Smart Mirror

University of Central Florida
Department of Electrical Engineering and Computer Science

Dr. Lei Wei
Senior Design 1

Group 5

James Timothy – Electrical Engineering
Matthew Caserto – Electrical Engineering
Greg Eugene – Computer/Electrical Engineering
Menashe Mordachai – Photonics/Electrical Engineering

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1 Executive Summary

The following document will show the processes taken to produce the Smart Mirror. This document will show the depth of research that goes into designing this rigorous project as a part of the Senior Design curriculum. This team of electrical engineers, some of which are also majoring in computer engineering and photonics, will take on this project and develop the technology that has yet been introduced into this product. Despite it being a product that has already made an appearance in the technological world, this group is hoping to develop some new and interesting features that would make this project stand out. The innovation of this project seeks to develop teamwork with the group as well as to nurture creativity and out-the-box thin king, all of which will be required in future careers.

The Smart Mirror project seeks to advance the technological world, as well as to ease everyday lives. The purpose of our Smart Mirror is to be placed in the bathroom, so when getting ready to tackle the day people may check the weather, emails, watch shows, or just browse the internet for entertainment. It can do all that and simply function as an ordinary mirror when needed.

The Smart Mirror will require the use of a two-way mirror to function the way that it's intended. For the display tob look as if it's floating freely in the mirror, using a two-way mirror which only lets the light of the display show through is critical. It's also necessary for the Smart Mirror to function as a regular mirror if the technological functions are not in use, which is another reason why the two-way mirror will be required.

For ease of access, the Smart Mirror will be able to function using gestures which will be processed by the sensors and translated into specific actions that was required by the user. The other method of access to the mirror is using an IR-frame, which will provide a touchscreen-ability to the Smart Mirror. Bluetooth will also be added to this Smart Mirror, so that the user can use their phones to access the mirror. Mainly accessing the data specifically for that phone.

2 Project Description

This section of the paper will explain in greater detail, the purpose of the Smart Mirror. It will also show the functions that we intend to put on this Smart Mirror given the allotted time. This will provide a clear objective on what is required of the mirror and how it will affect the daily functions of the user.

2.1 Project Background

In the life of an average person, our morning routine can be one of the most stressful parts of our day. There's a lot to do in the morning that's important to starting the day off right and that can have an effect on the outcome of your entire day. That's why it's important to condense everything to one place and simplify the morning or even evening routine to one place, the bathroom.

A majority of people start their day off by going to the bathroom and getting started on their morning routine, such as showering, brushing teeth, shaving, etc. These tasks require spending a lot of time in front of the mirror but what if it could do more than just displaying your own reflection? Such as displaying the weather, so you know what you'll wear that day; Showing news reports; The next event on your schedule and even ordering an Uber to be there as soon as you leave the house.

We want to create a mirror that will allow anyone to accomplish basic daily tasks while simply getting ready in the morning and the goal is to make it as minimalistic as possible. When it isn't being used, the tech should be completely invisible, and it'll look just like any other mirror. No visible camera's, sensors, and wires anywhere to be seen. This is important because the best kind of technology is the one you never notice. It's noninvasive and simple and will feel seamless in the use and functions.

Another important feature for us is making a navigation scheme that lets users easily navigate the OS but without actually touching the mirror. This is important because nobody wants fingerprints all over their bathroom mirror. We will accomplish this using an optical frame that surrounds the mirror and will act as a touch input device, sensing where a finger is place near the screen. The second input method will be a gesture sensor, most likely IR LEDs, that will sense hand movements such as a swipe left, right, up, and down. The combination of these will allow someone to easily get around the interface and use the mirror.

The features intended to be implemented are facial recognition, an LCD display, sensors for sensing touch and gestures for navigating the user interface, and Bluetooth connection for retrieving information from user's phones.

2.2 Objectives

The objective for this project is to use our combined skills and the education we've gained at the University of Central Florida to work as a group and build something together. It will challenge us in many ways from testing our team work to our problem solving. This is a very valuable experience as it will prepare us for graduation and finding a job afterwards to kickstart our future careers.
The objective of the project itself is to simplify the everyday lives of the user. The efficiency of everyday activities should be increased, as the user can get ready and check emails, etc. at the same time. The overall features of this project should be innovative and easy to use for the users. The secondary objective of the project is to create a smart mirror that can provide the best ease of access for the user. The use of gestures will make the mirror innovative and easy to use for those that have their hands full while getting ready. The use of Bluetooth, will allow the user can use their phones to access the smart mirror and their own personal data on said smart mirror, making it quick and efficient to access their data. The IR frame allows the user to use touchscreen to access the smart mirror applications, for those that enjoy the hands-on experience. Lastly, we may possibly put in a camera for facial recognition, making it easy for the user to access their own personal data with their face.

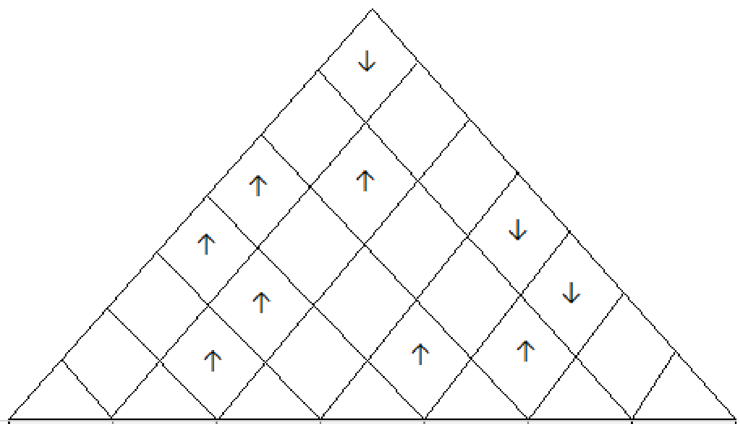
2.3 Requirements Specifications

- The mirror will have an LCD display that fits the mirror size as closely as possible
- The mirror will be mounted to the LCD panel as closely as possible to maximize display fidelity
- The mirror will have a quick turn-on time when someone stands in front of it
- The electronics will consume much less power when the mirror is not being used
- The electronics shouldn't be visible at all, besides the camera.
- The user interface will use mostly white to maximize the display contrast as much as possible
- The mirror processor and microcontroller will communicate over serial to relay information between the two devices
- The microcontroller must have enough I/O to connect to all the sensors and communicate to the processor
- The electronics will include Bluetooth for getting information such as weather and calendar events from a user's phone.
- The electronics will include a Wi-Fi module for getting information for when a Bluetooth connection isn't available.

2.4 House of Quality

The following section will contain the house of quality, which indicates the positive or negative correlation between two things in the chart. For this part, a positive correlation is beneficial for the project, while a negative correlation negatively impacts the project.

Table 1 – House of Quality



		Optical touch grid	Motion control	Facial recognition	Social media connectivity	Phone connectivity	Environmental measurements	Installation
		+	+	+	+	+	+	-
Cost	-	↑↑	↑	↑	↑	↑		↓
Usability	+	↑	↑	↑	↑	↑	↑	↓
Power consumption	-	↑			↑	↑		
Mirror size	+	↑↑						↑↑
Targets for Engineering Requirements		Precision (<5% variation)	Hand gestures	>99% accuracy	Twitter, Facebook, Netflix	Bluetooth functionality	Temperature, humidity (1% accuracy)	>5 minutes

The house of quality of this product shows the basic requirements that consumers want the product to have. To make the product marketable, it’s important to meet the consumers expectations as much as possible. This house of quality chart shows how each function that are placed on the smart mirror will meet the expectations for the product overall from the consumer perspective.

One of the most crucial component for consumers is the price factor of the product. The more features we put on our smart mirror will obviously raise the price factor of the product. However, if the product was to be marketable, it is essential to have these functions that have become a norm for the users in today’s technological world.

The next important factor is ease of access, which is exactly what we have done with the several functions placed on our smart mirror. We have designed our product in such a way that it should satisfy most of the users in terms of accessibility of the use of the product. From gestures to facial recognition, our smart mirror provides ease of access fit for most if not all consumers.

Another important component for consumers is the power consumption of the product. Consumers dislike products that will greatly increase their monthly electric bills. Some of the function we placed on the smart mirror will influence the power consumption. However, with most electric products, in terms of power consumption, it all depends on the amount of time the consumer uses the product overall. We have taken steps to help reduce power consumptions by making the display go offl when not in use.

The last factor that is important to some of the consumers is product dimensions. For our case, our smart mirror will not be too large as it would be too difficult to carry. However, from marketability sense of view, if we made our smart mirror larger it may provide a better experience for touchscreen users, as it would reduce the chance of the user to accidentally touch and open applications that are not intended, thus reducing stress. However, if we made our smart mirror small, it may be useable to more consumers, because most consumers do not have a large surface area in their bathroom walls to mount said mirror.

3 Research related to Project Definition

This section of the paper will examine research that was done on the different technologies and other projects that exists closely related to our project. This includes any software or hardware components.

3.1 Existing Similar Projects and Products

Many other smart mirrors exist, especially custom projects done created by others online. All of them have similar technology and features and while we will use some of those, we want to make something a bit different.

3.1.1 Mirror Design

The common approach to the smart mirror is just fitting a display behind the mirror and securing it in a frame to keep the two attached. An important step some projects neglect is removing everything but the LCD itself and the driver/power board to allow the display as close to the mirror surface as possible. This will allow better viewing angles and visual fidelity overall.

3.1.2 Mirrocool

Mirrocool is a company that has already created their own version of the smart mirror. They offer their customers a choice of two types of smart mirrors, the unframed option is meant to be mounted on the bathroom and the framed option is meant for hallways. The mirror that's meant to be mounted on the bathroom is IP65 water resistant certified, this rating means that the product is protected from dust and water that may harm the equipment. This product is like ours as it is also meant to be used in the bathroom. The screen is only visible when activated and it also allows the user to connect to their home WIFI. Their smart mirror also has a built-in high definition camera for the user to be able to user gestures and facial recognition. In our case, we have decided to go with a sensor to allow the users to use gestures to activate the smart mirror. They have also thought through the ethical issues in having a camera in the bathroom of the user and added on a privacy mode which essentially disables the camera all together. We have yet decided if we should add a camera in our smart mirror to be able to add in a facial recognition function. However, if we include this function in our camera, it would prove beneficial to our project. Mirrocool has also added in an app for smartphones so that the user may access the smart mirror functions remotely. This gives them the capability of using their smart mirrors as security cameras that takes pictures of guests that are unrecognizable by the mirror and sends a notification to the smartphone along with the picture. As we are building our smart mirror mainly for use in the bathroom, this function may prove unnecessary as most home intruders would most likely not go to the bathroom areas

3.1.3 Evervue MirrorVue Smart Touch Mirror

Evervue has innovated multiple different kinds of smart mirror variations. They have created smart mirrors for the bathroom, salon, conference room, retail, as well as showrooms. Their smart mirror has several different choices of applications depending on the operating system that the user requires (Windows, Raspberry, Android or Linux). Instead of just being able to see the daily weather and access the internet, it has other functions that would make it useable in most situations. Their smart mirror also provides the user with touchscreen capabilities, just as our smart mirror does. The differentiating factor is that we will use an IR frame to create this touchscreen capability, which mimics a resistive touchscreen, allowing only a single touch point on the mirror. Evervue has included a 10-point touchscreen in their smart mirror, which like capacitive touchscreens, allow for multiple touch points in the mirror. Also similar to our design, Evervue has included Bluetooth capabilities in their smart mirror to allow connections with external devices.

3.1.4 Savvy SmartMirror Electric Mirror

The company Savvy SmartMirror has created a smart mirror mainly for hospitality to be used in hotels. Besides the general functions like having a weather, time and date displays, they have added custom functions that would allow the hotel guests to see hotel advertising and promotions, as well as, amenities and services. They have included two different types of mirrors on their smart mirrors, one is the DuraMirror and the other is the Iris mirror. The Iris mirror will accomplish what we are trying to do with our mirror in that it will function as an average mirror when the display is turned off. The DuraMirror on the other hand goes and appears dark gray if the display is turned off. Just as Evervue did, the Savvy SmartMirror Electric Mirror also has touchscreen capabilities. This company also makes a voice smart mirror, which just as the name suggest, it responds to the hotel guest's voice. Voice technology is widely popular in the electronics market, just as shown by the innovations of the Amazon Echo and Google Home. As a stretch goal with our own project, our instructor has recommended us to have our smart mirror be able to function with the use of one of these voice technologies. This would give our smart mirror voice functionality which would increase the difficulty level of the project and set it apart from other senior design projects.

3.1.5 Biometric Verification

In researching technologies for the smart mirror, we looked at all types of products that implemented some form of facial recognition. From that researched what components would be necessary to build a functioning biometric system.

Facial recognition software applications are biometric based algorithms designed to identify the unique features of an individual by comparing segmented facial patterns to verify the identity of the person. By using deep learning algorithms, the software can analyze live capture features or use stored digital imprints to verify the identity of an individual by measuring their overall facial structure. For our particular system it was necessary to utilize a biometric technique of non-contact nature to limit physical contact with product to prevent residue and preserve visibility. Being one of the least intrusive and fastest forms of biometric technology, facial recognition as form of authentication has become one of the most viable options for security purposes. The feature measurements that are gathered by the algorithm are given a numerical code and stored in a database and then compared to other collected datasets of faces whenever a person stands in front of the imaging device. In today's market there are many consumer electronic companies that offer some form of facial recognition for both authentication and identification.

In 2009 Apple released its iPhoto application with both facial detection and recognition using the facial detection algorithm to determine if an objects features were at first consistent with those of face, and then facial recognition to distinguish people based on their unique features.

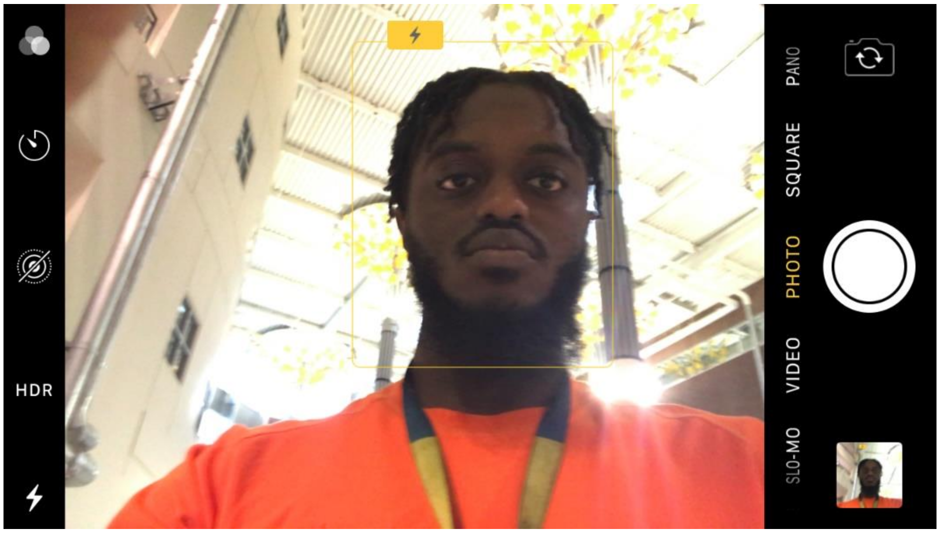


Figure 1 – iPhone facial detection example

In 2017 the iPhone X was released with a facial recognition system for unlocking devices using a 3D mapped facial imprint stored in a local part of the processor.

3.2 Face Detection

Face detection software extrapolates human faces from images and/or videos based on a set of mathematical rules used to define standard identifiers for human faces. Being that human faces do not drastically vary from one another we can compose a general structure for a face to use as a standard comparator: A forehead, two eyes, a nose and a mouth. For example, consider the following figures:

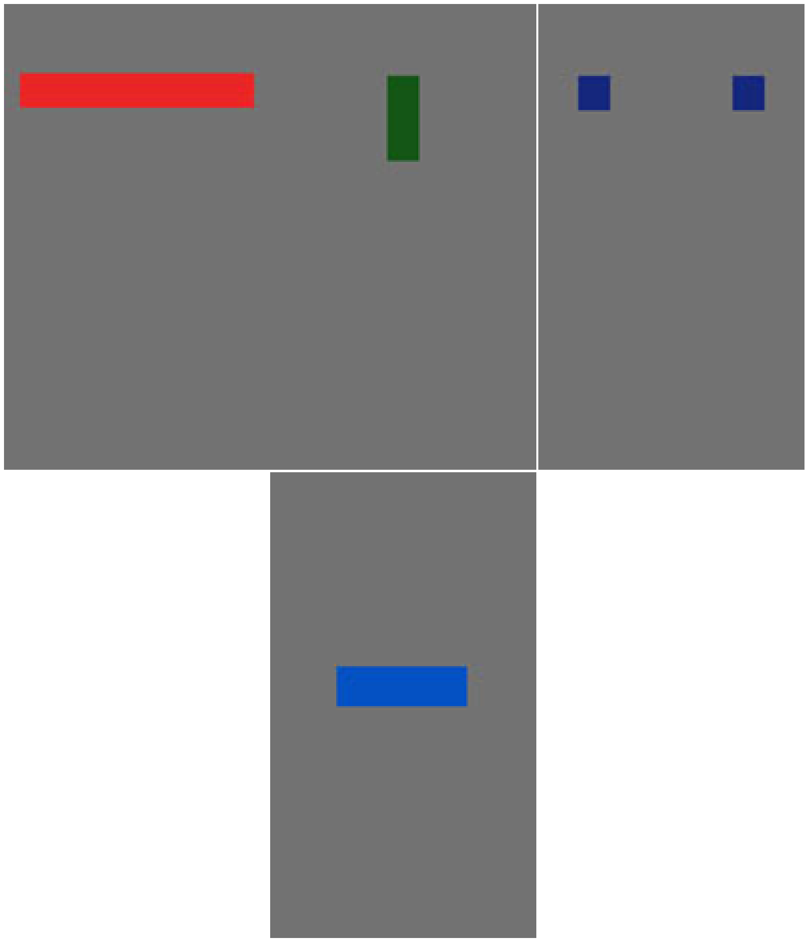


Figure 2 – Sections of facial detection

Each figure can be used as the representation of an individual feature. When we combine each figure, we have a construct that closely resembles the general structure of a human face.

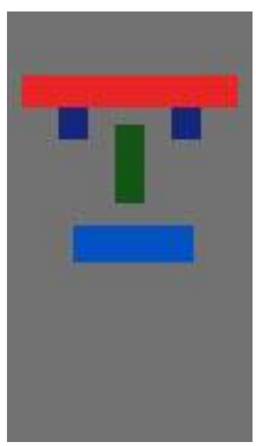


Figure 3 – Combined sections of facial detection to create a face

Using this composite as a template for the algorithm to determine if objects captured in an image/video have features similar to the model, we can establish whether or not the object is a face. Because we are matching a template, we are not so much concerned with accurately matching the shapes of the model to image features; rather, we just need to determine whether or not the features exist.

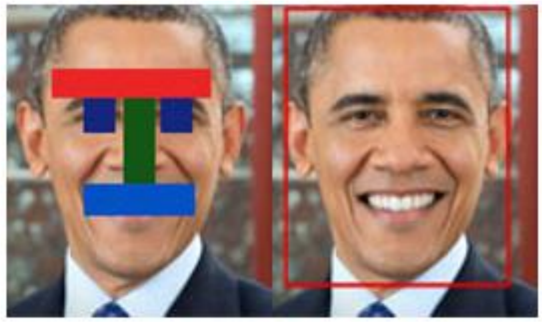


Figure 4 – The combined facial detection example

The algorithm first compresses the image to reduce the amount of information being analyzed. When given an input the algorithm must detect human faces while at the same time disregarding peripheral objects. By iteratively matching features we are able to detect areas of an image or video that does not match a face. This process is repeated multiple times increasing the probability of accurately detecting face features. By continuously rejecting portions of the image/video that do not match the model we are essentially determining what is not a face. The elimination of features can be quickly compared to relative position validation.

3.2.1 Face Detection - Color

This method requires an image/video capture to be in color. The algorithm searches for colors that are typical of human a skin tone, it then searches each object to see if it has an aggregation of features that resemble a human face based on a preset algorithmic structure defined by the program.

3.2.2 Face Detection - Motion

People move in real time so when using video images or any live capture method movement can be used as a guide to capture the area of the image that is moving. Aside from the subject of the image there are peripheral elements within the frame that also exhibit either direct or relative motion. The software will need to create reference points that act as markers to determine whether or not the object in motion is actually face that is moving.

3.2.3 Face/Feature Extraction

One way to reduce memory consumption is to extract image features and use them we can use it. Features can be defined as basic patterns, distinctive attributes or parts of an image that we can use to describe the things we see in an image. For example, a mouth or a nose can be used as a feature on an image of a person. The human eyes and mind work in conjunction with one another to accomplish this However with physical images, using basic image pixels is not descriptive enough. The importance of the use of features in computer image processing is being able to convert visual information into digital information. This allows algorithms to use mathematical approximations for comparing various features between similar vectors. With representation learning, the idea is to apply a set of filters that are able to distinguish one classification of images from another classification through the use of specific algorithms. For example, Google's Image search uses the basic qualities of a given set of data with low reconstruction error. The specific variables capture different commonalities within images. For example, one unit might be if there is a hat in a given image or another might be a particular kind of shape present in an image.

3.2.4 Face Recognition

Facial recognition software is a type of software that can be used to instantaneously identify individuals from either the use of video or digital image capture. Most facial recognition software uses some type of algorithm that analyze particular features on an individual's face. This can either be accomplished using such things such as the relative position of points on a face or size and shape of an individual's features. Unlike fingerprinting and voice recognition, facial recognition software yields nearly instant results because subject consent is not required. Facial recognition software is primarily used as a protective security measure and for verifying personnel activities, such as attendance, computer access or traffic in secure work environments.

An advantage of live capture is that the appropriate action can be taken whenever the biometric data is gathered. Like other biometrics solutions, face recognition technology processes and identifies the distinct characteristics of an individual that can be used for identification or authentication. Often times using some form of digital or video/live capture device. Face recognition algorithms have the ability to identify faces in images/videos and can compute their features, and then validate them based on stored datasets within in a user database.

The are many live capture methods used in consumer facing devices. For example, there are some ATM's that use face recognition to verify that the individual making the transaction at the machine is the individual whose information matches the card being used at the machine. The individual has to look in the direction of the live capture device; images are captured for verification and transaction continues otherwise, the transaction is not cancelled.

Face recognition software requires a live capture device to use identification instead of passwords to secure user devices such phones, computers or and laptops. For example, whenever individuals sit in front of their computer, the camera uses the image which the software then processes the face to identify the person in front of the device. If the individual in front of the computer is a registered user, then he will be automatically logged on to the computer.

