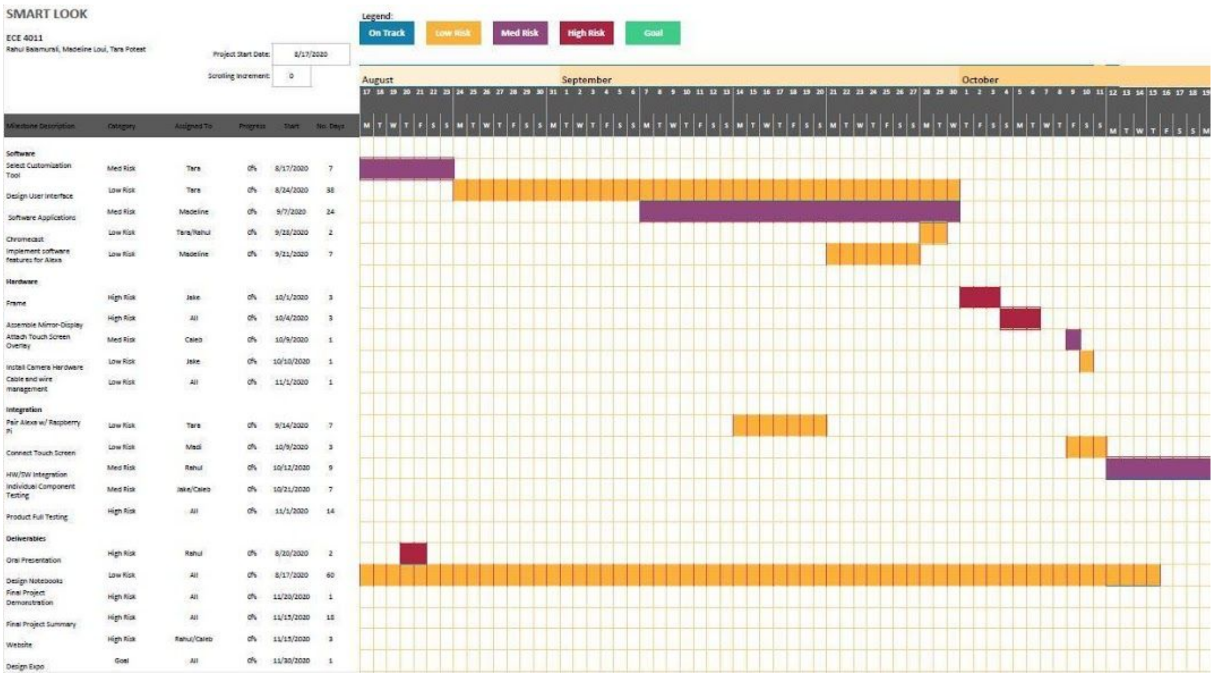
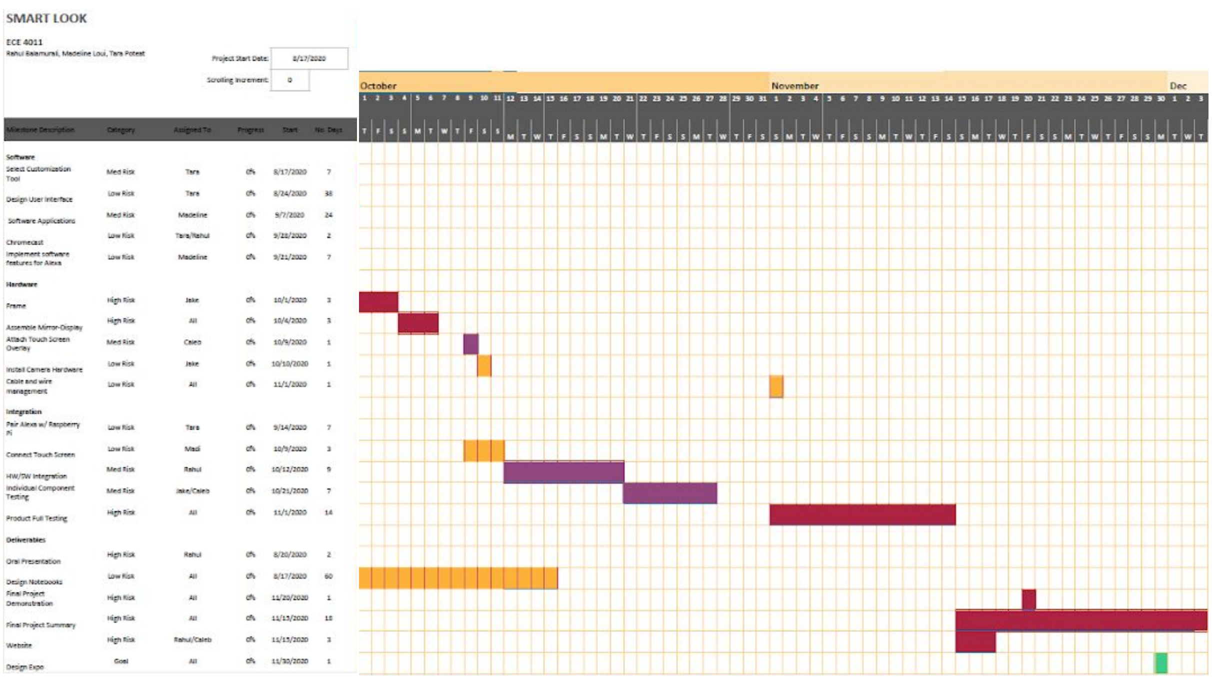