The main difference between detection and recognition is that with former the only thing we need to determine is whether or not there is an actual face in the image or live feed in front of the camera. With face recognition the goal is to determine the face and verify whether it grants access to the user. In the example above we used pattern matching to determine if the image had features consistent with a face this is detection. When the system is trained it would be able to should be able to recognize the person in the photo as the Barack Obama.

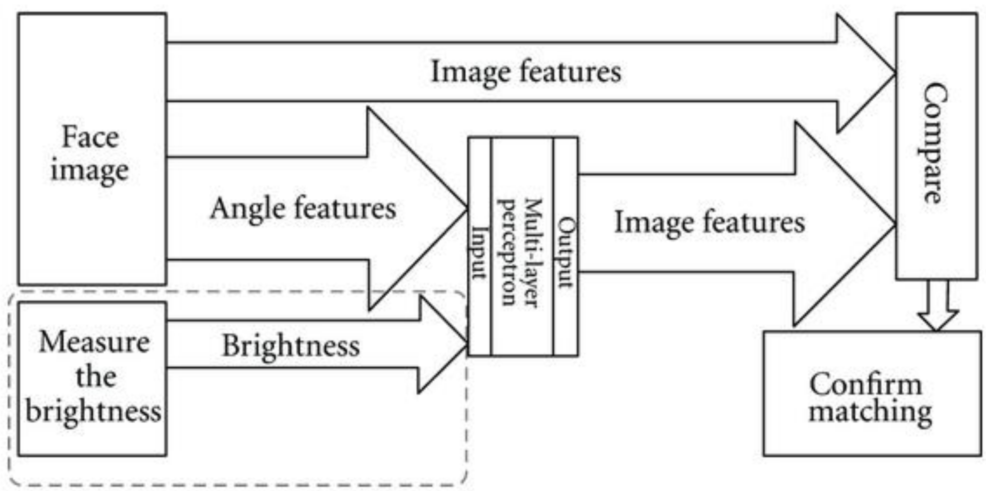


Figure 5 – Flowchart to determine facial recognition

3.2.5 Face/Feature Classification

Using OpenCV there are three methods implementing face recognition: Eigenfaces, Fisherfaces and Local Binary Patterns Histograms (LBPH). In the following sections after this one, it will review these three methods of implementation in detail and shows the similarities/differences of each method and which method would be best to implement for our project.

Each of these three methods performs face recognition by comparing scanned faces to be recognized with some training dataset of already known faces. In the training set, we supply the algorithm with faces and tell it to what person the face belongs. When the algorithm is presented with a face to recognize and it is foreign to the system, it references the data set determine whether or not it recognizes the face. Each of method uses the information in the set a different way. However, the initial goal of recognizing the user faces for accessing their own personal data stays the same.

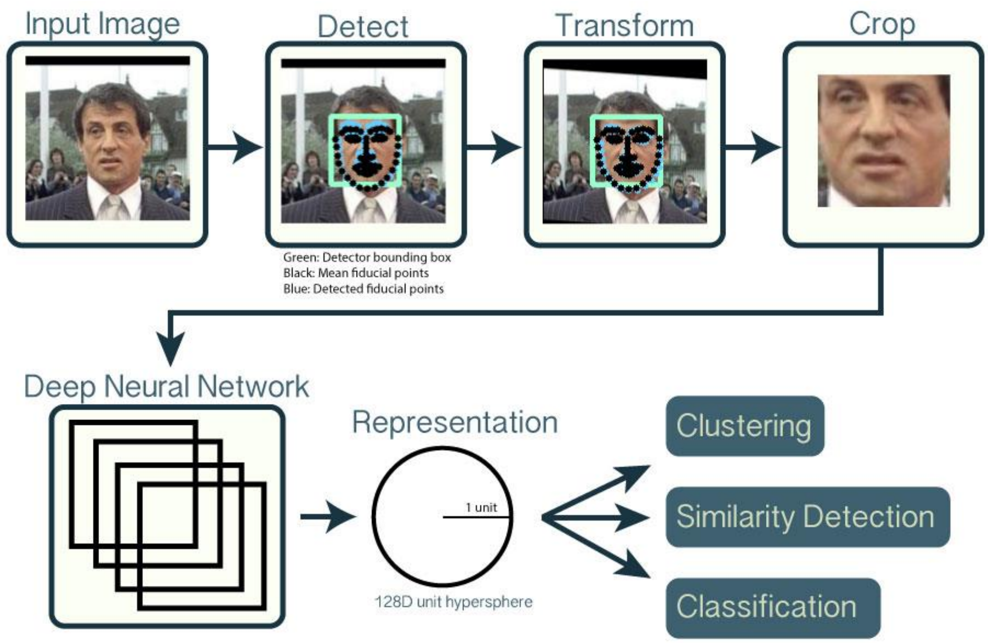


Figure 6 – First example of a training algorithm (Rank Red, 2017)

3.2.6 Local Binary Patterns

LBP's are image descriptors that need to be trained using multiple images. Our faces are comprised of features that contain micro visual patterns which can be extracted to create vector of features to classify faces and non-faces. Every image that is collect for training is divided into a set number of blocks. For each block within the vector, the LBP segments 9 pixels at any given time, using the pixel located in the center of the frame. To determine the value for the centermost pixel we need a reference point. We can start from just about any pixel and move either forward or reverse, once we pick our ordering method it must remain consistent for all other block pixels in our image and any other images in our dataset. We can use the Euclidean distance formula shown on the following page to calculate the straight-line distance between these two pixels. This distance allows the Euclidean space to become a metric space.

Equation 1 – Euclidean distance formula

$$D = \sqrt{\sum_{i=1}^{n} (hist1_i - hist2_i)^2}$$

Given a frame of data, the algorithm must perform a binary test on every block within the frame. The results of this binary test are stored in an 8-bit array, which is then converted to decimal. The algorithm then compares the value of the center pixel with every pixel each adjacent value within the frame moving outward accordingly. For each adjacent pixel that is greater than the center pixel, it is a assigned value to 1, and for every pixel with value lower than the center they are set to 0. Once that process is complete, the algorithm then reads the updated value of the pixels in a clockwise direction and generates a binary number. It then converts the binary number into a decimal approximation, and the resulting decimal number is assigned as the new value for the center pixel. this is done for every pixel in a frame.

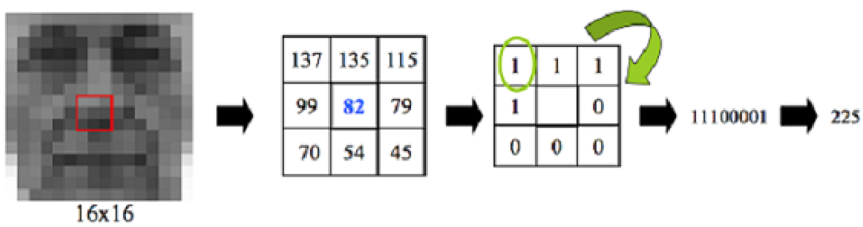


Figure 7 – Second example of a training algorithm (Raja, 2017)

OpenCV also implements LBPs, but strictly in the context of face recognition — the underlying LBP extractor is not exposed for raw LBP histogram computation.

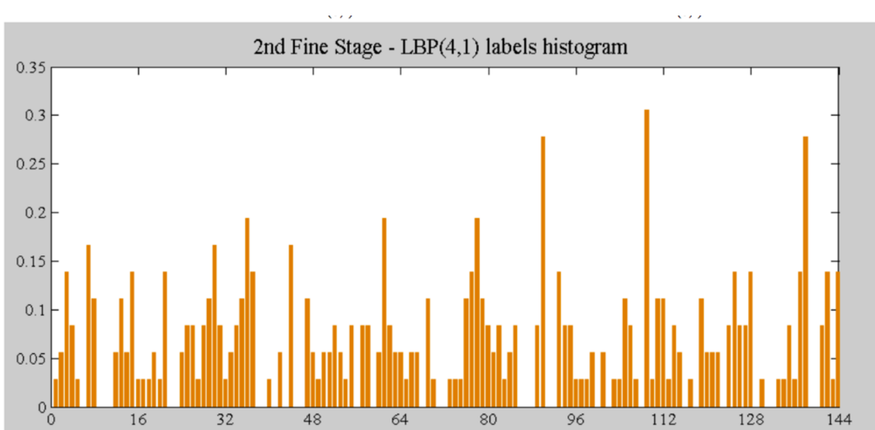


Figure 8 – LBP Histogram
Source: López & Ruiz; Local Binary Patterns applied to Face Detection and Recognition. (Raja, 2017)

3.2.7 EigenFaces

Eigenfaces are images that can be added to a mean (average) face to create new facial images. We can write this mathematically as,

Equation 2 – Formula used for EigenFaces

$$F = F_m + \sum_{i=1}^{n} \alpha_i F_i$$

where,

F is a new face,
F_m is the mean or the average face,
F_i is an EigenFace,
α_i are scalar multipliers we can choose to create new faces. They can be positive or negative.

To calculate EigenFaces, we need to use the following steps.
Obtain a dataset: generate a collection of f images comprised of different kinds of faces.

Align and resize images: align and resize all images to create standard center for the face so that all of the images are aligned. By using facial landmarks this calculated.

data matrix: Create a data matrix containing all images as a row vector.

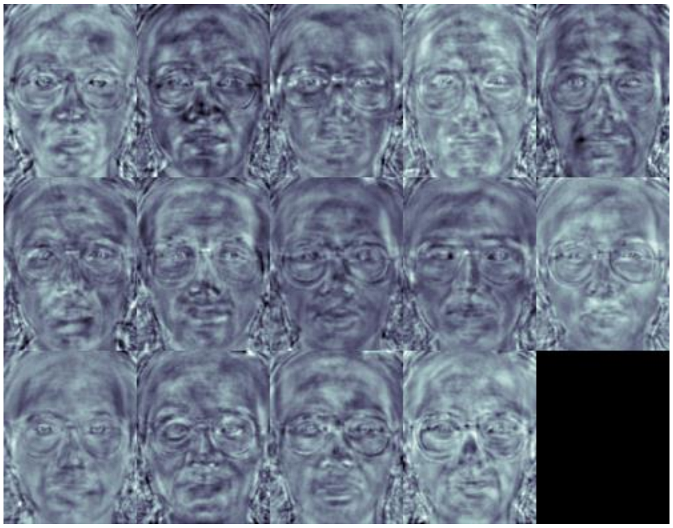


Figure 9 – Data Matrix

Mean Vector: calculate the mean by averaging all the rows of the data matrix. The calculation is not a necessary component of the algorithm because OpenCV actually calculates mean using other linear algebra packages.

Principal Components: The principal components of this data matrix are calculated by finding the Eigenvectors of the covariance matrix. Fortunately, the PCA class in OpenCV handles this calculation for us. We just need to supply the data matrix, and out comes a matrix containing the Eigenvectors.

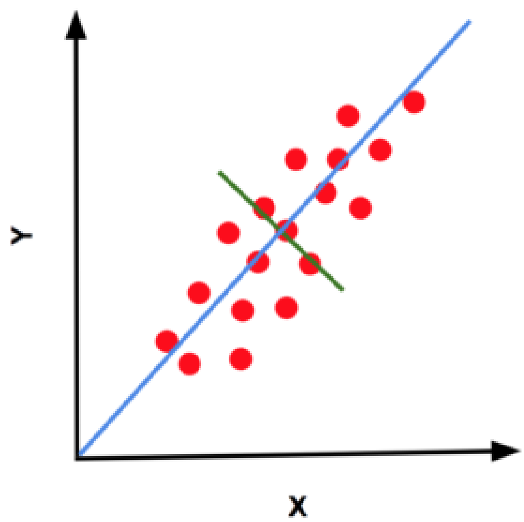


Figure 10 – Training data set (Mallick, 2018)

Reshape Eigenvectors to obtain EigenFaces: The Eigenvectors so obtained will have a length of 30k if our dataset contained images of size 100 x 100 x 3. We can reshape these Eigenvectors into 100 x 100 x 3 images to obtain EigenFaces.

3.2.8 FisherFaces

This particular algorithm is an improved version EigenFaces. EigenFaces inspects all the training dataset at one time and finds principal components from all of the training images combined. By doing this, it doesn't place emphasis on any feature that might distinguish one image from another. Rather, it focuses on the features that are representative of all the faces in the training dataset in its entirety.

EigenFaces also uses light as a part of its calculation, it uses this difference as an aspect of face recognition. These variances that are extracted represents just a singles individual’s features.

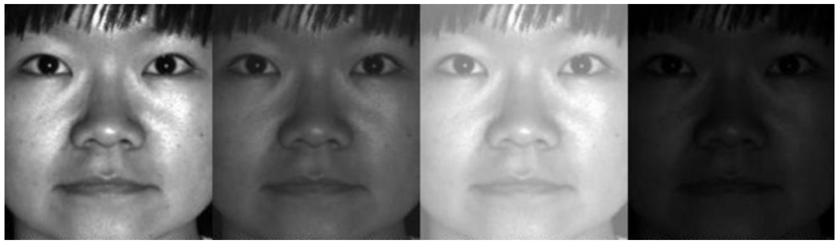


Figure 11 – Training images with different illumination levels

If we tune the EigenFaces algorithm to extract useful features from the face of each individual separately rather than extracting features from all them combined, regardless of the changes in illumination in any image it will not affect the other individuals feature extraction process. FisherFaces face recognizer algorithm extracts principal components that differentiate one person from another. In that sense, individual features do not become more dominant over the others.

3.3 Android Studio

We will be developing our interface using the Android platform currently more than 75% of Smartphone's use Android as their operating system. Android Studio uses the Gradle build system and uses modules to manage and organize codes. Every project has its own Gradle build files which means projects can state their own dependencies. The suite consistently updated and has very little bugs and provides a more stable performance guarantee. The Android device emulator uses multi-core processing, that makes development a lot faster. The emulator itself is faster than real smartphones, and new features can work best with the new emulator. Also, the new interface helps with fine tuning application by imitating interactive screen features. Once the app is completed the Google's Cloud Test Lab tests against a portfolio of physical devices. It works with proprietary tests developed by Google, that check for and correct any conflicts and other bugs. Developers can also preview the GPU Developer, which lets developers debug issues related to graphics.

3.4 Software system

Our software system will be written in C++. This language was chosen because it is a partial Object-Oriented Programming Language. It is a compact language and executes quickly. It has a well-developed system of libraries which makes it a very versatile language. It also supports graphics and image processing (OpenGL/OpenCV) which will be a fundament component for our system.

3.5 Raspberry Pi Compute Module

One of the things that looked at when picking our architecture was the recent exploitation “Meltdown” and “Spectre”. Although we’re only building this model for demonstration purposed we did research on a class of problems related to architectural peripheral channel attacks that have been known for a while and use as attacks on cryptography systems. The use of crypto instructions in general purpose processors drew the interest of cryptography researchers interested in discovering whether or not similar techniques could be applied to general purpose CPU’s. Given the success of the researchers exploits, many have more recently implemented different techniques to discover and exploit the side channels of the microarchitecture against other core processor specific function. This is done utilizing the time side channel for the cache system. The latest version of this is the side-channel uses instruction speculation. But general-purpose CPUs have many other side-channels that have yet to come under close scrutiny. With the "Meltdown" vulnerability this can easily be addressed with a revision to a current design, which is what usually happens with generation bumps. The speculative-execution "Spectre" vulnerability that can be found in most architectures including ARM models, which raspberry pi module are based on, can be fixed by implementing modification to the architecture. Patching the speculative execution side-channel doesn’t necessarily mean that the problem will be solved. Most modern processors have so many side channels in the CPU that most hackers will simply find and exploit the system. This will result in needing to make another architectural change to avoid further exploitation.

To avoid further exploitation in processor designs, there will need to be a more rigorous approach to side channel implementation as completed by their semiconductor design components. Doing so makes it extremely difficult to learn, re-engineer, re-design and exploit an architecture. The good news for Raspberry Pi Module 3 is a non-speculative Cortex A53 which. This is not a full guarantee that other possible side-channels won’t be found in the future.

The Raspberry Pi Compute Module (CM1), Compute Module 3 (CM3) and Compute Module 3 Lite (CM3L) are DDR2-SODIMM-mechanically-compatible System on Modules (SoMs) containing processor, memory, eMMC Flash (for CM1 and CM3) and supporting power circuitry. These modules are just like a laptop RAM module, it fits the same exact kind of slot. This module could be mounted on a PCB using the same technique used to mount the laptop RAM module to the laptop motherboard. These modules allow a designer to leverage the Raspberry Pi hardware and software stack in their own custom systems and form factors. In addition these module have extra IO interfaces over and above what is available on the Raspberry Pi model A/B boards opening up more options for the designer.

Figure 12 – Raspberry PI Compute Module, Source: (Raspberry Pi, n.d.)

The CM1 contains a BCM2835 processor (as used on the original Raspberry Pi and Raspberry Pi B+ models), 512MByte LPDDR2 RAM and 4Gbytes eMMC Flash. The CM3 contains a BCM2837 processor (as used on the Raspberry Pi 3), 1Gbyte LPDDR2 RAM and 4Gbytes eMMC Flash. Finally the CM3L product is the same as CM3 except the eMMC Flash is not fitted, and the SD/eMMC interface pins are available for the user to connect their own SD/eMMC device.

Note that the BCM2837 processor is an evolution of the BCM2835 processor. The only real differences are that the BCM2837 can address more RAM (up to 1Gbyte) and the ARM CPU complex has been upgraded from a single core ARM11 in BCM2835 to a Quad core Cortex A53 with dedicated 512Kbyte L2 cache in BCM2837. All IO interfaces and peripherals stay the same and hence the two chips are largely software and hardware compatible.

The pinout of CM1 and CM3 are identical. Apart from the CPU upgrade and increase in RAM the other significant hardware differences to be aware of are that CM3 has grown from 30mm to 31mm in height, the VBAT supply can now draw significantly more power under heavy CPU load, and the HDMI HPD N 1V8 (GPIO46 1V8 on CM1) and EMMC EN N 1V8 (GPIO47 1V8 on CM1) are now driven from an IO expander rather than the processor. If a designer of a CM1 product has a suitably specified VBAT, can accommodate the extra 1mm module height increase and has followed the design rules with respect to GPIO46 1V8 and GPIO47 1V8 then a CM3 should work fine in a board designed for a CM1.

Since this compute module is mostly similar to the Raspberry Pi 3 model B, we have decided to go with the Raspberry Pi 3 model B option. Due to time constraints, we believe it would be easier to reach our goal using the normal microcomputer rather than the module. It would prove time consuming to create a PCB around the module, while not giving any additional advantages.

3.6 Booting

The 4GB eMMC Flash device on CM3 is directly connected to the primary BCM2837 SD/eMMC interface. These connections are not accessible on the module pins. On CM3L this SD interface is available on the SDX pins.

When initially powered on, or after the RUN pin has been held low and then released, the BCM2837 will try to access the primary SD/eMMC interface. It will then look for a file called boot code. bin on the primary partition (which must be FAT) to start booting the system. If it cannot access the SD/eMMC device or the boot code cannot be found, it will fall back to waiting for boot code to be written to it over USB; in other words, its USB port is in slave mode waiting to accept boot code from a suitable host.

A USB boot tool is available on GitHub which allows a host PC running Linux to write the BCM2837 boot code over USB to the module. That boot code then runs and provides access to the SD/eMMC as a USB mass storage device, which can then be read and written using the host PC. Note that a Raspberry Pi can be used as the host machine. For those using Windows a precompiled and packaged tool is available. For more information see here.

The Compute Module has a pin called EMMC DISABLE N which when shorted to GND will disable the SD/eMMC interface (by physically disconnecting the SD CMD pin), forcing BCM2837 to boot from USB. Note that when the eMMC is disabled in this way, it takes a couple of seconds from powering up for the processor to stop attempting to talk to the SD/eMMC device and fall back to booting from USB.

Note that once booted over USB, BCM2837 needs to re-enable the SD/eMMC device (by releasing EMMC DISABLE N) to allow access to it as mass storage. It expects to be able to do this by driving the EMMC EN N 1V8 pin LOW, which at boot is initially an input with a pull up to 1V8. If an end user wishes to add the ability to access the SD/eMMC over USB in their product, similar circuitry to that used on the Compute Module IO Board to enable/disable the USB boot and SD/eMMC must be used; that is, EMMC DISABLE N pulled low via MOSFET(s) and released again by MOSFET, with the gate controlled by EMMC EN N 1V8. Ensure you use MOSFETs suitable for switching at 1.8V (i.e. use a device with gate threshold voltage, Vt, suitable for 1.8V switching).

3.7 The Optical Grid

Many devices today use a capacitive touch screen for input, making this form of interaction with devices come naturally to most people. However, when the main form of input for a device requires directly touching the screen, this results in oils being deposited on the display and smudges appearing. With an optical grid we can simulate the input of a touch screen which has become ubiquitous with modern technology but also allow people to hover their fingers just above the point they wish to interact with.

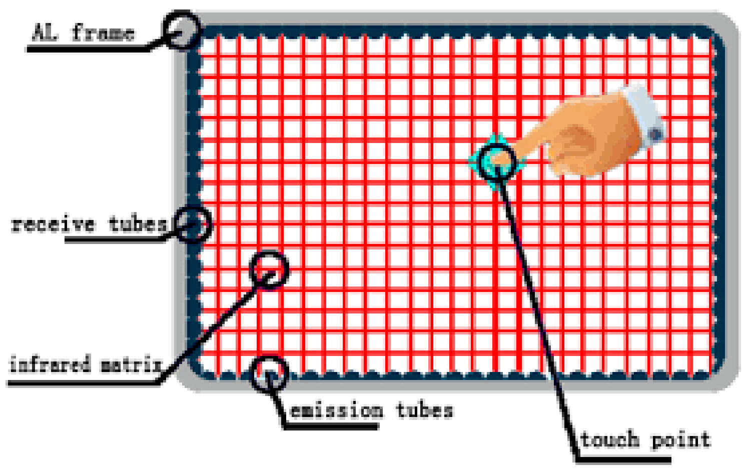


Figure 13 – Picture of the IR light source and photodiodes touch grid

This allows the user to both interact with the device in a seamless manner while simultaneously preventing smudging on the screen. Our optical grid will consist of an array of optical sources, either laser diodes (LD) or light emitting diodes (LED) and opposite of them an array of photodetectors. Whether we choose LDs or LEDs will be determined after testing with both technologies to determine which is easier to work with from a packaging and calibration perspective.

3.7.1 Theory of Operation

The light source and detectors will be embedded within all four sides of the mirror frame indicated in the following figure. Two sides will contain the light sources and the two opposing sides will contain the detectors. When aligned properly the light from each source should contact an opposing photodetector inducing a current to flow. When an object, such as a finger, is placed in between the light source and the photodetector, due to there being less light making contact with the photodetector, we can use this as an interrupt after calibration. Because of the arrangement of sources and detectors we can consider the surface of the mirror to be an x-y grid, thus allowing us to pinpoint the location of the “touch”. This, in turn, allows the user to interact with the mirror as if it was a touch screen. In the following figure, the red arrows indicate sides with IR light and the blue arrows indicate sides with photodiodes.

Figure 14 – Implementation of the IR frame

When this technology is implemented correctly, the optical touch grid will function as indicated by the following flowchart.

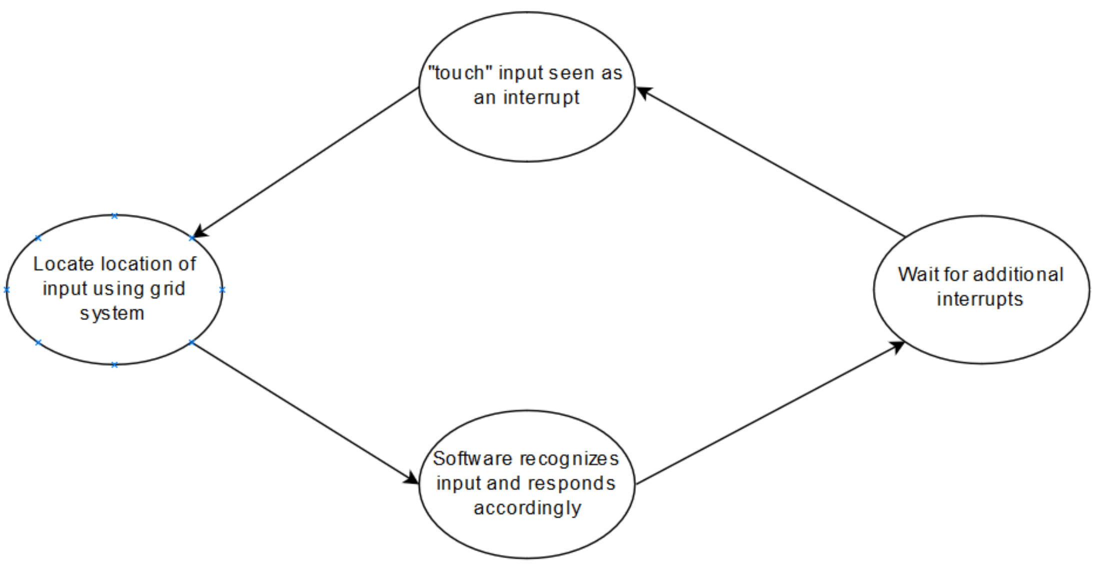


Figure 15 – Flowchart of the functionality for the IR frame

3.7.2 Wavelength

Additionally, the wavelength we choose to use greatly affects the usability of the device itself. If we were to use light sources in the visible spectrum, between wavelengths of 400 nm to 700 nm, then the radiating light could affect both the visibility of the screen behind the semitransparent glass as well as cause additional eye strain from the extra light. (Blue Light and Your Eyes, n.d.) For this reason, we have chosen to use light sources in the infrared region, which spans from the very edge of the visible spectrum at 700 nm to 1 mm wavelengths. There are multiple reasons and advantages to choosing infrared light sources instead of ultraviolet, which spans from wavelengths as small as 10 nm to 400 nm (the other edge of the visible spectrum).

The first reason we chose to use infrared light sources is it is a light source which emits less energy. The energy of a photon, a particle of light, can be determined by the following equation:

Equation 3 – Equation to calculate the energy of a photon

$$E = hf$$

Where E represents energy, h represents Plank's constant, and f represents frequency. We can determine the frequency of the light by dividing the speed of light, approximately three hundred million meters per second, by the wavelength of the emitted light. Using these known quantities, we can see that each individual photon in an ultraviolet light source contains more energy than both a photon from an ultraviolet light source and the visible spectrum. Since these spectrums of light are largely outside the visible spectrum, our eyes are not capable of dilating appropriately when exposed to large quantities of this light since it cannot detect it, which can result in eye strain and, in extreme circumstances, burning of the retina and permanent eye damage. So, by choosing a light source that emits less energy than the visible spectrum this issue is largely prevented.

3.8 Relevant Technologies

The following section of the paper will talk about all the relevant technologies that are available in the world today and how it relates to our project. It will also explain any current uses for this component, as well as how we will use it or something resembling it in our project.

3.8.1 Gesture Sensor

The gesture recognition system will use an Infrared LED and four photodiodes that sense reflected IR energy from the LED. There's many ways to do this but we're going to use a package from Broadcom called the APDS-9960 that has everything needed integrated into a small module. The detection range is 4-8 inches which will be perfect for what we want to do with it. It will allow us to easily detect hand gestures like swiping left, right, up, and down, and even more can be programmed ourselves.

3.8.2 Camera Module

The power to the camera will be switched using a MOSFET for security concerns. Connected to the power feeding the camera will be a status LED that will turn on when the camera is receiving power. Privacy is important, especially in a bathroom, so this lets users know when the camera is being accessed. This can't be disabled in software and that is important in keeping it safe and secure.

The camera we will use will most likely be a generic webcam because they're cheap and easy to setup. But it's also worth noting that the raspberry pi has a special high-speed camera interface that is just for that use. Raspberry pi cameras are available online that make use of this interface as opposed to USB which is slightly slower. The only negative to the Pi Camera is that it's more expensive but also comes with the advantage of not wasting a USB port so the sacrifice in cost might be worth it.

3.8.3 Serial Communication

Our project will have both a main processor and a microcontroller. The main processor will run the Mirror application, drive the LCD display, and monitor the Bluetooth and Wi-Fi connections. The microcontroller will be used to monitor the various sensors and relay that information to the main processor but also take actions from it was well.

Serial communication can be both synchronous and asynchronous. In synchronous communication methods, data is sent as alternating voltage levels on a wire and a second wire is used as the clock signal which signals when the data is valid at a certain moment in time. Asynchronous communication uses a oscillator that is required on both ends which determines exactly when data is to be written and read.

3.8.4 I^2C

I^2C is a very powerful and popular communication bus used for communicating between multiple devices. It was invented in 1982 by Philips Semiconductor, now NXP Semiconductors. It's usually used for attaching multiple low speed devices to processors and microcontrollers for data transmission across short distances such as a single circuit board.

The typical composition of a transmission is between a master and slave device. The interface consists of both a serial clock (SCL) and serial data (SDA). Both SDA and SCL are connected through a pullup resistor to the supply voltage. The communication happens by using a certain set of commands that are defined by the voltage on the two lines. The first command used to start a transmission is the START condition. A typical transaction between a Master and Slave will look like this:

Sending Data:

- Master sends a START condition and addresses the slave to be communicated
- Master sends data to slave receiver
- Master terminates the communication with a STOP condition

Receiving Data:

- Master sends a START condition and addresses the slave to be communicated
- Master sends the register to be read
- Master receives data from the slave
- Master terminates the communication with a STOP condition

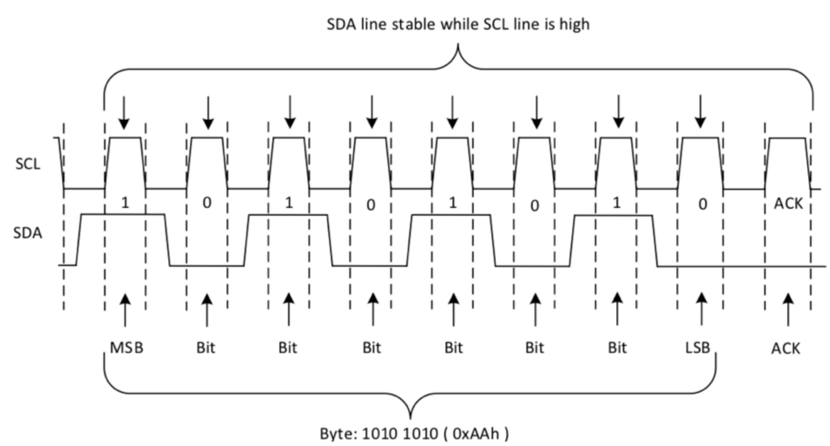


Figure 16 – Single Byte Data Transmission, Source: (Texas Instruments)

3.8.5 SPI

SPI stands for Serial Peripheral Interface. It differs from I^2C in that it's a high speed synchronous serial communication method and also requires four wires instead of just two. So, this is the option we'd want if speed is an important factor in our needs for communication between the main processor and microcontroller. The four pins used are:

Table 2 – SPI Pins

Pin	Type	Function
SCLK	Output	Serial clock output by master
MOSI	Output	Master output slave Input
MISO	Input	Master input slave output
SS	Output	Slave select(chip select)

The names for these data signals can vary depending out implementation but this is most common. In simplified words, SPI is using two shift registers to shift data in and out from the master to the slave and vice versa. It's a lot more complicated than that but typically specialized hardware included in a processor or microcontroller can make this easier. Although it's easy to see that not only does this use two more data lines than I^2C, but it's more complicated to implement.

3.8.6 UART

UART stands for universal asynchronous receiver-transmitter. It usually comes on an integrated circuit that is included in the microcontroller itself. It's similar to I^2C in that it can transmit data using two data lines but doesn't need a clock signal. Instead it sends start and stop bits to signal the start and stop of the data transmission. When a start bit is received, it starts reading at a specific frequency called the baud rate. The baud rate is a measure of the data transfer speed and it's unit is bits per second or bps. Both communicating UART modules must communicate at the same baud rate or close to it. A disadvantage to UART is that it doesn't support multiple slaves but in our case that's fine since the communication is happening between just two devices.

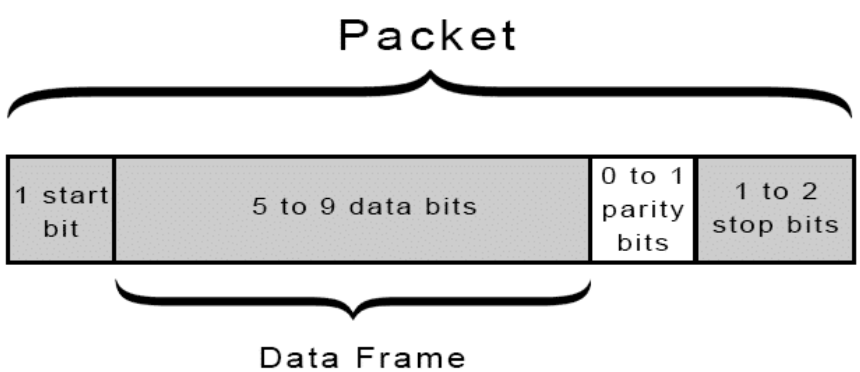


Figure 17 – UART Data Packet, Source: (Circuit Basics, n.d.)

3.8.7 Multiplexer

Considering the limited number of analog inputs on our microcontroller, a solution will be needed to connect the large number of photodiodes used by the IR frame to the analog inputs. We will be doing this with two or more multiplexers connected to create one large multiplexer. A multiplexer will allow us to connect over 30 analog inputs with a sacrifice of 5 digital output pins. We have two options:

- Use an individual multiplexer for the y and x axis
- Use one large multiplexer instead

The benefit to the first option is that the board will be more organized and have an input for the x-axis LEDs separate from the input from the y-axis LEDs. This will also make coding the two a bit more organized and simple, but it comes at the expense of twice as many digital pins. If we're using two 16x1 mux's for example, each will use 4 digital pins making for a total of 8. While one 32x1 mux will use only 5. Currently we don't have room to spare 8 digital output pins but if we do find that there's extra pins we will use a second mux to simply software development and have one MUX for each axis. It's also important for us to use an analog mux since they come in a digital variety and analog. We will be reading values from a photodiode which is just a diode that starts conducting when light hits it. This means a voltage across a resistor will increase or decrease depending on the amount of light hitting the photodiode and that will be an analog value.

Table 3 – Available Analog Multiplexers

Manufacturer	Type	Supply Voltage	Package	Cost
Texas Instruments	16:1	2-6 volts	24-SOIC	$0.08
Analog Devices Inc.	32:1	1.8-5.5 volts	48-TQFP	$10.8
Nexperia USA inc.	16:1	4.5-5.5 volts	TSSOP	$2.88
Maxim Integrated	02:1	4.5-18 volts	8-DIP	$4.08

I included a variety of Multiplexers that we might use and the relative specifications that will affect our project. Ideally, we want a large multiplexer for the most Photodiodes but 32:1 was the largest reasonably packaged available. The issue with this is that multiplexors of this size come in a very small TQFP package which can be quite difficult to solder by hand. So, it might be a better option to use two 16:1 multiplexers if we want a 32:1 device. I included the specs for a 2:1 mux for this exact purpose. It comes in a through hole DIP package which will be very easy to solder. The 16:1 mux still come in a surface mount SOIC or TSSOP package, but the pin pitch is larger, and they will be easier to solder overall. Although if we decide that a 64:1 mux is needed to get more LEDs and photodiodes in the IR frame to make the touch sensor more accurate, the 32:1 mux will be necessary. The other alternative is if we can find a 64:1 mux in a package we can reasonably solder to our board but seeing as the 32:1 mux is already hard to solder the 64:1 mux would probably have smaller connections thus making it even harder. The process for connecting two mux's is easy and is shown below:

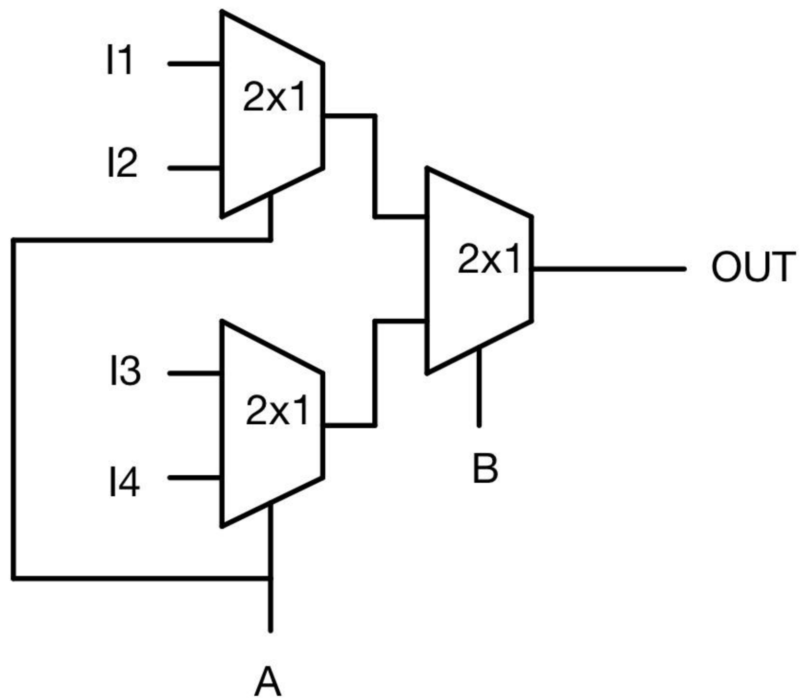


Figure 18 – 3 Multiplexers used to create a larger one

3.8.8 Printed Circuit Board (PCB)

The PCB is found in most, if not all, electrical devices. The PCB is a way to connect all the electrical components of a project together. PCBs are made by using a conductive material, typically copper foil, on a non-conductive surface, typically fiberglass **(How Products are Made, n.d.)**. There are three different types of PCB constructions available as of today, single-sided, double-sided, and multi-layered **(How Products are Made, n.d.)**. As the names suggest, the single-sided PCB has the conductive material printed only on one side of the circuit board, whereas the double-sided PCB have the conductive material printed on both sides. However, the last type, the multi-layered PCB, is different from the other two types. It consists of several layers of printed circuits with insulation separating the different layers. Despite the meticulous construction, the multi-layered PCB simplifies circuit patterns **(How Products are Made, n.d.)**.

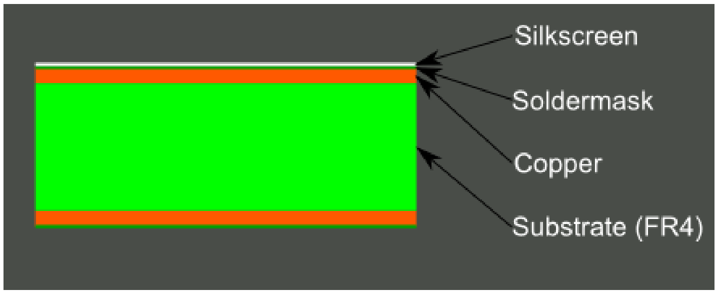


Figure 19 – Double-sided PCB construction, Picture source: (jimb0, n.d.)

As for the components mounted on the PCB itself, there are two different methods to do so. The much older and outdated method is to simply place the component through the board and solder or glue the pieces in place so that it meets the conductive material **(How Products are Made, n.d.)**. While this is sufficient method, it raises a few issues because if the components should become non-functional it would be more difficult to replace. Also, with solder it would increase the likeliness of a short to occur if the solder should come into contact with each other. The newer method involves surface mounting components into the PCB **(How Products are Made, n.d.)**. This method is much more effective as it simply allows the user to replace non-functional components with another without the need for unsoldering and re-soldering the pieces into place. It also reduces the risk for solders to come into contact with each other and shorting out connections, thus killing two birds with one stone.

3.8.9 Power Supply

Research into the power supply is important for this project because we have a lot of different components and voltages to take into consideration. The first step of the power supply will be AC to DC conversion because our circuits will run on DC current as do most electronics. The AC will be stepped down to a lower voltage using a small transformer and then a full bridge rectifier will rectify the AC to a DC supply.

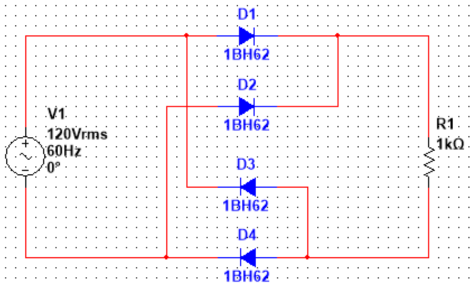


Figure 20 – Full Bridge Rectifier

Some parallel capacitors will be added to the output to the rectifier to give a stable DC, otherwise there would be noticeable drops in the supply. In some circuits this wouldn't matter but for a microcontroller it's important to have a stable DC input voltage. The rectified DC will be most likely 12-24 Volts depending on what our LCD display operating voltage is and that will be powered straight from there. Next will be dropping this voltage to 5 Volts to power out microcontroller, Raspberry Pi, and the various sensors and camera we will include. We have multiple options of doing this, one being a linear regulator, and another being a switching one. We're going to be using a buck converter or DC/DC converter that will step down the 12-24 volts to 5 volts for our other electronics. The reason we will be using a switching regular is because it is more efficient, and we want less wasted energy. It also produces less heat which means we can get away with not using a heat sink for the regulator.

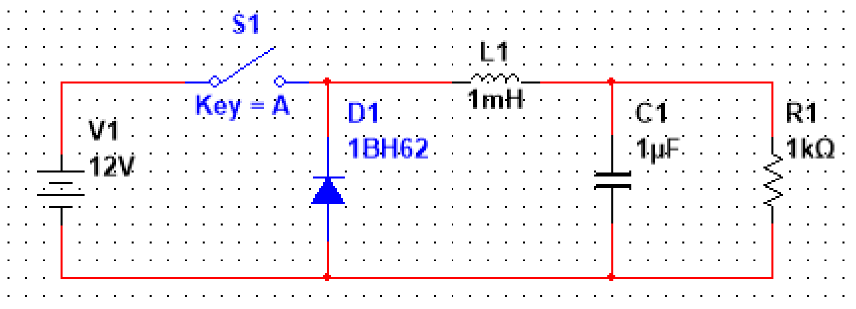


Figure 21 – Buck Converter Schematic

A buck converter typically consists of two semiconductors, a diode and a transistor which acts as the switch. Two timing components are also used such as a capacitor and inductor.

While these take care of the power regulation another aspect of our power design will be power MOSFETS that will switch on or off the power leading to the display and camera module. This will have to be incorporated either into our power supply or somewhere on the Microcontroller board. If we do decide to build our own power supply, that will increase cost as an extra PCB will be needed but the advantage is that it will most likely decrease size and allow us to have a smaller form factor in our final design as opposed to just throwing an off the shelf power supply onto the board. We could also go with the option of buying a 24 Volt AC to DC power supply off the shelf and then just doing all the DC regulation on our existing circuit board to minimize cost and that might be the best option for us at this time. This means we could simplify everything to one, cheaper, board and not worry about the AC step down and rectification.

Table 4 – Voltages required for various components in the project

Components	Required voltage
Gesture sensor APDS-9960	3.3v
Raspberry pi	5v
Atmega32u4	5v
IR Frame LEDs & photodiodes	3.3v

3.8.10 Wireless Technology

The wireless technology refers to the capability of remotely connecting other technologies to this project, as well as, the capability this project has to connect remotely to other technologies. In our case, we are using Bluetooth to have the user's smartphone to connect wirelessly to our product. This product is also having the capability to connect to the internet via WIFI technology.

The use of wireless technologies makes our smart mirror innovative and give it a sleek and neat design. It also increases the overall ease of access of the product, which is what we are aiming for. Having less wires like ethernet cables in the bathroom, which is where our product intended use area is, minimizes the chance of accidents to occur. Therefore, also tackling a safety concern while remaining innovative.

3.8.11 Bluetooth

One of these wireless technologies we plan to use in our project is Bluetooth. Bluetooth technology use short radio waves of mobile devices to create personal area networks (PANs) **(Gechlik, 2009)**. It was made as a wireless alternative to the RS232 data cables, making it more convenient and capable of connecting to several devices **(Gechlik, 2009)**. Simply put, this technology acts like a wire to connect two technologies together. We will repurpose this widely popular technology in use for our project to allow users to connect their smartphones wirelessly to the smart mirror. The connection would in turn access user specific data, making it convenient to check on things like their personal emails and social media.

In the case of our smart mirror project, the smart mirror would have the master role and the user's smartphones would have the slave role. The smartphone works like a key to accessing user data stored in the smart mirror. The different keys open different sets of data.

3.8.12 WIFI

WIFI is a networking technology, also using radio waves, that allow high-speed data transfer over a short distance. Its innovation allows local area networks (LANs) to operate without the use of cables **(Encyclopaedia Britannica, n.d.)**. The use of internet is probably the most popular thing amongst today's population. By integrating this wonderful technology into our smart mirror, it would increase the versatility of our project. The addition of this technology would allow users to check live weather conditions for the day before going outside. It would allow them to access their social media and emails, allowing the Bluetooth technology mentioned before to have a use in our project.

3.9 Components and Parts Selections

This section of the paper will explain the different parts and components that will be used in the project. It will explain the specs of each part or component and explains why that specific part or component will be used in the project.

3.9.1 Microcontroller Considerations

The microcontroller in our project has two roles. One of which is to monitor the device inputs such as the IR touch sensor and also gesture sensor and then relay that information to the Raspberry Pi. This also includes receiving commands from the Pi, such as to turn power to the camera on and off when it is needed.