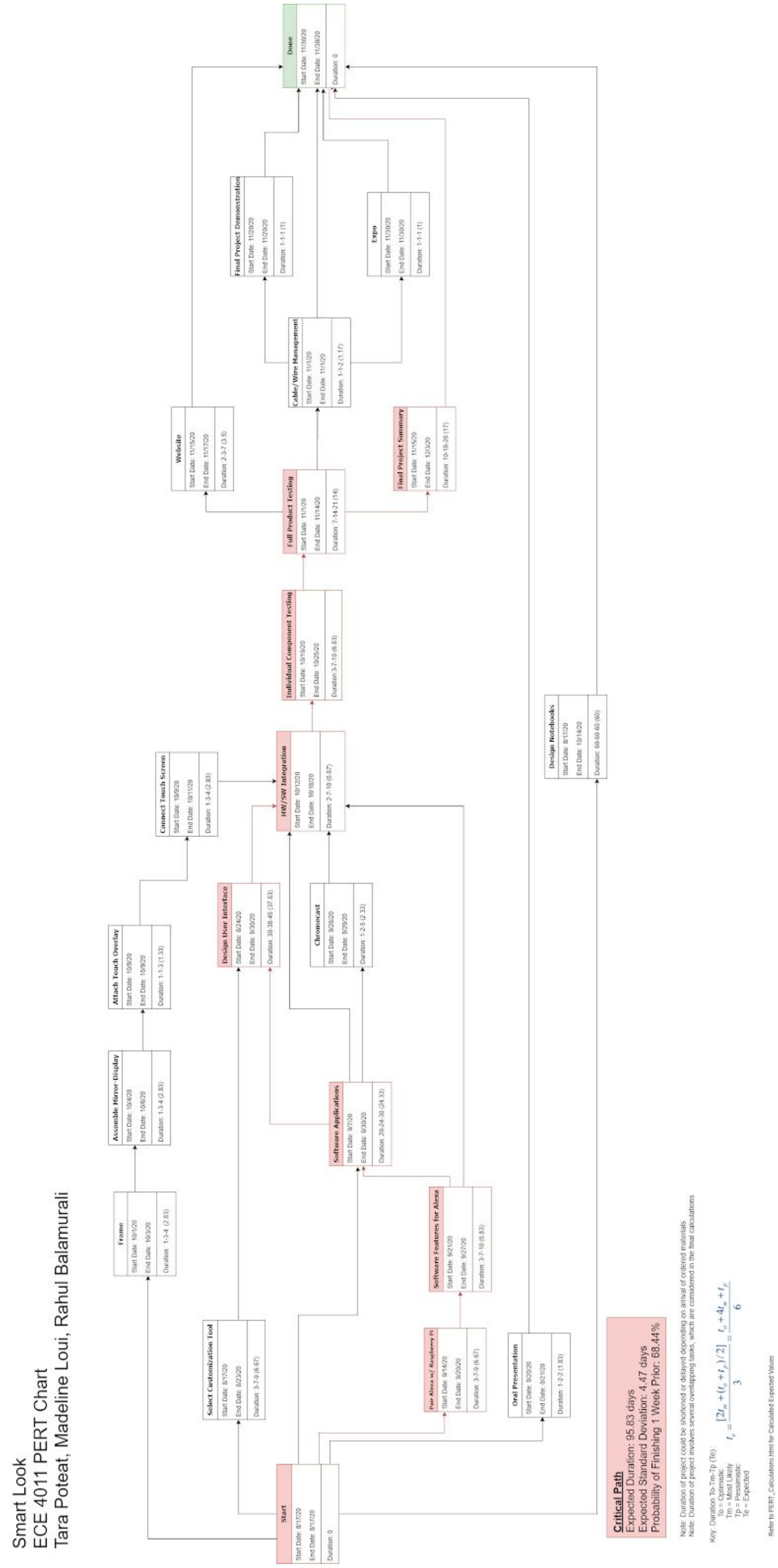
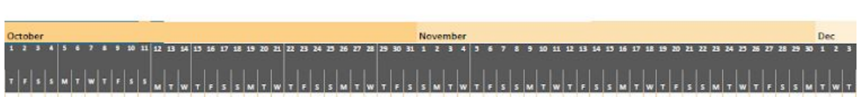
Appendix A – Gantt Chart