The second use is to monitor activity in proximity to the mirror itself. This will be a power saving feature so that when nobody is using the mirror, it will cut off power to the display to save power. Neither of these is too intensive so a basic low power microcontroller will work for our needs.

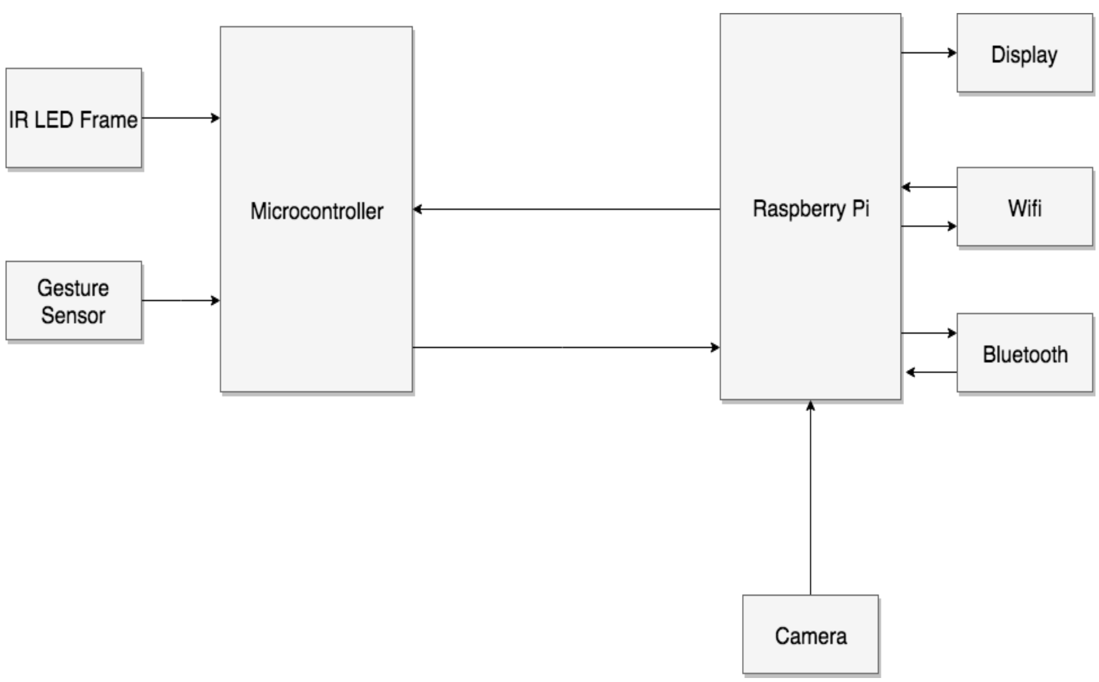


Figure 22 – Complete connections between microcontroller and microcomputer

3.9.2 Texas Instruments MSP430FG461x

The MSP430 microcontroller from Texas Instruments is the first microcontroller we considered based on our familiarity with it from previous classes and its low power modes of operation. The positive's to using the MSP430 are that it's programmed in C which is simple and familiar to the group as a whole. It also has a JTAG interface that allows debugging of the microcontroller at a closer level. The only negative I see to the MSP430 is that it doesn't have as many available libraries as some competitors do. Although its biggest advantage is the multiple low power modes it has built into the system. These would really be useful for our project since when the mirror isn't being used, we want it to be consuming very little power.

Table 5 – MSP430FG461x General Specifications, Source: (Texas Instruments)

Specification	**Value**
CPU Architecture	16-Bit RISC
Operating Voltage	1.8-3.6 Volts
Clock Speed	Multiple Oscillators allow the microcontroller to have different clock speeds ranging from a few KHz to 25MHz
Flash	92-120 KBytes
ROM	0-120 KBytes
RAM	4-8 KBytes
Communication	Enhanced UART, SPI, and I^2C
Inputs/Outputs	80

3.9.3 Atmel ATmega328

The second microcontroller considered is the ATmega328. It's an 8-Bit low power microcontroller that I would say is the most user-friendly option on the market. It also meets all the requirements our project needs for our current implementation. Considering our needs are simple, a powerful microcontroller really isn't needed.

The most important features for our project will be serial communication and low-power modes of operation. Since the microcontroller will just be reading sensors and communicating back to the main CPU, those needs are easily met. The only issue here might be the availability of I/O pins. Our IR touch sensor will have a large amount of output pins to be read by the microcontroller, but a multiplexor can easily solve this problem. We also must consider the MOSFET outputs needed for switching the power to the camera and display as discussed above.

The greatest advantage that the ATmega328 has over some of its competitors is huge community support and a plethora of libraries available online for Serial communication, LCDs, Wi-Fi and Bluetooth devices, various sensors, and many more. Installing the Arduino bootloader onto this microcontroller will even allow it to be programmed with the Arduino IDE. This will make our prototyping stage much easier and cheaper than any other option because we will be able to just use an Arduino Uno device and Raspberry Pi to prototype our system.

Table 6 – Atmega328P General Specifications, Source: (Atmel)

Specification	Value
CPU Architecture	8-Bit RISC
Operating Voltage	1.8-5.5 Volts
Clock Speed	8-20MHz @ 4.5-5.5 Volts
Flash	32KBytes
EEPROM	1KBytes
RAM	2KBytes
Communication	UART, SPI, and I^2C
Inputs/Outputs	23

3.9.4 Texas Instruments Tiva C Series

The Tiva C Series from Texas Instruments is a microcontroller based on the Arm-Cortex M4 architecture. These days ARM is a name we hear all too often so it's hard not to take a look at what they have to offer. ARM's architectures are used in everything from smart phones, tv's, laptops, and smart watches. I've seen them in almost every new piece of technology today, so they were heavily considered for use in our project. Early on in planning our project, the microcontroller was going to be the main processor and we were looking into running an operating system called RTOS on one for managing processes and possibly using an FPGA for driving the display. I've seen this done in other products before and it looked promising so that was the early idea. After more research though it looked like using OpenCV would be difficult on this microcontroller and so we decided on using a Raspberry Pi as the main processor and the microcontroller was dropped to just managing smaller systems in our project. So, with that change, using an Arm M4 based microcontroller was overkill in terms of what we wanted to accomplish with it.

Table 7 – Tivia C Series General Specifications, Source: (Texas Instruments)

Specification	Value
CPU Architecture	32-Bit RISC
Operating Voltage	1.5-5 Volts
Clock Speed	80 MHz
Flash	256KBytes
EEPROM	2KBytes
RAM	32Kbytes SRAM
Communication	UART, SPI, and I^2C
Inputs/Outputs	43

3.9.5 ATMega32u4

The ATMega32u4 is very similar to the ATMega328 in many ways but a few only apply to how we're using it in our project. The most important difference is the native USB 2.0 support. Another is that the 32u4 has a few more I/O ports which will be nice to have in case we end up making changes or additions that require more.

Table 8 – ATMega32u4 General Specifications, Source: (Atmel)

Specification	**Value**
CPU Architecture	8-Bit RISC
Operating Voltage	1.8-5.5 Volts
Clock Speed	8-20 MHz
Flash	32Kbytes
EEPROM	1Kbytes
RAM	2.5Kbytes
Communication	UART,SPI, and I^2C
Inputs/Outputs	26

So now we must compare these microcontrollers and choose one that fits our needs the most. The features that matter most to our project are Low Power, Arduino compatibility, I/O, and Max clock frequency, and USB Support. Some of these features matter less than others but they all have some effect on our design, if not small.

Table 9 – Important microcontroller features

Microcontroller	**Low Power**	**Arduino**	**I/O**	**USB**	**Max Clock**
MSP430	Yes	No	80	No	25 MHz
ATMega328	Yes	Yes	23	No	20MHz
ARM Cortex M4	Yes	Some	43	Yes	80MHz
ATMega32u4	Yes	Yes	26	Yes	20MHz

Our set of requirements are simple and so the features of each microcontroller boil down to these key factors:

- Low Power Consumption
- Arduino Compatibility
- I/O
- USB Support
- Max Clock Frequency

Low power consumption is important in our list because ideally the Microcontroller will be the only device consuming power when the mirror is off and that will be the bottleneck in our power consumption. Arduino compatibility is important to our project because it will simplify the coding process very much and open a world of libraries for use from sensors to Bluetooth modules. This will allow us to focus more on the system design and less on how to implement all the small details. I/O is the most important because we need enough inputs/outputs to interface with our various sensors and control electronics from multiplexers to MOSFETS. The last feature we are observing is the clock rate of the microcontroller. The clock rate will determine how fast our programs can execute and that can affect how quickly our operating system on the Raspberry Pi will be able to update the user interface. If the microcontroller clock is too low, our program will noticeably skip as it takes input because it's constantly waiting on updates. Our choice for microcontroller will be the Atmega32u4 for its many online resources, tutorials, and libraries available and native USB 2.0 support.

3.9.6 IR Light Sources

In order to embed our light sources into the frame of the smart mirror we have narrowed our options down to two different technologies: the LED and the LD. The reason we have chosen these two options as candidates for integration into our optical grid is due to their small size, low power draw, and most importantly, their availability in the desired wavelengths. In the following text we will discuss the merits of both technologies and the reasoning for choosing the LED over the LD.

3.9.7 Laser Diode

The laser diode (LD) holds one distinct advantage over the LED, that being its significantly narrower bandwidth. The narrower bandwidth of the laser diode, in theory, would make it much easier to calibrate the photodetectors and filter out unwanted noise and detect only the center frequency. Having the narrower bandwidth would in turn allow us to put more LDs next to each other. In turn, the touch sensor for the smart mirror would be more accurate, and it would also allow us to make the UI smaller.

The disadvantage of using a LD, however, is the alignment. One of the distinct differences, other than the bandwidth, of a laser and a LED is the rate at which the light from each source diffracts. Since a laser diffracts very little in comparison to a LED the alignment must be very accurate to ensure adequate contact between the light and the photodetector. In addition to this, we must ensure that, once aligned and assembled, we have secured both the photodetectors and the LDs well enough to prevent any misalignment occurring due to transportation.

Another large factor that turned us away from using LDs in our project is the heat aspect. Lasers tend to get very hot, so if we were to use it in our project, we may need to add in heatsinks to negate the heat. This would in turn, increase costs for the project and the addition of the heatsinks might still prove useless. Using normal LEDs would not only be cheaper, but it would also be safer from the lack of heat creation. In turn, we would only need to design the UI around the more widely spaced LEDs.

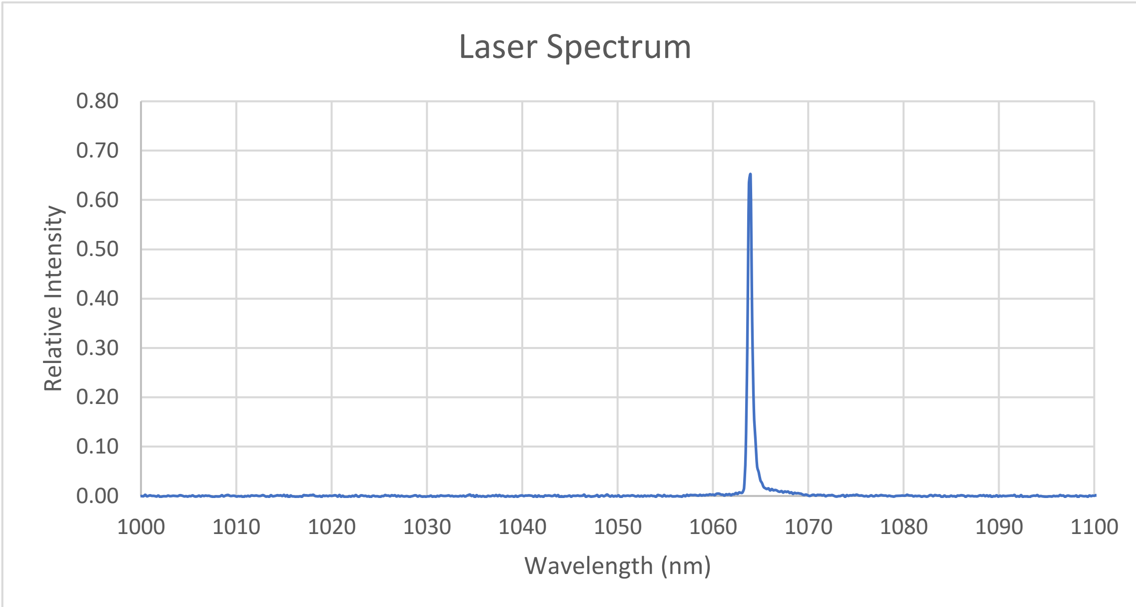


Figure 23 – Spectrum of a laser diode

3.9.8 Light Emitting Diode

While cross contamination and noise concerns may favor the LD, the LED offers a wider variety of packaging options which make it favorable. LED strips can be purchased allowing for simpler assembly. Additionally, due to the LED emitting light in a nearly omnidirectional manner, alignment becomes less of a concern. However, this results in another issue taking its place. Specifically, the highly diffracted light being emitted will result in excess noise on the adjacent detectors, which ideally would only be receiving light from the corresponding LED opposite of it. This is both the most significant advantage and disadvantage of using LEDs as our light source.

We have however, thought up of a fix to help stop the cross contamination. Ideally, we just have to tighten the spread of the IR rays of the LEDs and contain it so that it only shines in the direction that we require. In order to accomplish this, we have designed the frame in such a way that the LEDs will be embedded on the sides of the frames (see section 5.5). Doing so blocks the right and left side spread of the IR LEDs rays and what we have left would just be the top of the LED exposed. The top of the LED would then shine towards the photodiodes and creating the same effect as a laser diode. Doing this, we hope to create a straw-like effect, where it's just like an LED directly connected to a photodiode using an invisible straw in the middle.

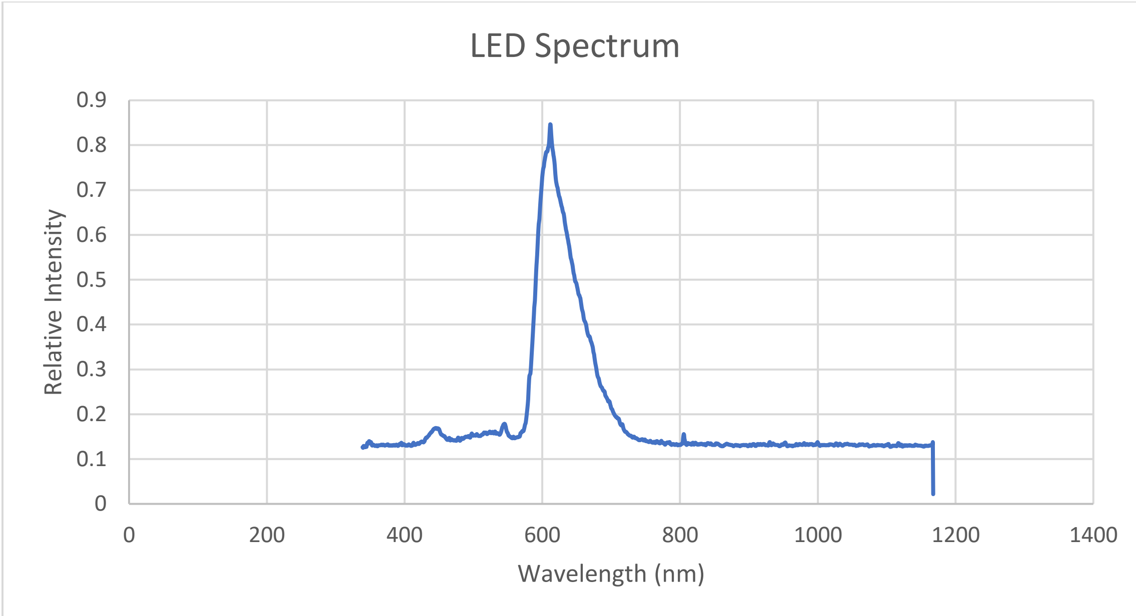


Figure 24 – Spectrum of a red LED

3.9.9 Noise

Since it is likely that the photodetectors will pick up a range of wavelengths around the specified frequency, greater care will be needed if using LEDs since their emitted spectrum is far greater than that of the laser.

The LD, due to the inherently low diffraction and narrow spectrum of a laser is unlikely to produce a significant amount of noise or cross contamination if implemented into the optical grid when compared to (Zumbahlen, 2012) (Laser Classes, n.d.) (Power Supply Safety Standards, Agencies, and Marks)the LED, thus noise would effectively be a non-issue.

A possible solution to the excess noise which would be Introduced when using LEDs as the light source would be to confine the photodetector with a straw as shown in the following figure.

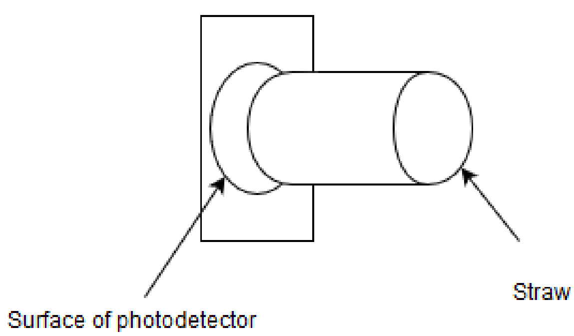


Figure 25 – Illustration of noise limiting straw

By placing a straw in front of the surface of the photodetector we can limit the detected light that comes at an angle. This, in theory, would reduce the amount of noise from adjacent LEDs and allow us to better calibrate and filter out noise for the optical grid.

An alternative solution to dealing with noise is by using LEDs of differing wavelengths and photodetectors that detect at the appropriate wavelengths. Two commonly available IR LEDs are those that emit 850 nm light and 940 nm light. By setting them up in an alternating pattern such as the one illustrated in the figure below, we can use photodetectors that specialize in detecting their corresponding wavelengths.

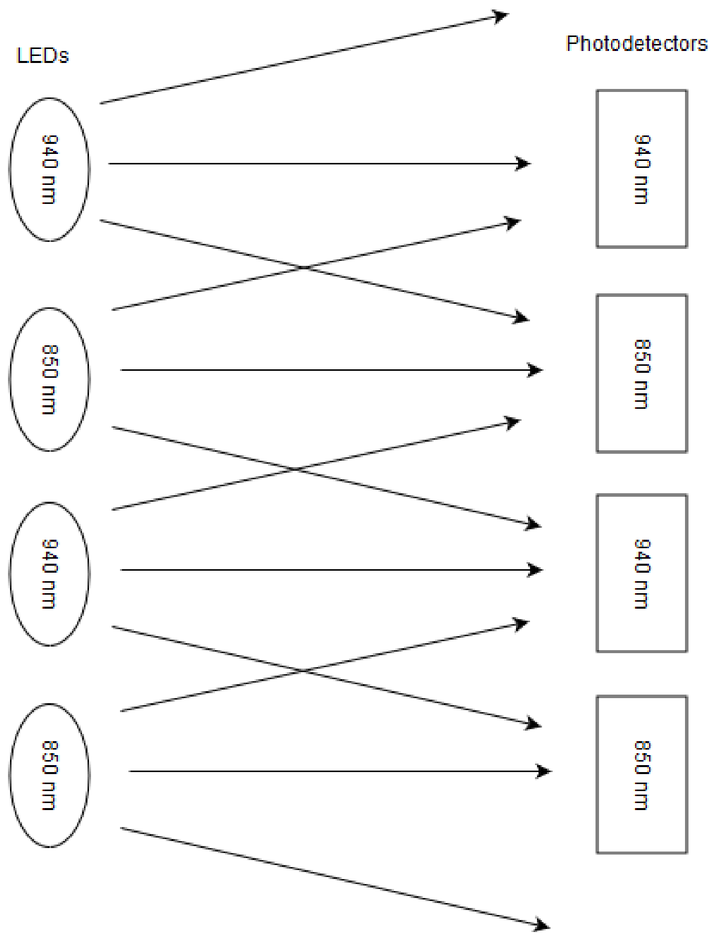


Figure 26 – Alternating pattern of LEDs and photodetectors

While this method will still result in cross contamination, it will not have a significant impact or increase in noise due to the different wavelengths being detected by the adjacent photodetectors. With regards to packaging this method will be the simplest to implement since no additional components are required other than the light sources and detectors, which are required regardless of the optical grids implementation methodology.

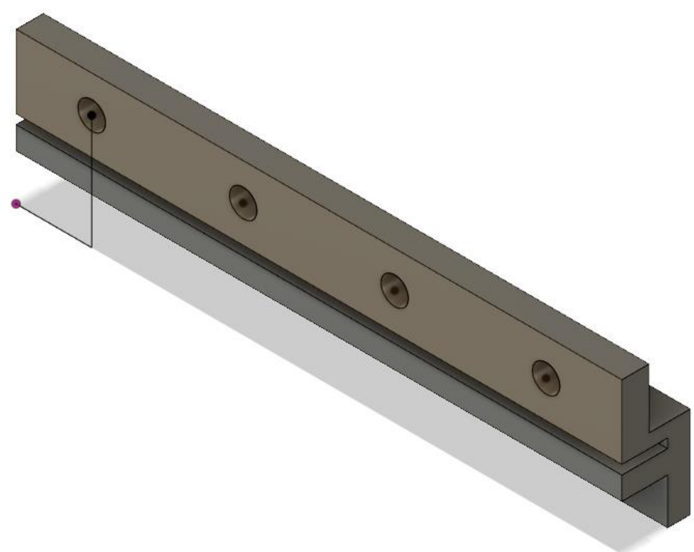


Figure 27 –3D model design to hold LEDs/Photodiodes and the mirror panel

While this method will reduce the amount of cross contamination from adjacent IR light sources, it will not completely eliminate them. The biggest factor in how effective this method is will be the resolution of the “touch” input. In order to increase the resolution of the input the number of detectors and light sources must increase. This results in the spacing between the IR light sources and photodetectors decreasing. By decreasing the space between adjacent components, we may end up with a situation such as the one illustrated in the previous figure where the spacing is close enough that a significant amount of light from LEDs emitting the same wavelength of light provide a significant amount of cross contamination.

Ultimately this method leads to a tradeoff, increased resolution in exchange for increased cross contamination between the light sources and detectors.

The final solution which can be used to prevent noise is by placing a lens in front of each of the photodiodes. In theory, by placing a lens in front of the photodiode

and ensuring that the photodiode is placed at the focal distance of the lens, adjacent LEDs will be unable to shine light onto the photodiode. This is due to the way light propagates and focuses through a lens. The LEDs will sit far enough away from the lenses that we can make a simple assumption, namely that the light from the LEDs is actually coming from an infinite distance away. What this assumption does is it allows us to assume that the light from the LED which is placed on the optical axis approaches the lens parallel to the optical axis. When this light is focused by the lens, the light will converge on the other side at the focal point, which is where the photodiode would be located.
As far as the adjacent LEDs are concerned. Since these LEDs would be offset from the optical axis, when they are focused by the lens they will be focused at a point offset from the optical axis. This means that the light from the adjacent LEDs will not make contact with the photodiode, thus drastically reducing the potential for cross contamination. This is illustrated in the following figures.