Smart Look
ECE 4011 PERT Chart
Tara Poteat, Madeline Loui, Rahul Balamurali
Start
Frame
Assemble Mirror Display
Attach Touch Overlay
Connect Touch Screen
Select Customization Tool
Design User Interface
Software Applications
Chromecast
HW/SW Integration
Individual Component Testing
Full Product Testing
Website
Cable/Wire Management
Final Project Demonstration
Expo
Final Project Summary
Done
Design Notebooks
Oral Presentation
Software Features for Alexa
Critical Path
Expected Duration: 95.83 days
Expected Standard Deviation: 4.47 days
Probability of Finishing 1 Week Prior: 68.44%


October
November
Dec

Appendix C – Raspberry Pi Comparison Chart [18][19][20][21][22][23]

Model	Processor	Memory (GB)	System storage	HDMI	WiFi built-in	Bluetooth built-in	Fan or Heat sinks	Power Supply	USB slots	Other slots or add-ons
Labists RP4B kit	Broadcom BCM2711 quad-core Cortex-A72 (ARM v8) 64-bit at 1.5GHz	4	SD card (32GB class-10 SD card provided)	MicroHDMI x2 (4kp40 support)	Dual band 802.11b/g/n/ac WiFi (2.4/ 5.0 GHz)	5.0	1 CPU fan +3 copper heat sinks	USB-C 5V 3.1A	2.0 x2 3.0 x2	2-lane display port 2-lane camera port NOOBS preinstalled
Element 14 RP3B	Broadcom BCM2837B0 quad-core Cortex-A57 64-bit ARM v8 2GHz	2	SD card support SD card not provided	HDMI x1	802.11b/g/n/ac WiFi (2.4 GHz)	-	-	USB 5V 3.1A Not provided	2.0 x4	NOOBS preinstalled
SMI RP3B	Broadcom BCM2837B0 quad-core Cortex-A57 64-bit ARM v8 1.4GHz	2	SD card support SD card not provided	HDMI x1	802.11b/g/n/ac WiFi (2.4GHz)	4.2	-	Micro-USB 5V 2.5A	2.0 x4	-
Canakit RP3B+	Broadcom BCM2837B0 quad-core Cortex-A57 64-bit ARM v8 1.4GHz	1	SD card support SD card not provided	HDMI x1	Dual band 802.11b/g/n/ac WiFi (2.4/ 5.0 GHz)	4.2 Module	2 aluminum heat sinks	Micro-USB 5V 2.5A Not provided	2.0 x4	NOOBS preinstalled
OKDO RP3B+	Broadcom BCM2837B0 quad-core Cortex-A53 64-bit ARM v8 1.4GHz	1	SD card support SD card not provided	HDMI x1 Display Port x1	Dual band 802.11b/g/n/ac WiFi (2.4/ 5.0 GHz)	4.2 Module	-	Micro-USB 5V 2.5A	2.0 x4	2-lane display port 2-lane camera port
ABOX RP3B+	Broadcom BCM2837B0 quad-core Cortex-A53 64-bit ARM v8 1.4GHz	2	SD card (32GB class-10 SD card provided)	HDMI x1	Dual band 802.11b/g/n/ac WiFi (2.4/ 5.0 GHz)	4.2 Module	2 copper heat sinks	Micro-USB 5V 3A	2.0 x4	2-lane display port 2-lane camera port NOOBS preinstalled *No ethernet
CanaKit RP4B	Broadcom BCM2711 quad-core Cortex-A72 (ARM v8) 64-bit at 1.5GHz	4	SD card support SD card not provided	MicroHDMI x1 (4kp40 support)	-	-	1 CPU fan +3 aluminum heat sinks	USB-C 5V 3.1A		Power ON/OFF switch

NOTE: Under "Other slots or add-ons", if "NOOBS pre-installed" is not listed under respective models, then those models are not equipped with NOOBS

<u>Selected Model:</u> *Labists Raspberry Pi 4B - $99.99 USD*