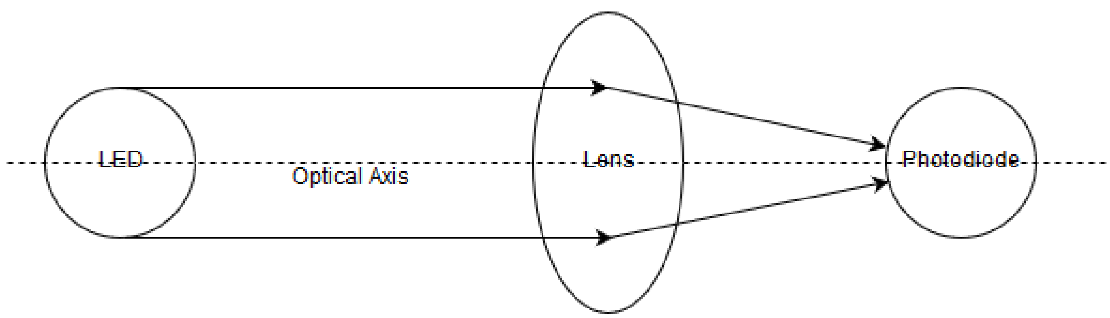


Figure 28 – Light focused from an LED on the optical axis

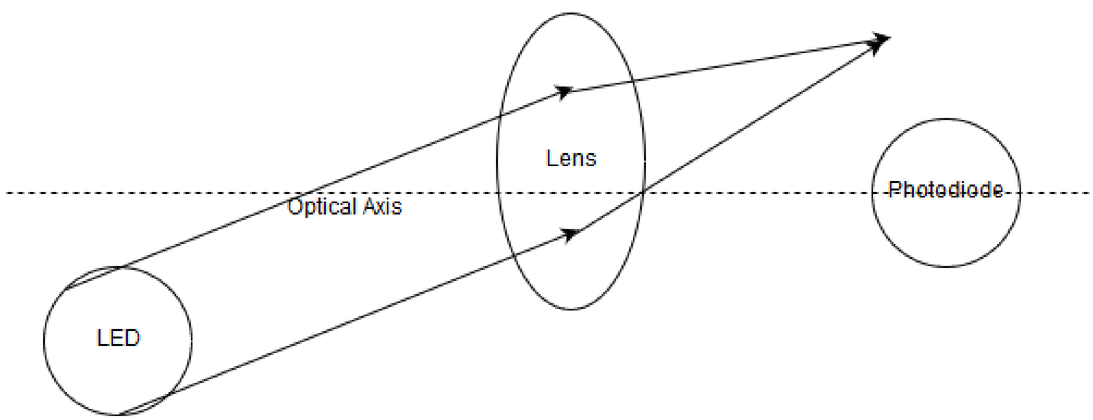


Figure 29 – Light focused from an LED offset from the optical axis

Ultimately, due to simplicity and economic constraints, we have decided to make use of the straw method. This method will adequately block the light shining from adjacent LEDs in addition to being simple to assemble from readily available components.

3.9.10 Choosing the LED

Ultimately, we decided to use 940 nm LEDs with photodetectors that are sensitive to that specific wavelength. Our reasoning for this is due to the LEDs we have decided to use have an emitting angle of 30 degrees. While this will still result in more noise than a laser diode, the excess noise on the adjacent photodiodes can largely be prevented by including straws as depicted in Figure 25 in front of the photodiodes, making the need for LEDs with two different center frequencies unnecessary.

Additionally, using LEDs instead of laser diodes allows for simpler assembly of the mirror frame. Since a laser diode requires some type of heatsink to prevent overheating and failure of the laser diodes. In contrast, an LED puts out minimal heat, allowing for more options on assembly.

The final reason for choosing LEDs instead of laser diodes is cost. Cheap laser diodes can commonly be found in packs of 10 for about the same price as a pack of 100 LEDs. By using LEDs we are able to reallocate funds to other parts of the project.

Table 10 – Comparison of the two IR emitter technologies

LED vs Laser Diode		
	Pros	**Cons**
LED	Low heat output and power draw	Requires straws to prevent cross contamination on photodiodes
	Cheap	Wide bandwidth
	Wide emitting angle allows for some misalignment	
Laser Diode	Narrow bandwidth	Hot, requires heatsink
	narrow emitting angle, no cross contamination	Expensive
		Requires near perfect alignment with photodiodes

3.9.11 Photodetectors

Through research we have studied various types of photodetectors and their typical applications. After coming to an understanding of which type of photodetector is best suited for interaction with a microcontroller, we have come to the conclusion that, between the photoresistor and photodiode, the photodiode best suits the requirements for the smart mirror.

3.9.12 Photoresistor

The photoresistor is a light-dependent variable resistor. The resistance decreases as the light shining on the photoresistor increases. A photoresistor is a passive component without a PN junction and is less sensitive to light then the other two options which will be discussed. While a photoresistor was considered for use in this project, it was decided that the alternatives provide a potentially better solution since they are active components. As a result of the photoresistor being a passive component without a PN junction the change in resistance is gradual, making it more difficult to digitize the resulting signal.

3.9.13 Photodiode

The photodiode is a device which converts light into current. Electrically it is connected to a circuit the same way a normal diode is, the difference is how it is turned on. A photodiode must be exposed to enough light in order to conduct current.
When discussing photodiodes, there are two operating modes that must be defined: photovoltaic mode and photoconductive mode.

When a photodiode is operating in zero bias, meaning no external voltage is applied to the diode, the flow of current is restricted, and voltage gradually builds up. This phenomenon is due to the photovoltaic effect and is thus called the photovoltaic mode.

The photoconductive mode is used when the photodiode is reverse biased. When in the photoconductive mode the amount of current is linearly proportional to the irradiance, which is defined as the amount of power per unit area provided by the incoming light. For the purposes of this project it is likely that we will use the photoconductive mode as it seems to be common to convert the resulting current into a voltage that can be digitized.

3.10 Possible Architectures and Related Diagrams

Given the allotted time that we have, we had to trim down this project to fit our timeline. However, should there be a change of pace that allows us to finish our project in an earlier time than projected, we would like to add certain things to this project to advance it even further. This collection of different components/architectures is called our stretch goals.

3.10.1 Power supply

Currently, we have decided to go along with any available power source that would fit the necessary constraints of our project. We are aiming for our smart mirror to be used in the bathroom to ease access for morning activities. Since most bathrooms only have sockets, the power supply we need to design needs to be an AC/DC power supply. Currently each component would require their own AC to DC converter, which are quite bulky, therefore requiring a power strip. Since our Smart Mirror is meant for use in the bathroom, it would pose a safety concern if a power strip is anywhere near the sink. However, should time allow, we have considered constructing our own power supply that would be custom fit to work with this project. The custom power supply would allow us to have less components having to use their own individual power supplies thus cluttering the socket area. We have considered the idea of adding a built-in battery in our smart mirror to combat this situation. However, since we are building this smart mirror with ease of access in mind, the fact that the users will have to charge the mirror when it runs out of battery seems slightly inconvenient. If the user also has the power continuously charging to combat this inconvenience, it would affect the battery life of the product. As for things like batteries, it would require the user to continuously remove and place the smart mirror back on the wall, which once again is inconvenient. Also, it would greatly increase the risk of the user of breaking the mirror and injuring themselves. With all these in mind, we have decided that a normal AC/DC power supply would be the best thing to use for our smart mirror.

There are two different types of power supplies, one is regulated and the other is unregulated. The regulated power supplies provide a constant voltage with a range of values for current, while the unregulated provides constant power with varying voltages and current **(Olson, 2015)**. With the regulated power supplies, multiple regulators can be used to offer multiple output voltages to operate different devices **(Olson, 2015)**. Voltage regulators are used to put the voltage source to a certain amount that is required by the device. There are two types of voltage regulators as well, there's the linear and the switching regulators. The common topologies used with these switching regulators are buck (step down), boost (step up) and buck boost (step up/ step down), it basically refers to what the regulators can do to the given input voltage **(Analog Devices, n.d.)**. The linear regulator on the other hand just keeps the output voltage at a constant rate based on the input put into it. Efficiency wise, the switching regulator is supposedly 90% efficient while the linear is only 50% **(Analog Devices, n.d.)**. In terms of cost, the unregulated power supplies are cheaper than the regulated power supply. For our purposes, we probably would want the regulated power supply because each of the different components that we have require different types of voltages. For the purposes of energy efficiency, we may use the switching regulator. However, due to higher cost ranges for the switching regulator we may have to use the linear regulator instead.

Table 11 – Linear vs Switching regulators, Source: (Renesas, n.d.)

	Linear	Switching
Efficiency	Low with high voltage difference between input and output and high between low voltage differences	High
Complexity	Low	High
Size	Larger at high power	Smaller at high power
Cost	Low	High
Ripple / Noise	Low	High due to high frequency

3.10.2 Compatibility with Voice Technology

During our divide and conquer paper discussion with the instructors, they suggested for us to make our projects to be able to work with existed voice technologies, such as, the Amazon Echo. From past senior design groups, the instructors have seen a trend of popularity amongst the judges to see senior design projects that are integrated to work with voice technology. The integration of our smart mirror with these voice technologies would require more than a simple Bluetooth connection. The voice technology device would have to have access to all the functions of the smart mirror for it to be able to use those functions. To do this, it would require for us to tweak the software in our smart mirror in such a way that would allow for this connection to occur. When done successfully, this would give us yet another method to access our smart mirror, thus furthering its ease of accessibility. This would also add depth to our project and thus would most likely greatly impress the senior design judges.

3.11 Parts Selections Summary

The following section of the paper will explain in detail the parts that are chosen for this smart mirror project. It will give explanation as to why those parts are chosen over the other parts. Important aspects, such as, price, functionality and other limitations will be included.

3.11.1 Voltage regulator selection

Based on the voltages required of each component from table 3, we need a 5v DC voltage regulator for the Atmel ATmega32u4 microcontroller and the Raspberry Pi 3 model B. There are two different choices to use for the voltage regulators, switching and linear. The Raspberry Pi is more demanding in terms of current, with the regulators it may be better to use a switching one to avoid overheating. However, some testing was to be done to see if the switching regulator was necessary. Based on that, the regulators we have chosen are, the LLM7805CV and the LM2598.

Table 12 – Comparison of 5 V voltage regulators

LM7805CV	**LM2598**
Linear regulator	Switching regulator
Input voltage: 35v max	Input voltage: 7 – 40v
Output voltage: 4.9 – 5.1v	Output voltage: 4.8 – 5.2v
Output current: 1.5A max	Output current: 1.2 – 2.4A
Price: $0.50	Price: $2.81

Due to the high output current of the switching regulator, we have decided to go with it. As mentioned before, the Raspberry pi requires a lot of current. The LEDs and the photodiodes will also be drawing current. Using the linear regulator will result in overheating even with the heatsink and thus will break the voltage regulator. Even though the pricing is more expensive, it is an essential component to power all the things in our project. Also, we do not require many regulators, so the pricing won't really affect our choosing of the best bang for the buck. For the 3.3v that are required from the same table 3, resistor(s) will be used to obtain this output voltage. Doing this will prevent the need to buy a linear/switching regulator for the 3.3v DC output and thus save us money. However, should the resistors fail to create us the desired voltage value, we will get the required 3.3v regulator.

3.11.2 Microcomputer selection

Initially, we have considered using the Raspberry Pi Compute Module 3 for our project. Simply, this compute module would plug in to our PCB, just like a DDR2 SODIMM RAM module to a laptop. This would involve difficult routing work and would take a lot of time to implement. The senior design class is too short to implement this to our project and would not really add any overall benefits as opposed to using a normal Raspberry pi 3 model B or the model B+.

Nevertheless, we have taken three different options for microcomputers that we liked and compared them to each other. We have looked up their design specifications to see whether or not the microcomputers would be useful for our project. The following table shows the different microcomputers that were considered including each of their individual specifications that were used to make the comparison.

Setting aside the price points, we would have used any of the three microcomputers if it would greatly benefit our project since the microcomputer is one of the largest and most important components that is required in our smart mirror project.

Table 13 – Comparison of the two Raspberry Pi microcomputers

	Raspberry Pi 3 model B	**Raspberry Pi Compute Module 3**	**Raspberry pi 3 model B+**
Processor	Quad-core Broadcom BCM2837 64-bit Speed: 1.2 GHz	Quad-core Broadcom BCM2837 64-bit Speed: 1.2 GHz	Broadcom BCM2837B0, Cortex-A53 (ARMv8) 64-bit SoC Speed: 1.4GHz
Memory	1 GB RAM	1GB RAM	1GB
Storage	MicroSD	4GB eMMC flash device	MicroSD
Network	100Mbps ethernet BCM43438 wireless LAN Bluetooth Low Energy (BLE)	100Mbps ethernet BCM43438 wireless LAN Bluetooth Low Energy (BLE)	300Mbps ethernet Gigabit Ethernet over USB2.0 2.4GHz and 5.4GHz IEEE 802.11.b/g/n/ac wireless LAN Bluetooth 4.2 (BLE)
GPIO pin	40	N/A	40
USB port	4x USB2.0	N/A	4x USB2.0
Power	300 – 600mA, 5v	300 – 600mA, 5v	2.5A, 5v
Power supply	MicroUSB, GPIO	powered by PCB	microUSB, GPIO
Price	$34.99	$30.00	$35.00
Software	Raspbian Occidentalis	Raspbian Occidentalis	Raspbian Occidentalis

Despite cheaper pricing, overall it does not hurt the project to use a Raspberry Pi 3 model B instead of the Compute Module 3. While using the Compute Module 3 would have given the project more sense of difficulty, it would also have taken more time to implement into the PCB. The Raspberry Pi 3 model B also has a larger storage capability than the Compute Module 3. Using the Raspberry Pi 3 model B allows us to use a Raspberry Pi hat to plug straight into the GPIO pins which would make our design more compact. Ideally, the Raspberry Pi hat in our case would be our PCB circuit design. Therefore, switching to the Raspberry Pi 3 model B would do the opposite of our initial idea of placing the Raspberry on our PCB using the DDR2 SODIMM slot input, now the PCB is placed on the Raspberry pi. Lastly, two of our members already own the Raspberry Pi 3 model B, so it would make the cost for this component technically free. The overall benefits of the Raspberry Pi 3 model B+ are relatively small compared to the regular model B to invest another $35 on it. The only things that really changed are a slightly faster processor and faster ethernet speeds. The processor speed at this point is not worth the money investment for a small change. As for the ethernet connection that all varies on the speed of the user's internet to begin with. Even if the user has 300Mbps internet download speed, the overall speed would not make much of a difference on our smart mirror project.

3.11.3 MicroSD card selection

The purpose of the MicroSD card in the Raspberry Pi would be of that of a hard drive in a computer. It stores the operating system and other important data that are required for the Raspberry Pi to operate properly. The Raspberry Pi 3 model B supports up to 64GB storage space. There are more aspects than just storage space to keep in mind when choosing the microSD card. The cards themselves have varying read and write speeds that could affect the project greatly. Just like SSD technology in computer hard drives, which are much faster than the HDD variant at loading various applications and the operating systems of computers. Ideally, we would want to have the largest storage device capable of being used in the Raspberry Pi 3 model B, while also being the fastest in the read/write speeds. The higher the storage space in the microSD does not just affect the project in terms of storing more applications and whatnot. It also promotes longevity of the microSD because wear leveling of the object would be spread out across more memory space. Essentially, having a storage space that is the bare minimum to fit the operating system and other essential files would mean that the read/write load would be spread on smaller memory which would degrade the device faster. Lastly, the Raspberry Pi requires a FAT32 format with the microSD cards. Even if the cards do not come in this required format, it can be reformatted using a simple process. With all this in mind, the microSD cards we have chosen are the SanDisk Ultra 64GB MicroSDXC, the SanDisk Ultra 16GB MicroSDHC and the Samsung EVO MicroSDXC 64GB.

Table 14 – Comparison of the different MicroSD cards

	SanDisk XC	**SanDisk HC**	**Samsung**
Storage space	64GB	16GB	64GB
Speed	Transfer: Up to 100MB/s	Transfer: Up to 98MB/s	Read: Up to 100MB/s Write: Up to 60MB/s
Price	$18.99	$7.82	$19.99

With every technological feature being pretty much similar, it just comes down to pricing and needed capacity. The 16GB variant from SanDisk may prove large enough for storing the required things for this project, as well as having a decent wear leveling. Since cost will be a large issue with this self-funded project, the SanDisk Ultra 16GB MicroSDHC is the obvious choice for now.

3.11.4 Gesture sensor selection

This component is one of the major components in our project that would affect accessibility of the smart mirror. Certain actions from the user will do certain things on the smart mirror. The first gesture sensor that comes to mind was the Xbox 360 Kinect. Since one of the group members had this item available it would have lowered costs for the project. The Kinect sensor is one the first sensors used for wireless gaming and promote user movement. The components included in the Kinect would allow us to harvest not just a simple gesture sensor but also a RGB camera used for facial recognition and a microphone if we chose to add voice recognition to the project. The other gesture sensor we reviewed was the APDS-9960 from Broadcom, as well as the ZX Distance Gesture Sensor. The following table compares the two components more clearly.

Table 15 – Comparison between the two gesture sensor components

	XBOX 360 Kinect	**Broadcom APDS-9960**	**ZX Distance Gesture Sensor**
Price	Free	$2.72	$24.95
Detection range	0.7 – 6m	100mm without customer calibration	Up to 12 inches
Motion	Presumably 360°	Up-down-right-left	Distance (Z-axis) and side to side (X-axis)
Communication	-	I^2C	UART / I^2C

Even though the Kinect would lower the costs of the project even more, the lack of knowledge with the hardware components would make it difficult to implement in the project. There was no telling whether it would require special software for it to work or if it would work all together. Also, the required motion for accessing the mirror should be simple. Comparing the ZX Distance Gesture Sensor against the Broadcom APDS-9960, they both use I^2C to communicate, which is what we had planned to use to connect to it. It mainly comes down to pricing, so it would overall be better to use the Broadcom APDS-9960 because it's cheaper.

3.11.5 Display selection

The display of the smart mirror needs to be large enough to fit all the necessary information, while also being cheap. Undoubtedly, the display of our smart mirror project will be the costliest item to get. Also, having high definition displays have become a norm for all technologies. Consumers tend to seek the best high definition display available for anything that involves a screen, such as, television or laptops. Also, ideally it would be better to use computer monitors than a television for our project because we are trying to get the most barebone components. By choosing a computer monitor, there are less components to remove to get just the monitor and the required input connections. Also, it would be cheaper because there are less components included. To reduce costs even further, two different monitors were made available for us to use on this project provided by group members. One of the monitors is an eMachines E17T4W and the other is a Dell E228WFP.

Table 16 – Comparison between the two available LCD displays

	eMachine E17T4W	**Dell E228WFP**
Price	Free	Free
Resolution	1280*720	1680*1050
Size	17”	22”
Connection	VGA	DVI, VGA
Input voltage	100 – 240vAC	100 – 240vAC

Keeping everything in mind, the clear choice was the Dell E228WFP because it has a larger screen size, which would mean we have more space for the UI. The Dell monitor is also a higher resolution than the eMachine monitor, which would mean the picture would be clearer.

3.11.6 Power supply selection

The power supply for the smart mirror will power the monitor, microcomputer, microcontroller, IR LEDs and the photodiodes. Based on our research into the monitor we have obtained the monitor will require 12V. The other components required voltages are listed on Table 3. Using the components made available to the group, from other unused personal electronic devices, we were able to salvage from an old portable DVD player a 12V AC/DC converter and a 20V AC/DC converter from an old laptop charger. Currently, we have decided on the 20V converter to power our project. To power the monitor, we would just have to add another voltage regulator to change it to the required value. However, as one of our stretch goals, we mentioned building a power supply of our own for this project, so this decision may be changed in the future.

3.11.7 Mirror selection

Ideally for this project, any surface that is relatively reflective would work great. Since we have decided on a display, the Dell E228WFP, which have the dimensions 24”x17”, we searched for a surface that would be ideal for the mirror aspect of the project. In our search, we found a two-way glass mirror 18”x24” with thickness of 0.25” on Amazon. There are both mirropane and mirroview selections from the same seller. Both of them do the same things, but the mirroview is slightly more reflective and blocks out more light than the mirropane. There was also an acrylic see through mirror available on Amazon of the same dimensions. The following table compares the three mirrors more clearly.

Table 17 – Comparison of Mirropane vs Mirroview two-way mirrors

	Mirropane	**Mirroview**	**Acryllic**
Reflectivity	16%	66%	-
Visible transmittance	11%	20%	30%
Price	$129.99	$159.99	$36.99

Ideally, we wanted to use an actual glass mirror for this project, however other than just the cost other potential factors turn us away from choosing either the mirropane or the mirroview two-way mirrors. It would be nerve-wrecking should the mirror break in transit for the actual demo of the project and it would also weigh down the project. Most mirrors are wall mounted, the extra weight could affect whether it stays on the wall. The biggest thing that definitely turned us away from the mirrors are definitely the pricing, as mentioned exhaustively, the project is self-funded. The pricing of both mirrors go well beyond the allocated budget we first allocated for this project.

4 Related Standards and Realistic Design Constraints

The following section will explain in detail the standards and constraints that corresponds to this project. For the sake of marketability, standards need to be used. Standards are also important to use for our project to be comparable with other products out in the world. Also, the various constraints show the limiting factors that greatly affects this project.

4.1 Constraints

One of the most challenging things is coming up with and clearly defining an innovative software system within the scope of the requirements for the project. Design the system only one part of the entire equation; the other part of it is being able to develop the idea and getting it to presentation as quickly as possible while at the same time ensuring the quality level of the system will create a viable end product that meets or exceeds both personal and formal expectations. There are many constraints that will be mentioned in the following sections that contribute to wasted time and physical work that can extend project deliverable timelines which essentially tends to cause a halt in the design-to-production phase of the project.

When development groups don't have the appropriate access to dynamic dataset or other assets, sometimes it is not entirely possible to test for redundancy or system flaws as efficiently and comprehensively as is necessary for us to make sure that systems performance will not result in an overall reduction of quality in the product. We want to ensure that our system is not of low-quality when it makes it to 'market'. Having to contend for particular constraints can produce inefficiencies in the development process that can lead to both intended and unintended costs for our development group. An example of this is, deciding to contend for things security which cause programmers to use high-value time to create low priority code; for the sake of this project, that has an actually human temporal cost which increases the time it to complete deliverable. We also have contend with known and future unknown external things that can impact the development of the project that will need to have a contingency plan put in place.

In order to make sure that our system will perform up to our expectation in regard standards in implementation, we will definitely have to test our system with data that is as close to and actual information or live conditions as possible and has the range to cover all intended use cases. If we don't have easy access to the necessary input data, we will have to manually develop full production sample data sets, which will of course add extra costs in regard to time spent on peripheral parts of the project.

There is sometimes a confusion amongst development teams because some tend to believe that all testing processes are automated, but that not necessarily the case. Only when the system itself is being test itself does the process happen automatically. Before getting to that step, there still needs to be scripts that are developed manually codes written to maintain the automation. Another thing to take into consideration is that most of these test properties can rarely be utilized through each test stage.

Once we begin the testing phase and we find that there are defects in our system, our software team has to try to identify the root cause of the issue before we can actually fix it. In a complex development environment, considering all of the constraint, this is usually a lot easier said than done. This can be made especially difficult if there is a lack of communication in the end-to-end transaction path.

Infrared touch screens do not have an overlay of an additional screen on top of the LCD panel. IR displays actually use infrared emitters and receivers that produce an invisible grid of light beams that project across a given surface. These beams are projected in both horizontal and vertical directions in order to create an ‘x’ and “y” axis. This guarantees that the image quality will be the best possible since there isn’t an overlying screen on top of the LCD display itself. Whenever an object disturbs the path of one or more of the invisible IR light beams, the sensors can locate the touch point.

Infrared displays will always require the use of a bezel due to the way the system itself works. There is no possibility of completely utilizing edge-to-edge screens in conjunction with an infrared display. When using infrared touchscreen technology, there is always a possibility of having false ‘ghost’ triggered commands. If a foreign object comes into contact with the interface, it will block the light beam the same way a finger would. Much like your finger, the foreign object will also activate the interrupt command.

The best display for use with a sensor is one that can display all of the graphical information that is being projected that the image sensor has captured and does not exceed those capabilities. Most of the properties of that display then will simply have the same characteristics as that of the sensor.

Infrared devices do have some degree of sensitivity to water and moisture. Even small traces of condensation can interfere with its operation. With that being said, infrared offers a viable alternative to other types of touchscreen technology on the market.

Because infrared technology uses light emissions for detection, the detection software can be affected by strong light sources such as industrial light or direct sunlight. The over resolution of fundamental infrared technology is not as good as some other forms of technology. Which is why it is usually no considered suitable for applications that may require inputs to be precise.

Generally speaking it often considered that infrared technology is challenging when being applied to panels that are smaller in size. As of late, there have been infrared touch screens developed for small sizes. There also is usually a space requirement with infrared technology which is why the devices tend to be larger. Infrared technology will detect any object that blocks light emission. Which can cause it to incorrectly detect insects or dusts.

The smart mirror will include various hardware and software constraints which must be accounted for during the design and manufacturing processes.

4.1.1 Economic Constraints

The biggest issue that we currently have with this project is the fact that it is self-funded. This means that this project will require low cost parts that may not function as good as a higher cost component. One example being the overall size of the Smart Mirror. The larger design requires not just a larger two-way mirror but also a larger monitor to take advantage of the newly acquired surface area. Additionally, while a larger mirror may be desirable for some individuals, it does not add any additional complexity to the electronics or software of this project. By first creating the smart mirror in a smaller, more manageable size we are able to reduce cost on the non-electronic components and the LCD display which will be used in the smart mirror. Due to the design of the mirror and the methods with which the user interacts with it, increasing the size should be as simple as purchasing a larger two-way mirror and frame and making the appropriate changes toward the spacing of the LEDs and photodiodes.

Another example would be the overall design of the Smart Mirror. Since it would be expensive to have a custom-made housing for this project it would mean that we would have to hand make the casing ourselves. While this won’t necessarily affect function, it will affect the overall aesthetics of the project.

4.1.2 Time Constraints

The time limit for this project is the combination of the summer semester and the fall semester. The sum of these semesters span roughly 6 months, the first two months of which are allocated to brainstorming and writing documentation for the project. This is all done in Senior Design 1, however towards the end of Senior Design 1 we will have the components ordered and tested as well as the initial overall design of the project completed.

The second phase of this project which occurs in Senior Design 2 consists of the building, testing, and validating of the design. During this phase we will have the initial design of the custom PCB manufactured and tested while the entire project begins to come together into a physical product. As we continue throughout the testing and validation process it is possible that we will come across potential bugs and constraints that were previously unknown, which can result in the design of the custom PCB changing.

4.1.3 Environmental and Social Constraints

As far as environmental constraints go this project should not be affected by changes in the environment. Nor will it drastically cause change in the environment. In terms of social constraints, there is the concern that with the fact that the Smart Mirror can connect to the internet, other users may be able to access personal data from another user for harmful means. However, with the way that the design of our Smart Mirror works, is that it will only allow that specific user to access his or her own data.

While the mirror will not affect the environment around it, depending on where someone decides to place the mirror, the environment can affect the mirror. For instance, if the mirror were to be placed in a humid environment such as a bathroom that contains a shower, excess moisture can cause potential problems for the circuitry. In order to deal with the potential humidity, we can adhere to the Ingress Protection (IP) rating standards. These are international standards that are used in rating various electronic product’s protection against foreign particles, such as water droplets. A common IP rating currently used to protect smart phones from water intrusion is the IP68 rating. The IP ratings will be discussed in greater detail in section 4.6.5 of this document.

As previously mentioned, the social constraints are also something which must be considered. Providing adequate security for the user’s information as well as reassuring the user that the mirror does not infringe on their privacy is something which must be done. The physical component relating to the privacy of the user will be discussed in section 5.5 of this document.

4.1.4 Testing Constraints

Due to the nature of a smart mirror the testing constraints are limited only by the feedback the team can receive from other users. Since the smart mirror will be rather compact and accessible for use by any person approved by the team members for feedback, there should be no issue testing all the features implemented into the device.

4.1.5 Ethical Constraints

As of right now, we are still deciding if our Smart Mirror should have a camera for the use of facial recognition. Depending on placement, such as the bathroom as our Smart Mirror is intended for, it would develop into a fairly serious issue if the mirror was somehow hacked into and another person is able to monitor the user activities. It would pose an issue in general regardless of placement, if another person is able to observe the daily activities of the user. Such is the reason why people have been covering their laptop cameras with tape. We may come up with a way to combat this by simply designing an LED to go on to show that the camera is being used, as suggested by our instructor. We could also come up with a simple cover for the camera, when not in use by the user. This would make sure that the camera does not pick up any user activities regardless of if the malicious hacker can access the camera in the first place.

Any webcam that is connected to an individual's electronic device whether it's a personal or business device, makes it entirely possible for a competent hacker to gain control of and use the webcam to spy on its user. Whether the hacker is collecting information solely for entertainment purposes or whether gathering data industrial purposes, it definitely creates a privacy concern at the bare minimum. If a system still requires a webcam or some sort of live capture device, it is important to make sure the electronic device is as secure as possible and consider using a live capture device that use a light indicator that lets user know when the device is active. For our project unplugging the live capture device while not in use is not possible so is important to ensure that the device cannot be used maliciously when not actively in use.

There are some malware and viruses that are capable of activating a device webcam remotely without the user realizing it. This can be potentially dangerous and have damaging consequences which is why it is important that device is being used within spec to at least prevent extra security breaches.

There are also technologies that exist that can capture ultrasonic sounds because which has become quite frequent. Certain applications are created with the ability to track high-frequency sounds. There certain sounds that we as humans cannot perceive, but there are certain receivers that can. That being said electronic device can be used to spy on you their user and collect sound waves that are not perceptible to them.

The issue in regard to ultrasonic sounds is becoming extremely important to note because marketers can collect and use that information, they collect to create specifically targeted advertisements for the user of a device. They application look for specific signal, what some would consider to be insignificant auditory clues that can suggest where an individual may like to shop and what they like to buy. Marketers can then pair cookies to track an individual behavior across their devices.

There are already hundreds of applications that implement some form of ultrasonic sounds to track the behavior of the user. These behaviors can include actual location and media viewing habits of the user.

The concern in regard to this issue is so prevalent that Google announced that any application that uses any form ultrasonic tracking would either be banned or suspended. Developers will have to go through a process to prove they are operating within the guidelines of Google Play Store's updated privacy policies. The new policies require developers to inform user that an application makes use of ultrasonic features and requires the user's permission before accessing the devices microphone.

When granting software systems or application access to their cameras and microphones, there are a multitude of things that can happen.

- Some devices can record you at any time once the app is running in the background.
- Take pictures/videos of an individual without informing them.
- Upload the pictures/videos to the internet and social platform without informing the user.
- Upload any pictures/videos taken immediately.
- Use real-time facial recognition software to detect or recreate facial features.
- Initiate a livestream through the use of the camera without the consent of the user.
- Determine whether the user is using their device by themselves or using in a group.
- Capture random frames from a video stream via a streaming service and use an advanced facial recognition software to locate existing photos of a user on the internet and create a 3D model of the user based on captured facial features.

Because the device is connected to external networks is possible for hackers to gain access to the device with any relative efforts via applications, files, and messages online video services. By exploiting the systems to open a listener (rootkit) on the user’s device files and internal directive on a system can be altered. Hackers can alter the files with the program and then send the user of the device malicious files, which when opened, grants the hacker complete control over the user’s device remotely.

Once the user opens the file, the hacker can:

- Install any software/app they would like to run on the device.
- Use keyloggers to collect all of the user’s passwords.
- Steal the user’s documents from the device.
- Take pictures of the users or stream videos from the devices camera.
- Copy already recorded or live audio from the devices microphone.
- Collect incriminating images/documents from the user’s device

It might be also be possible to track the location of an individual. This is already possible with basic surveillance cameras located in shops and on streets that track passerby’s. This level of access allows individuals to search for cameras by their location within a specific, time zone and device manufacturer.

4.1.6 Safety Constraints

There are two stages to analyze whether a steam can damage your electronics. The first being, is it possible for the steam pass through the external package and reach the electronics? The second being, if does in fact reach the electronics, can it cause damage? It is entirely possible for shower steam to easily damage electronics, especially by oxidizing the delicate wiring inside the device. This can cause issues with communication between the Infrared frame and the LCD display which can get covered with excessive water vapor until it just stops working. The best thing to do when using electronics in a high humidity location like a bathroom is to design an enclosure to and use components that will allow for waterproofing of the electronics.

Especially with system that employ some type of touch input such as our smart mirror, you want very careful with ensuring that device is designed for use general use in the bathroom. This generality tends to apply more to older devices than newer ones, but taking that caution is still necessary part of design and implementation. If you know that your device has exposed internal components, then absolutely do not use them in the bathroom, as the internal electronics will get wet and distort the functionality of the device.

Another thing to do is look at ways beyond the physical design that we could use to prevent damage to IR frame and other internal electronic components inside the device. One way is to seal is the components and any exposed places with electrical foam design specifically to protect electrical components from environmental elements such as steam or condensation from taking a shower. This may help cut down on damage and keep our IR frame and other electronics functioning within spec.

That being said, this is not a complete guarantee. Another thing that needs to be taken into consideration about steam is that it is usually hotter than the actual temperature of the water itself. This can contribute in causing damage to the device by heating up the internal components of the device and then the water vapor condenses as it cools, causing further water damage. The issue with steam is that it is twofold as it is an invisible vapor, so you aren’t entirely sure what the spread of the stream is. Showery steam is when the steam begins to condense into water vapor.

Generally speaking using electronics while in the shower is usually not considered to be a good idea. Even the electrical foam method isn’t a complete guarantee that your electronic devices and their internal components will be safe from the steam that is produced by your shower, as the enclosure can still cause the temperature to rise inside the device and heat up which can possibly damage the internal components. The best thing to do create specially designed units that consider the overall humidity and temperature of the bathroom.

Remember, steam is not visible, the vapors that can be seen are not the only things that can cause damage to the system. Making sure the system employs some measure of Wireless and/or Bluetooth wireless communication when using peripherals such as phones or external speakers are a must to ensure safety as they are usually waterproof and designed to take the steam from your shower and the humidity levels of the bathroom.

As mentioned before, our Smart Mirror is intended to replace the bathroom mirror so that the user may be productive while getting ready to tackle the day. With this intention in mind, there is a concern that should any parts of the hardware come to contact with water that it would raise some safety issues. However, we will design our Smart Mirror in such a way that it should cause no issue when it encounters water/steam.

4.1.7 Manufacturing Constraints

As mentioned previously the smart mirror will be built by hand. This limits our options for the construction of the smart mirror since the materials must be limited to something that can be assembled without any specialized machinery. For example, the frame of the mirror is likely to be made of wood since it is a relatively simple material to work with and soft enough that it can be cut and modified with simple hand tools. Wood also carries the added benefit of being economical in addition to being readily available from local stores such as Home Depot. In order to protect the wood from excess moisture and to aid in the presentation of the smart mirror, we will apply a sealant, which is typically polyurethane, varnish, or lacquer, to the wood. This will give the wood a unique aesthetic as well as prevent moisture from damaging the wood over time.

For the smaller and more intricate parts of the smart mirror, we will have access to a 3D printer. Using the manufacturing capabilities of the 3D printer will allow us to create inserts in the frame to hold the various electronic components, such as the LEDs and photodiodes in place. This will expedite the assembly process because the precision of the 3D printer will ensure that the spacing between the components allows for adequate alignment.

4.2 Related Standards

The standards of a project are what makes the item marketable. There are certain standards that are widely used around the country/world for certain specific things. The following of these given standards ensures product safety and compatibility and it also keeps things consistent with other technologies that abide by those standards. Therefore, as engineers, it is important that those standards are followed, not just for marketability, but in generality.

4.2.1 Lead Solder Safety

Solder is the metal used to make solid electrical connections between components and the pads on a PCB. It comes in many different forms and varieties but an issue that has come up lately is the safety of it including Lead. Lead is a soft metal with a low melting point and that's why it has been used in Solder for so many decades. The issue with lead of course is the dangerous effects it can have on people.

The dangers of lead these days are well known and that's why it is used less now, and many lead-free solder options are available. The largest disadvantage here is that lead-free solder is typically harder to work with because it has a higher melting point than the lead equivalent. Lead can be especially dangerous when hand soldering because the fumes from the solder is hard to avoid breathing unless you have a fan or vacuum that can displace it.

Because of these obvious dangerous we will be working with Lead-Free solder since its overall safer and not terrible to work with for the most part.

4.2.2 Laser Safety Standards

Since lasers were considered for use in this project, it is vital to know the various precautions one must take when handling them. When dealing with lasers care must be taken depending on the classification of the laser. When classifying a laser, the maximum permissible exposure (MPE), which is the highest power or energy density of the light source considered safe. This is measured at the cornea or at the skin for a given wavelength and the length of time exposed. The classifications are as follows:

- **Class 1:** A class 1 laser is eye safe. This is due to the maximum permissible exposure cannot be exceeded when viewing the laser with the naked eye or magnifying optics.
- **Class 1M**: This is a laser that is eye safe except for when viewing through magnifying optics.
- **Class 2**: A class 2 laser is considered safe due to what is known as the blink reflex, which is when one averts their eyes due to bright lights. The blink reflex typically limits exposure to no more than a 0.25 seconds and only applies to 400-700 nm lasers. These lasers are limited to a continuous power output of 1 mW. If the emission time is less than 0.25 seconds or the emitted light is spatially incoherent then the 1 mW power threshold may be exceeded. If one suppresses the urge to blink than this can result in eye injury.

- **Class 2M**: A class 2M laser is similar to a class 2 laser except it cannot be viewed through optical instruments without high risk of eye damage.
- **Class 3R**: A class 3R laser is only considered safe when handled with care and limited viewing. The MPE can be exceeded, however, with little risk of injury. Lasers in the visible spectrum classified as 3R are limited to 5 mW of continuous emission. Wavelengths outside of the visible spectrum and non-continuous outputs have other power limitations applying to them.
- **Class 3B**: Class 3B lasers are considered hazardous of directly exposed to the human eye but can be safely viewed from diffused reflections from matte surfaces. The acceptable emission limits (AEL) for a continuous laser between the wavelengths of 315 nm to far infrared is 0.5 W. If the laser is not continuous in the visible spectrum the limit is 30 mW. Protective eyewear is required when there is a possibility of direct viewing of these lasers. Additionally, these lasers must have a key switch in addition to a safety interlock.
- **Class 4**: This is the highest class of laser and the most dangerous. A class 4 laser can burn the skin or cause permanent eye damage from direct or indirect viewing of the beam. Additionally, it is possible for a class 4 laser to ignite combustible materials. This may occur from direct or indirect reflections of the laser beam.

(Laser Classes, n.d.)

4.2.3 Power Supply Standards

The safety standards for the power supply are something which must be considered for any electronic device, especially for electronic devices which plug into a wall outlet. These standards affect every component in the system, whether it be in the form of insulation or the components used. The classifications for the circuits will be defined in the table below.

Table 18 – Circuit classifications, Source: (Power Supply Safety Standards, Agencies, and Marks)

Circuit Definitions	
Hazardous Voltage	Any voltage which exceeds 42.2 Vac peak or 60 Vdc without a limited current circuit.
Extra-Low Voltage (ELV)	A voltage in a secondary circuit which does not exceed 42.4 Vac peak or 60 Vdc, the circuit has at least basic insulation separating it from hazardous voltage.
Safety Extra-Low Voltage (SELV) Circuit	A secondary circuit which cannot reach a hazardous voltage between any two accessible parts or an accessible part and protective earth under normal operating conditions or when experiencing a single fault. A SELV circuit will not exceed 42.4 Vac peak or 60 Vdc for a duration longer than 200 ms under

	fault conditions. Under no conditions can the limits of 71 Vac or 120 Vdc be exceeded. a SELV circuit must be separated from hazardous voltages by at least two levels of protection.
Limited Current Circuits	Limited current circuits may be accessible even if voltages are greater than those specified in the SELV requirements. Limited current circuits are designed such that, when experiencing a fault, the current which can be drawn is not hazardous. The limits are: For AC frequencies < 1 kHz the steady state current drawn will not exceed 0.7 mA peak or 2 mA dc. For frequencies > 1 kHz the limit can be calculated by multiplying the limit of 0.7 mA by the frequency in kHz but cannot exceed 70 mA. Parts which are accessible not exceeding 450 Vac peak or 450 Vdc a maximum circuit capacitance of 0.1 µF cannot be exceeded. Parts which are accessible not exceeding 1500 Vac peak or 1500 Vdc cannot exceed a stored charge of 45 µC or have available energy exceeding 350 mJ. The same segregation rules specified for SELV circuits must be met as well.

The smart mirror will fall under the Safety Extra-Low Voltage (SELV) circuit type. Since we will be using a laptop power supply which can supply a maximum voltage of 12 Vdc. The electronics used will not have an operating voltage above 5Vdc, thus the circuitry in the smart mirror itself cannot exceed the limitations specified for a SELV. Additionally, since a laptop power supply will be used, the insulation between mains voltage and the circuitry for our smart mirror will already be taken care of.

4.2.4 IPC PCB Standards

IPC, which is the Association Connecting Electronics Industries, is a trade association which aims to standardize both the assembly and production requirements of electronics. IPC is responsible for many of the standards that commercial PCBs must meet in order to maintain both their reliability and longevity. The IPC standards range from general documentation, design and material specifications, performance, and inspection documentation. The ones that pertain to this project include:

- IPC-2220: PCB design in CAD standard.
- IPC-2221: Generic standard on printed board design.
- IPC-2222: Sectional design standard for rigid organic printed boards.

These standards will be adhered to because they ensure that the final result works as intended. By implementing IPC standards throughout the design and manufacturing process of the PCB we can guarantee better performance and a longer lifespan for the project. Additionally, by following well established standards that are common among many PCB manufacturing companies, we can ensure that there is no confusion when communicating our requirements and reduce the risk of miscommunication between all parties involved.

4.2.5 IEEE 802.11

The 802.11 is the standard for wireless local area network (WLAN) communication. Its comprised of both sets of media access control (MAC) and physical layer specifications (PHY). This standard is created and maintained by the Institute of Electrical and Electronics Engineers (IEEE). This wireless communication allows for electronic devices to connect to the internet without the need for an ethernet cable connection. Every subsequent improvement on this wireless communication technology is still tied to the same standard number 802.11, with variations of different letters in the end. This wireless communication technology is now known widely as WIFI. When speaking about WIFI, one of the most important aspects for comparison is speed. In today's busy world, everyone is always dependent on speed to get things done fast and to be able to accomplish more in a day's work. When referring to internet speed, usually Megabytes-per-second (MBps) or Megabits-per-second (Mbps) is used. Also, the most important aspect for the speed of WIFI usually refers to the download speed or data stream rate. Another somewhat important aspect is the modulation. Just like how we have AM and FM radio stations that pick up different signals, there are different signals that WIFI can put out for devices. This does not really affect the current 802.11 model, just the past a and b variants.

Table 19 – Comparison of various 802.11 variations, Source: (Wikipedia, n.d.)

Various 802.11 types	Data Stream Rate (Mbits/s)	Modulation
802.11 (June 1997)	1, 2	
802.11a (September 1999)	6, 9, 12, 18, 24, 36, 48, 54	DSSS, FHSS
802.11b (September 1999)	1, 2, 5.5, 11	OFDM
802.11g (June 2003)	6, 9, 12, 18, 24, 36, 48, 54	DSSS
802.11n (October 2009)	(20MHz bandwidth): up to 288.8 (40MHz bandwidth): up to 600	OFDM
802.11ac (December 2013)	(20MHz bandwidth): up to 346.8 (40MHz bandwidth): up to 800 (80MHz bandwidth): up to 1733.2 (160MHz bandwidth): up to 3466.8	MIMO-OFDM

For the purposes of our project, we will be implementing WIFI to our smart mirror by using the Raspberry Pi on-board wireless LAN. The Raspberry Pi 3 model B has a BCM43438 Wireless LAN on board. This is a part that has a combination of WIFI, Bluetooth and an FM receiver together. The WIFI portion is a 2.4 GHz 802.11b/g/n with a 20MHz bandwidth. This component that we are to use with our project in in compliance with the 802.11 wireless communication standard.

4.2.6 Bluetooth Standard

The start of what would later become known as Bluetooth was initiated by a man named, Nils Rydbeck, in 1989 at Ericsson Mobile. The purpose was for wireless headsets which we still see used today. The specification is based on a frequency-hopping spread spectrum technology.

Implementation

Bluetooth operates between 2400 and 2483.5 MHz including guard bands that are 2MHz wide at the bottom and 3.5 MHz at the top of the spectrum. Bluetooth devices transmits the data as packets and sends it over one of the 79 designated Bluetooth channels, with each channel having a bandwidth of 1 MHz and it typically jumps frequencies at 800 jumps per second with Adaptive Frequency Hopping enabled. Much like other communication protocols, Bluetooth also uses a master/slave architecture. A master can communicate with a maximum of seven devices at once. Devices can even swap roles with a slave becoming a master and a master becoming a slave.

Uses for Bluetooth

Bluetooth is used in applications where low power and short-range communication is a consideration. Bluetooth devices are typically used in mobile devices to connect them to peripherals such speakers, watches, cars, and more. Bluetooth devices are separated into different classes that defines power and range as follows:

Table 20 – The different Bluetooth classes and features

Class	Power(mW)	Typical Range (meters)
1	100	100
2	2.5	10
3	1	1
4	0.5	0.5

Most Bluetooth devices used are battery powered class 2 devices. The power consumption and range are determined by the higher-class device. So, a class 3 device connected to a class 1 will have a typical range of 1 meter and power consumption of around 1 mW. Many different specifications of the Bluetooth standard exist ranging from the first one being Bluetooth 1.0 to the most current release of Bluetooth 5.0.

Why Bluetooth?

In our project, we are using Bluetooth because it's the best way for connecting to a phone to send and receive data. Doing this requires a phone app to be written for communication to take place though. We will need an app that can only do simple requests such as sending calendar events, local weather, messages, and emails. Some of these things can be done by the Wi-Fi connection on the raspberry pi but others will be more difficult. The smart mirror is meant to be simple and doing email on it through Wi-Fi would require signing into an account and that is cumbersome. With a connection to the phone the process will be made simple since, ideally, you're already signed into your email account on the phone and those notifications can be sent and read on the mirror.

We're also using Bluetooth because it will allow us to have a section in the app just for settings that will allow customization on the mirror that might be difficult to implement in its own user interface. So, a range of settings could be changed on the fly just using the included phone app without the hassle of navigating the mirror. Ideally the mirror will only be used for getting information and not inputting anything that might be too tedious. This will lower the overhead on the mirror software itself and make the interface as simple as possible.

4.2.7 IP65

IP ratings stands for Ingress Protection ratings, which are defined in international standards. This rating specifies the protection of a product against outside intrusion from particles like dust, as well as, water. Our smart mirror is ideally meant for use in the bathroom. This means that water and steam will most likely encounter it somewhat often. While the dust particles won't particularly affect the components in our project too majorly, the combination of water and dust would prove harmful to the overall wellbeing of the various electrical components.

There are usually two digits to follow the letters IP, the first digit refers to the level of particle protection and the second refers to the level of moisture protection. The lower the number the less protection is offered, with a rating of 1 meaning no protection offered whatsoever. There are 7 levels of rating for the particle protection and there are 9 levels of rating for the moisture protection. In our case we have gone for a 6 rating in the particle protection, which would protect against dust that can harm the equipment. A rating of 7, essentially means protection against all dust particles would be too extreme to implement in our project. The rating of 5 for the moisture protection essentially states that our project would be protected from water spray from all directions. This may be too over the top assuming that most people would not just splash their mirrors with water. A rating of 2, which would protect against condensation may prove significant enough for our project, however we wanted for the smart mirror to have a prolonged life against all odds.

Table 21 – IP ratings, Source: (The Enclosure Company, n.d.)

Particle Protection Levels	
1	No additional protection
2	Protection from objects greater than 50mm in diameter
3	Protection against objects not greater than 80mm in length and 12mm in diameter
4	Protection from objects with a diameter of 2.5 mm or more
5	Protection against objects larger than 1mm
6	Protected slightly against harmful dust
7	Protection against all dust
Moisture Protection Levels	
1	No additional protection
2	Protection against condensation/steam
3	Protection against water droplets deflected up to 15° from vertical
4	Protection against spray up to 60° from vertical
5	Protection against water spray from all directions
6	Protection against low pressure water jets from all directions
7	Protection against strong water jets and waves from all directions
8	Protection against temporary immersion
9	Protection against prolonged immersion under pressure

4.2.8 C11 Standard

C11 is the informal name for ISO/IEC 9899:2011, a past standard for the C programming language. C11 essentially just standardizes features that have already existed in many C compliers for years and so it doesn't introduce anything new besides an improved memory model that allows better support for multiple threads of processor execution. Many changes were made from the previous standard C99, including:

- Macros for complex numbers
- The "quick exit" function for ending a program
- Static Assertions
- Anonymous Structures and Unions
- Removal of the "gets" function
- Improved Unicode Support
- Multi-threading support

The C standard is important in specifying what is required in a C program and what can be optional so that compatibility between different operating systems and compilers will work as intended. The C standard also provides a set of libraries that make writing code easier and doing certain tasks in C much simpler.

4.2.9 USB 2.0

USB 2.0 might be used by our microcontroller for programming and sending touch data to the Raspberry Pi as mouse input. Certain libraries exist on the Arduino for emulating a mouse through software on a microcontroller. Taking advantage of this feature requires native USB 2.0 support on the microcontroller itself. The Atmega328 does not have this ability. Most Atmega328 boards use an FTDI chip to convert USB signals to SPI for programming the microcontroller through USB. Because of this, we’ve been persuaded to reconsider our microcontroller choice to one that has USB 2.0 support built into the chip itself. In this case, we will have the option to program through USB and emulate a Human Interface Device (HID) or mouse. The advantages are clear in this case because it will make programming and debugging much faster.

5 Project Hardware and Software Design Details

This section of the paper will explain in detail the hardware and software that will be used on the project. It will explain why those components are used and how they will connect. The software design sections will explain how the software will be designed and how they will be used in the project.

5.1 Microcontroller

The following section explains how all the different components will connect relating to the microcontroller. The microcontroller will take as an input the power supply to activate it. Also, it will input the communication from the Raspberry Pi that has the PCB connected to it as well as the camera module. Next, it will input the IR gesture sensor to process whether the correct sets of gestures have been used to access the smart mirror. Lastly it will input the IR touch sensor to see where the user has touched in the mirror to give them access to the required data. In turn, the microcontroller outputs communication to the Raspberry Pi, this is for processing user input from the IR touch sensor back to the Raspberry Pi to process the required data. It also outputs the display MOSFET, to show the UI. Lastly it outputs the camera MOSFET to display to the user the output of the camera module connected to the Raspberry Pi, for taking pictures and whatnot.

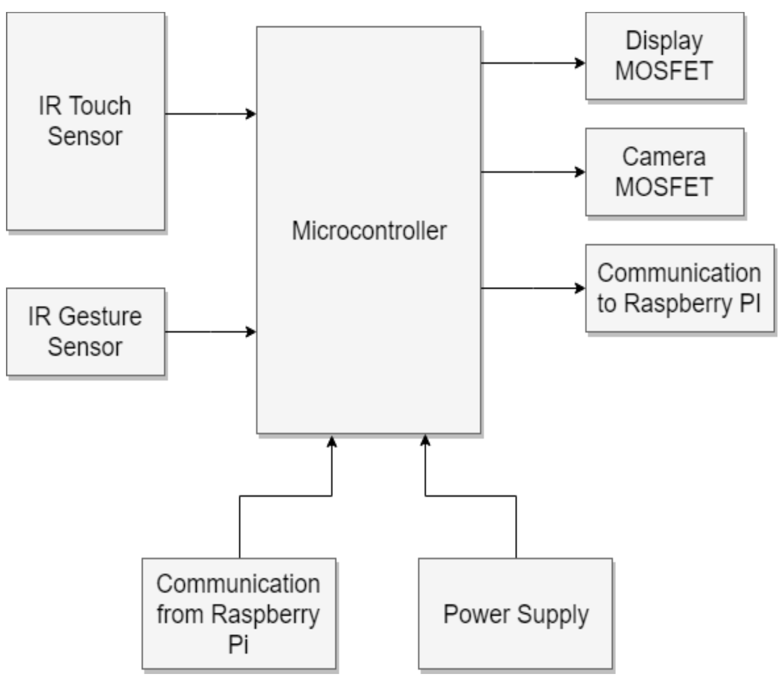


Figure 30 – Microcontroller Block Diagram

The microcontroller system will be setup as in the block diagram shows above. The microcontroller we'll be using is the ATMega32u4 since it's simple and has more than enough features for our needs.

5.2 Communicating with the Raspberry Pi

The microcontroller in our implementation will be the Master and the Raspberry Pi will be the slave. When it monitors input from any of the various sensors it will start sending data to the Pi immediately, so the display can be updated according to the input. Since the Pi is a slave, normally it won't be able to initiate communication with the microcontroller, but we will work around this by using interrupts. If the Pi wants to send a command, such as activate the camera, it will pull an interrupt pin High on the microcontroller. Once this happens the microcontroller will then request bytes from the Pi. The first byte will be the command such as turning on the camera or a sensor info request. If the command requires more bytes to be sent, the microcontroller will request it.

5.3 Gesture Sensor

The Gesture sensor as stated above will be an APDS-9960 from Broadcom. Ideally this will be mounted somewhere convenient such as the bottom of the smart mirror and pointing upwards to be used in the middle of the display. Our idea is to have it hidden behind a translucent piece of black plastic or glass that it can still function behind, yet not be too obvious to anyone using the mirror.

Figure 31 – Broadcom Gesture Sensor, Source: (Broadcom)

This tiny device has everything we need built straight into it for the gesture sensing we want to do. It's an all in one RGB, ambient light, proximity, and gesture sensor. Most of these features will come in handy for making our smart mirror work the way we want it to. The proximity sensor will be especially useful when trying to save power and detect if anyone is around or using the mirror. Using that sensor, the display can be turned off when nobody is using the mirror. It also has an I^2C interface for communicating with it and other devices easily. We will use a breakout board for this device that provides access to all the necessary connections and also has all the support circuitry so that we don't have to design a second PCB or implement superfluous components onto our own. This will simplify the design and leave space for more important items like our multiplexers, microcontroller, headers/connectors, and the logic level shifters for communication between the Pi and microcontroller. Since we're aiming to have a small PCB, space is a precious commodity and we need to make the most use of it as we can. We will accomplish this by using surface mount components where we can and by packing everything together as tight as possible.

5.4 User-Interface

The user-interface for the mirror will be essential in making the mirror accessible and easy to use. A good interface can make or break any product. The iPhone was a success in some ways because of how easy it is to use and that made it the phone of choice for most people. Following is our prototype design:

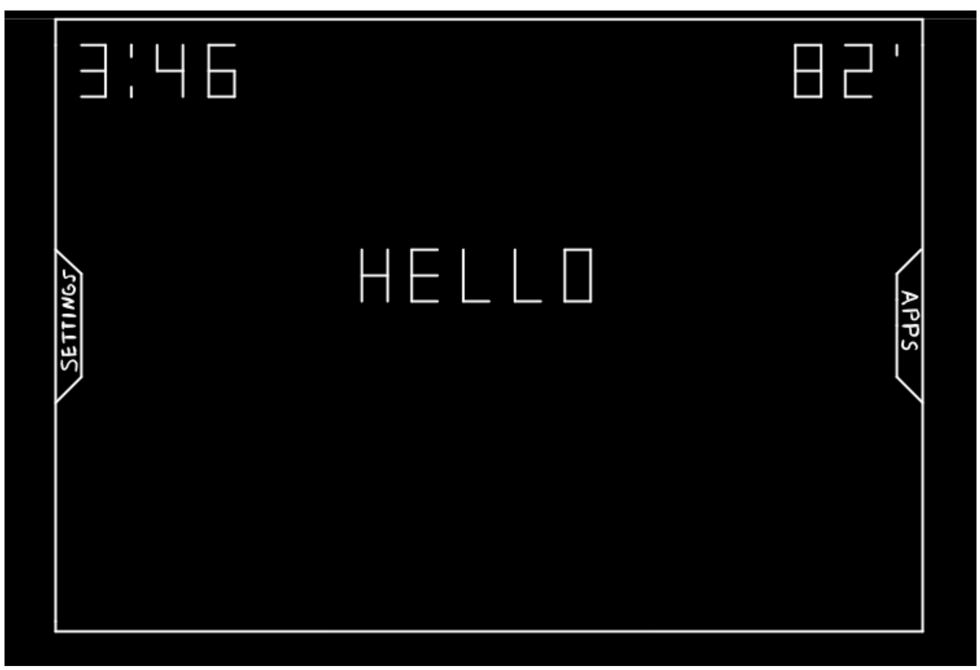


Figure 32 – Prototype user-interface for smart mirror

Here is the prototype interface we designed to be the home screen of our smart mirror. It's meant to be as simple as possible and only display essential information. When the mirror first turns on it will show a greeting such as "Hello" but that will fade away and make room for other things. All the widgets on the mirror such as the time, temperature, and menu options are displayed at the edges of the screen so that the most important feature, the mirror, isn't obstructed. With a simple swipe left, the app drawer will be revealed to the user so that they can select from an array of apps installed.

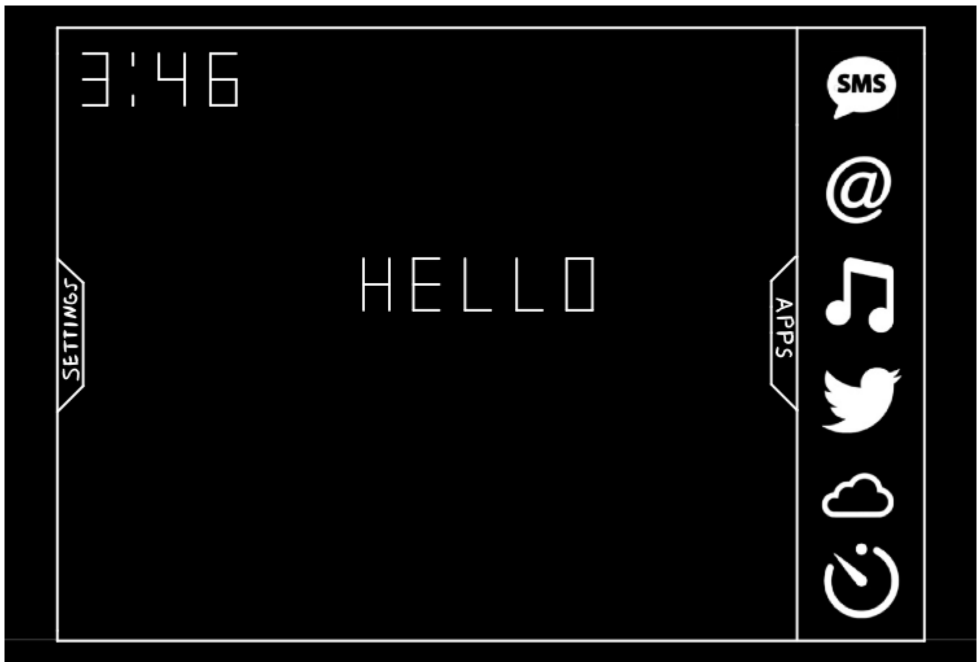


Figure 33 – User-interface with app drawer open

Here is a second prototype sketch with possible apps shown on the right side of the mirror. From this menu any app can be selected for use pressing outside this area will just close the app menu. Another feature not shown is a widget area at the bottom of the screen. This area will be where options such as your next appointment, currently playing music, and other text-based information from apps.

5.5 Frame Design

Unlike most smart mirror designs, this project does not have a real touch screen. Instead of a touch screen our smart mirror will take input through an optical grid which will be a close approximation of a touch screen. Due to this design choice, the frame of the mirror will have added complexity compared to other smart mirrors. This results in extra care being necessary when designing the frame of the smart mirror, because this particular mirror can have potential misalignment issues in addition to an increase in required internal space to route the extra wires.

In order to prevent misalignment of the LEDs and photodiodes when assembling the smart mirror we have decided to use wooden cutouts made from a laser cutter to ensure accurate and consistent spacing.

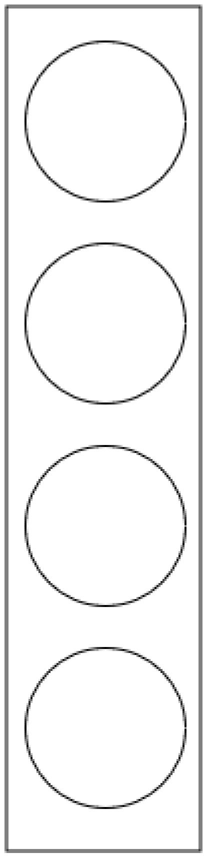


Figure 34 – Cutout for LEDs and photodiodes

The figure to the left shows an example of the cutouts which would be used. The diameters of the holes will be just large enough to fit the LEDs and photodiodes inside of them. Once the components are placed in and the electrical connections have been confirmed, the components will be glued to the wooden cutout to ensure stability throughout the remainder of the frame construction.

These cutouts will be placed between the surface of the glass and the outer frame of the mirror with the cutout being perpendicular to both so that the light from the LEDs flow across the surface of the glass toward the corresponding photodiode. This methodology for installing the LEDs and photodiodes serves two purposes.

The first purpose is to make alignment of the LEDs and photodiodes as simple and automated as possible. By using a laser cutter to create the outer dimensions as well as the spacing and diameter of the circular cutouts we will prevent potential issues with alignment.

The second purpose is to provide adequate space within the frame of the mirror to route the wires from the LEDs, photodiodes and other electronic components.

In addition to the LEDs and photodiodes being embedded within the frame, the camera will also be embedded within the frame. A hole will be cutout from the surface of the frame to allow the camera through. However, depending on where the user decides to place the mirror, a camera may not be ideal or even desired. To combat this, a sliding camera lens cover will be installed within the frame to prevent potentially unwanted features from being abused. We decided to use a simple, mechanical method to shut the camera off from outside view to prevent speculation on the user's part. Every individual, regardless of their field of work or level of education understands that when you place a non-transparent object in front of a camera, the camera cannot see past that object. However, not every person understands how electronics work. Had we decided to turn off the camera electrically without being able to cover the camera, it is very likely that some users would begin to assume that the mirror will be used to spy on them. By making a simple cover for the camera this suspicion has no credence and user trust can be more easily retained and obtained.

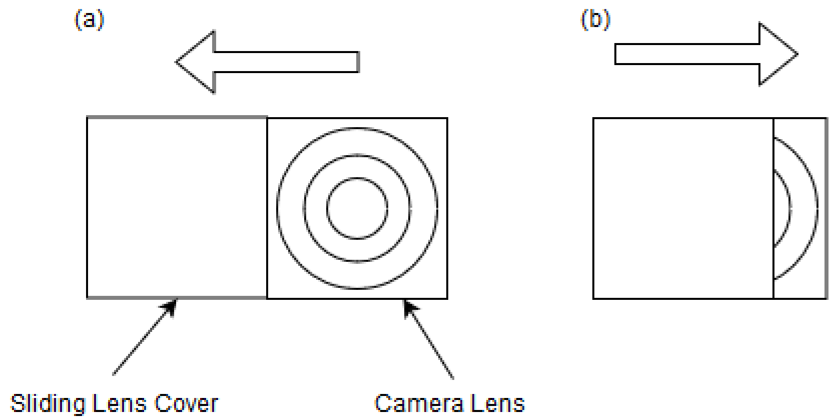


Figure 35 – Sliding lens cover. Part (a) shows the camera fully visible with the lens cover open. Part (b) shows the lens partially covered with the cover closing.

The material used for this frame should ideally be waterproof. Since we are going for a bathroom mirror design, this mirror is most likely going to come into contact with water or steam pretty often. The best material to use would be some sort of plastic material because its 100% waterproof and it comes in varying colors, so we would not have to paint the frame afterwards. The second-best choice would be some sort of hardwood, which we would still need to apply some sort of waterproof coating on and possibly paint/stain it as well. If we were to use some kind of softwood, water would easily penetrate if we do not do any waterproof coating and it would rot the wood and disrupt the integrity of the frame strength.

5.6 Software Design

The Raspberry Pi 3 Model B is a single board microcomputer with both wireless LAN and Bluetooth connectivity. The face recognition software will be called on the backend of the system by the OS to enable or disable user functions the mirror. Ideally, the software will process whether the user is a new or existing user. New users will have to create a new ID and then added to the user database. The new user can then access their own personal applications and it will be kept in file to be used for the next time the user accesses the smart mirror.

The existing users, on the other hand, will have to be authenticated and compared to the database of existing users before finally loading the user profile. The software will then connect to all the applications that are related to that user, before finally exiting when the user terminates the program. The following flowchart will show clearly what the software is intended to do.

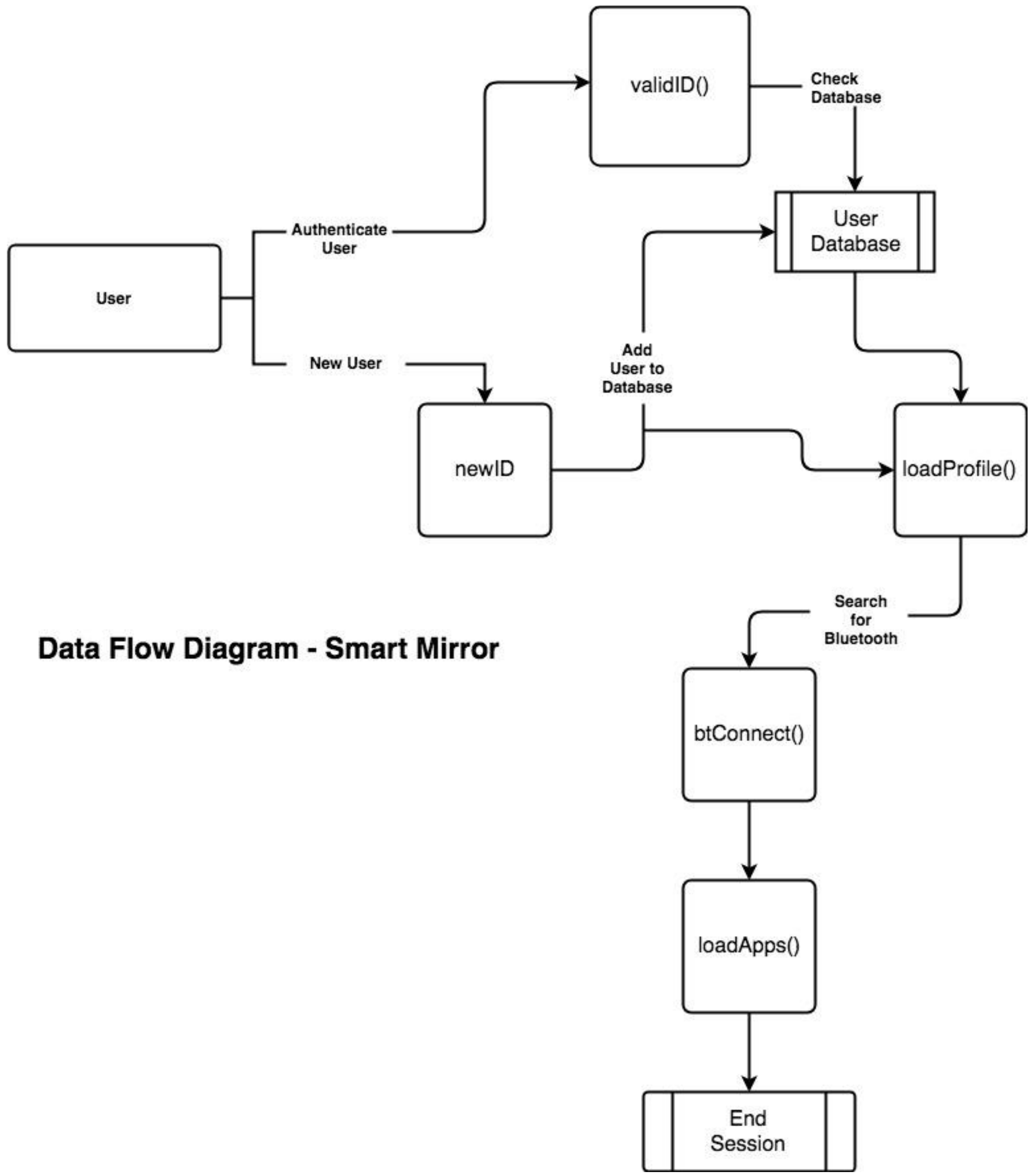


Figure 36 – Data Flow Diagram for Operating System

5.7 Installation

The operating system we'll be using for our project is Raspbian. It's an extremely flexible open-source system and has serious community support. Once we downloaded the OS image we had to write the image to an SD card using the r-disk method as described in the documentation for our Raspberry pi.

We booted up the Pi launchpad and start configuring the module using the configuration wizard by entering command line prompt sudo raspi-config in the terminal. We need to make sure that the system had the ability to boot to desktop and not just the command line. We configured the time to so that we could use that process for our application instead of having to write one from scratch.

5.8 Screen rotation

We are designing our system to be used in used in both landscape and portrait mode. Therefore, we will have a script that will rotate the screen 90 degrees based on the orientation of the mirror. We were perplexed about how we would accomplish this at first, but we found out that it wasn't as hard as we thought it would be.

In the 'BIOS' settings of the Pi 3 Launchpad there is a stored /boot partition of the system. This partition holds a configuration file that has all of the settings for the module. In order for us to rotate the monitor we just have to manipulate this setting.

5.9 UI System Design

Due to the fact that we will be using a semi-reflective material for our smart mirror. Our mirror itself will only physical work as a mirror as long as there isn't a light behind it. It is extremely important to make that background for the system is black or dark. We get the best contrast when the information display is white against a black background.

We would like to add some colors to differentiate applications of course but for the main system itself we wanted to create as clean UI as possible. We don't want the colors to overpower the mirror.

5.10 Backend API

API stands for Application Programming Interface. API's are a piece of software that allows multiple applications to communicate with one another. This means that an API is the system that delivers service requests to a client from a provider that the information is being requested from. The system then returns a deliverable back to the client.

The API will define the functionalities that operate independent of their respective executions, which allows those functionalities and classifications to differ without conflicting with each other. In this regard, an API makes it easier to develop programs by providing building blocks that streamline the development process.

When we're creating our code for our backend API, we didn't have to begin the process from scratch. A fundamental part of improving our productivity was how the API made complex processes very reusable with simple lines of code. The speed of the API allowed us to build our application to keep up with pace of our application development.

We found that we were much more productive using an API instead of writing most of code from scratch. With the API we didn't have to reinvent the wheel every time we created a process for an application. We only needed to focus on the individual components of the application itself such as scheme design, while leaving all of the all of the communication functionality to API itself.

One of the biggest advantages of using APIs is that they allow for a certain independence of functionality between multiple systems within a program. The end-to-end of the API separates the receiving application from the framework that provides the service. As long as the deliverables from the service provider makes its way to the client and remains unchanged, any changes to the framework on the backend should not be noticed by the applications that rely on that API. This gives the service provider a lot of flexibility in regard to how particular services are offered. For our smart mirror, if the framework for the API involves server communication, the content provider can simply switch from physical servers to virtual ones.

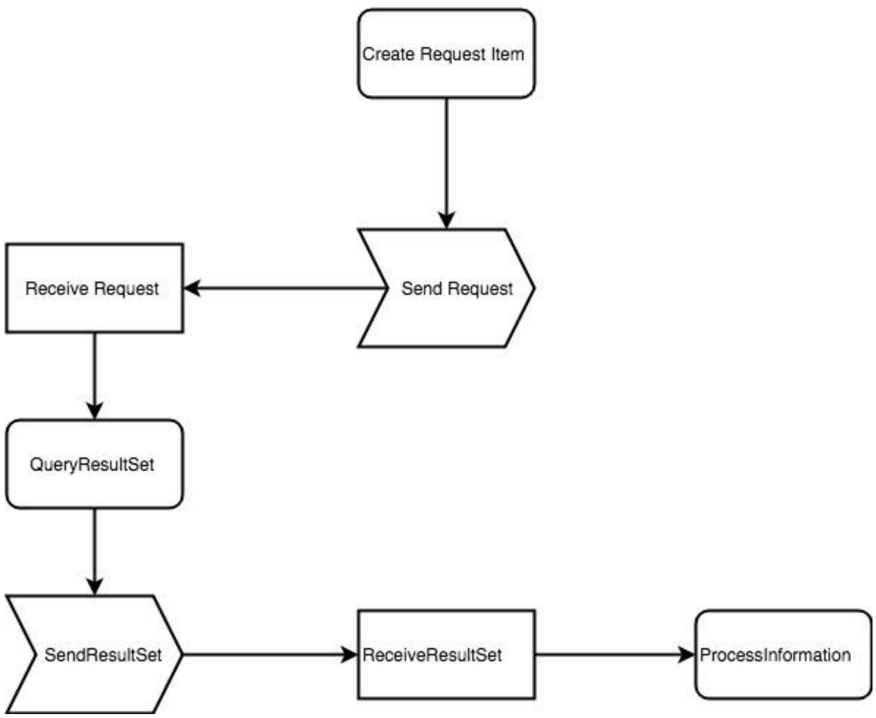


Figure 37 – Data Flow Diagram for Back End API

5.11 Features

When we first started the project, We decide that the interface would allow for limited user interaction with the mirror itself. This is because we want the mirror interactive and still function as one and no one wants an excess of smudges on their mirror. Most importantly we found that we want our smart mirror to have as passive interaction as possible. This would appeal to the accessibility portion of our mirror design.

Making sure that the mirror could be used as a mirror without having the view impeded by excessive information. We wanted to make use of the outer sections of the mirror so that content can be viewed while at the same time leaving enough room for people to see themselves.

There was certain information we felt we needed to display on the main screen for the user to see:

- **Start up message**
  Once the user is recognized we need to have a personalized message for that particular user.

- **Weather**
  We will be showing them the forecast based on their location

- **Clock/Calendar**
  We will be integrating the internal clock and a calendar system

- **News feed**
  We thought it was important display daily news for the user

We also entertained ideas for other possible home screen applications like a music application, to allow users to listen to their favorite songs while getting ready.

5.12 Auto refresh

Early in the development of our project we discussed nontraditional input methods. Being that we will not be have a keyboard and mouse connected to our Smart mirror whenever our system is updated, there would be no easy way for us to refresh the applications on the smart mirror. This refresh would essentially allow for programs to update to real-time changes. One solution we found and the most intrusive was to restart the entire module and have it update on start but would be highly inefficient and take an extremely long time to check for updates.

Since we have the ability to update our files using the GIT version control system, we determined that every update would have its own commit hash, which we would be able to read using PHP. This gave us the ability to add a piece of script that would compare the commit on the local host and against the one that is being displayed on the screen. If the two hashes don’t match, then the script should reload the page and display the most updated version. This comparison will be completed by the main js file, but this will only happen if the main application file has the most current version of the commit hash available.

The comparison itself will be straight forward as it will be checked every 5 seconds. This will allow us to update the smart mirror interface, by logging into our module using ssh, push our changes to the appropriate folder, and completing a pull.

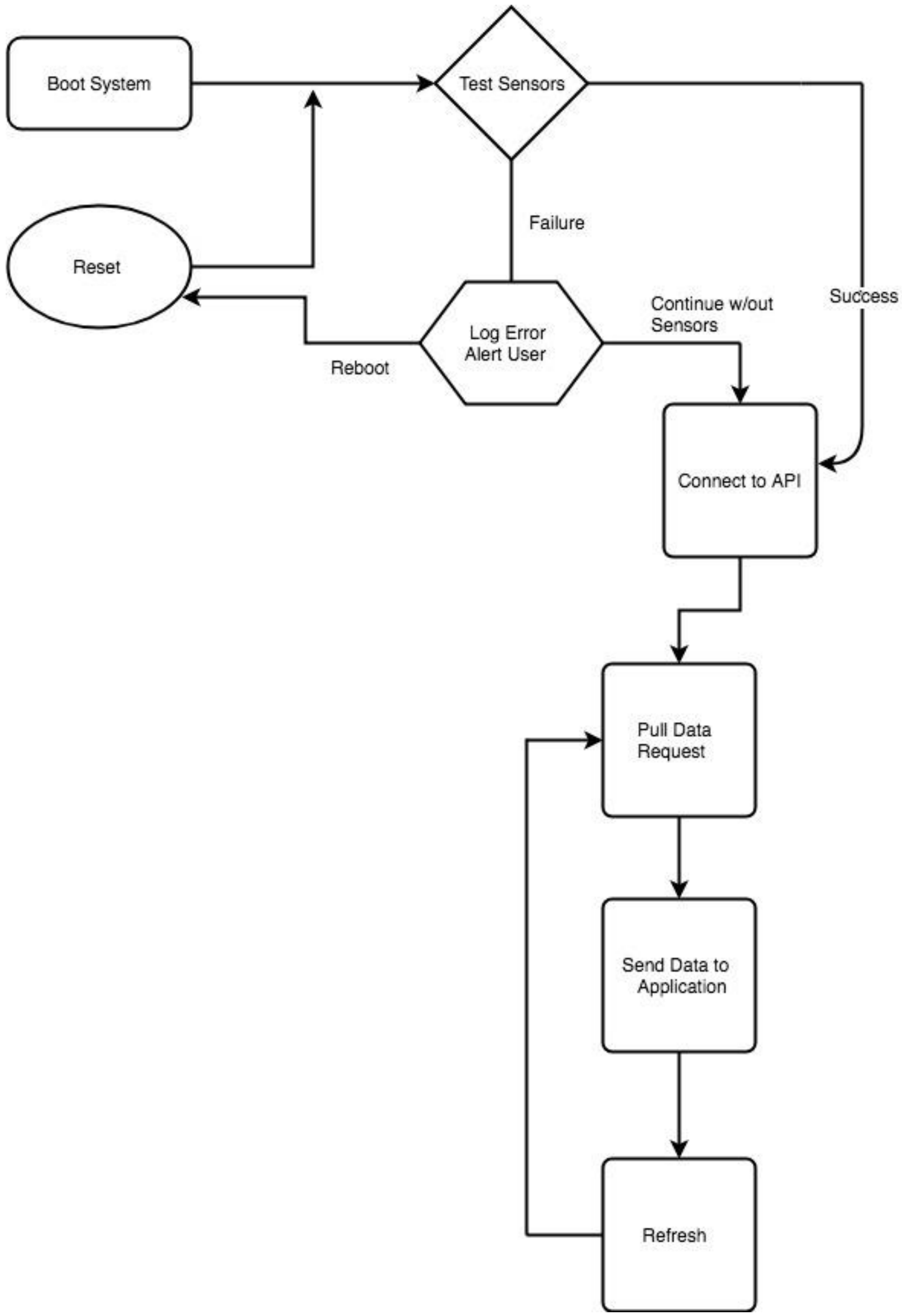


Figure 38 – Data Flow Diagram Post-Boot Data Pull

5.13 Kiosk mode

What we want is for our system is to make sure that the Raspberry module actually shows the application in kiosk mode on launch. What this does is that it completely disables all screen saving features and makes sure our application starts after the module boots and points to our application in full screen mode.

Due to the fact that the device will have multi user capabilities, publicly accessed device needs to clean itself of the current user's data when the user leaves. The simplest way to address this is with an inactivity timer. This can be a problem in the sense that the device may have a queue of users, and when the next user begins to use the device before the inactivity timer runs out they may have access to the previous user's data. One solution to this, is making use of a proximity sensor or creating automatic log off functions for the system. Whenever a user's is finished using the device the smart mirror needs to delete all of the recorded data of the user. This means clearing the cache and other user data stored during the session.

It is also important very important for the device to reset to the startup screen of the application whenever a user has ended a session. It would be extremely confusing for the next user of the device.

Being that the smart mirror may run unattended for long periods of time, and many web enabled applications are designed to be run in and out of use. This means that it may be possible for the application to continuously to use larger and larger chunks of memory every time the application is run. This is particularly an issue for any device where the specific applications are being used repeatedly. There is a point at which enough memory has been used and the OS starts to lag which may cause the entire system to stop functioning properly. The system needs to be programmed well enough to monitor its own usage and whenever necessary close and relaunch an application or restart the system entirely.

Windows OS in particular, often has a barrage dialog windows that pop up on the desktop or task bar to alert users of for reason that are not related to the applications currently in use. Over this can be very disorienting for the user and even serve as a potential security risk. Kiosk mode is designed to prevent irrelevant items from being displayed to the user.

Using a kiosk style software solution will provide the system with the security that it needs. Due to the limited range of application there won't be any serious security holes left open inadvertently a or confusing experience for the user of the device. This will enhance the user experience while keeping user's data secure.

5.14 Languages

This section will contain the different programming languages considered for use in our project. The three considered options are Phyton, C++ and Java. This section will list the advantages and disadvantages for each programming language.

5.14.1 Python

Python has a comprehensive system library, that is also very well integrated. The libraries are usually very simple to implement, and you can begin using them very basic understanding of the language. Python is an object-oriented language, but most errors are detected at run time because it's interpreted language rather than compiled.

Python allows programmers to be highly productive working individually due to its vast yet simply implemented features. Larger scale python development has issues. In some senses Python can be considered strongly typed, but not in the same way c++/java is expected. An example of this is function signatures. They never specify a type for return or input, so it is considered best practice to use distinguishable variable names. The types that are passed to a function are not resolved until they are called. It is entirely possible and perfectly acceptable for a function to return multiple types from different locations within function.
Python also comes with thread support but due the Global Interpreter Lock (GIL) it's not normally worth it to use.

Python manages memory automatically using a garbage collector. For speed Python compiles a script into bytecodes resulting in a PYC file that loads faster into the interpreter.

5.14.2 C++

C++ gives programmers access to low level hardware and direct access to memory. This puts C++ in a unique class in comparison to the other two high-level languages we mention. C++ is an Object-Oriented Language. In comparison to other Object-Oriented Languages C++ has always bogged from a somewhat labored syntax largely due to the fact that it supports a lot of legacy C code and still adds enough new arrangements for all the OOP concepts that were integrated as well.

C++ is a good choice in regard to ensuring performance at the sake of accepting some complexity to achieve that goal. In the past c++ had a pretty limited system library although it was a language developed for creating system libraries, but the language itself did not provide a lot of support for it. This was eventually modified by improved libraries, and now most of these libraries are incorporated into the new versions of the language
With its latest enhancements c++ has made a resurgence and has a lot of support. it is still more challenging to get used to the syntax than Python.

5.14.3 Java

Java is an object-oriented language with a syntax that is simil (The Enclosure Company, n.d.)ar to C++. Java has an extensive number of libraries and frameworks. The productivity of a programmer tends to be higher due to its flexibility, but the learning curve for Java is relatively the same as C++.

The difference between Java and C++ is that it runs in a virtual machine called a JVM. The JVM manages memory through a process called garbage collection. Because it runs byte codes it is entirely possible to assemble other languages into the same code.

Table 22 – Comparison of C++ and Java (Kumar, 2016)

	C++	**Java**
1.	C++ was developed by **Bjarne Stroustrup**. Development began in 1979.	Java was developed by **James Gosling** and his team. Development began in 1991.
2.	C++ is a **compiled language**.	Java is both compiled and interpreted.
3.	C++ supports **conditional compilation** and inclusion.	Java does not support conditional compilation.
4.	C++ programs are **platform dependent**. They need to be compiled for a particular platform.	Java programs are platform independent. Java programs are written for Java Virtual Machine (JVM) and wherever a JVM is installed, Java program will run without needing recompilation.
5.	C++ does support **operator overloading**. Function overloading is also available.	Java does not support operator overloading. However, function overloading is possible.
6.	C++ fully support **pointers**.	Java has restricted support for pointers. Pointers are supported internally you can not writer pointer programs.
7.	C++ supports **structures**.	Java does not support structures.
8.	C++ supports **unions**.	Java does not support unions.

9.	C++ does not have built-in support for **threads**.	Java fully supports threads.
10.	C++ supports manual **object management** through *new*and *delete* keywords**.**	Java relies on automatic garbage collection. It does not support destructors the way C++ does.
11.	C++ supports ***goto*** statement (however the use of goto is discouraged as not considered a good practice)	Java does not support *goto* statement (although *goto*is a reserved keyword in Java)
12.	C++ supports **multiple inheritance**.	Java does not really support multiple inheritance. But similar results can be achieved through the use of interfaces.
13.	C++ provides support both for **call by value** and **call by reference**.	Java supports only *call by value*.
14.	C++ does not support **comments within source code**.	In Java programs, you can write comments using */** … */*
15.	C++ has no support for the **unsigned right shift** operator (>>>).	Java supports the unsigned right shift >>> operator.
16.	C++ provides ***virtual*** keyword to support function overriding.	Java does not support *virtual* keyword. All the non-static Java functions are by default virtual in nature, and therefore, can be overridden.

6 Project Prototype Construction and Coding

This section will explain the processes and methods that will be taken when designing the hardware prototypes of the project. This includes any software that will be used to design said prototype. This section will also exhibit and explain the coding that will be involved for this project.

6.1 Bill of Materials

The following section will show the parts that are acquired for this project, followed by a table indicating what each part is. These parts are going to be used to create the prototype for this project, which will help to enhance the final product.

Figure 39 – Parts selected for the prototype of the project

The above picture shows all the required essential components to use for building the prototype of the project. Some parts may be changed in the future to better the overall finished project. The parts above correspond to the table below.

Table 23 – The names of the items corresponding to the letters in Figure 38

Letter	Item
A	Raspberry Pi 3 model B
B	Arduino Uno Rev3 (for testing in place of our PCB)
C	IR LEDs
D	Photodiodes
E	Broadcom APDS-9960 gesture sensor
F	CD4051 DIP-16 single 8 channels analog multiplexer
G	L7805CV 5volts linear voltage regulator
H	12v, 10A relays

6.2 Printed Circuit Board (PCB)

Printed circuit boards (PCB) have become synonymous with modern electronics. A PCB allows for electronics to take on form factors which were previously impossible and allows for the electronics themselves to shrink since most mechanical stress burdens the PCB instead of the electrical components. Additionally, due to the rigidity of the PCB the assembly of electronics has been automated to reduce human error and improve efficiency. Electrically, the PCB has embedded copper paths connecting the various components of a circuit together.

However, even though the PCB has revolutionized electronics, designing a PCB is still a challenge. One must take many factors into account when designing a PCB.

The routing of the traces must be taken into consideration when presented with area constraints. The width of the traces must be wide enough to avoid burning of the traces when current passes through them. Spacing between traces must be accounted for in order to minimize unwanted coupling. The desired cost to manufacture the PCB must be made clear, as this directly influences both the footprint of the PCB as well as the number of layers the final board will have. All of these must be taken into consideration in addition to the quality of the substrate and they type of substrate to ensure that the finished product works as intended and is as cost efficient as possible.

6.2.1 Grounding

Grounding is a crucial element of PCB design. While the concept of a ground is simple and easy to understand, implementing a ground into a PCB can prove to be one of the more challenging components of PCB design. In a linear system, which are the most common types of electronic systems, the ground is used as a reference which we base our signal off. Additionally, it is the return path for the current in a system. Improper grounding solutions can the accuracy, and thus the performance, of many linear systems. It is a fact that without a proper grounding solution a PCB cannot function properly. Grounding can become an issue for any analog device, and proper implementation of a ground plane is essential for a PCB-based circuit. Thankfully, several principles of quality grounding, most notably the use of ground planes, are intrinsic and intuitive to the design of PCBs. Due to this being a notable advantage to PCB-based analog circuits, this section will be used to discuss grounding in PCB design.

Some other aspects of grounding which must be taken into consideration include signal return voltages and the control of spurious ground, both of which can degrade performance. These can be due to several factors, including external signal coupling, common currents, or excessive IR drops in the ground conductors. Proper routing and sizing of the conductive traces, differential signal handling, and ground isolation techniques enable control of these parasitic voltages.

Modern signal processing systems typically require mixed-signal devices such as analog-to-digital converters (ADCs) and their inverse, digital-to-analog-converters (DACs), as well as digital signal processors (DSPs). The need for high-performance ADCs and DACs stems from the requirements for processing analog signals that have wide dynamic ranges. Maintaining the previously mentioned wide dynamic range with low noise is dependent upon the use of capable high-speed circuit design techniques, such as proper signal routing, decoupling, and grounding. Adding to the complexity, mixed-signal ICs contain both analog and digital ports, increasing the potential for error with respect to proper grounding techniques. Additionally, since the digital current level of mixed-signal ICs can range from relatively low to relatively high, different treatment is typically required based on the digital current level for optimum grounding. Here we will discuss several grounding methods which are commonly used to overcome potential bugs.

Star Ground

The star ground methodology is established from the theory that all the voltage levels in a circuit are referenced to a single ground point, which is known as the star ground point. The defining feature of this method is that all the voltages on the PCB are measured with respect to the star ground point and not just to wherever a probe can be attached to.

While the star ground method is simple in theory, implementing it can be a different story. For example, if we make use of the star ground system, drawing out all signal paths to minimize the signals interacting with each other and the effects of high impedance signals or ground paths poses several problems. When the power supplies are connected they typically result in unwanted ground paths or the supply currents flowing into the intentional ground paths are large enough to corrupt the transmission of the signal.

Separate Analog and Digital Grounds

Digital circuitry is noisy. Saturation logic such as TTL and CMOS result in large, fast current spikes from the power supply when switching. Logic stages benefit very little from power supply decoupling. In comparison, analog circuitry is very vulnerable to noise. As a result, it makes sense to separate the analog and digital circuitry to prevent the noise from the digital circuitry corrupting the performance of the analog circuitry. This separation involves separating both the ground returns in addition to the power rails.

However, the analog and digital grounds in a circuit must be connected at some point for signals to be referenced to a common point. The star ground, which would be the common ground for both analog and digital signals, should be carefully chosen to prevent digital current from leaking into the analog portion of the circuit. This star ground is typically done at the power supplies.

Ground Planes

A ground plane can be implemented by making one layer of a PCB one continuous piece of copper to be used as ground. In theory, the large amount of metal will result in as low of a resistance and inductance as possible. This results in the best possible conduction, which in turn minimizes spurious ground difference voltages. While ground planes provide a solution for many ground impedance problems, there are factors which must be considered. PCB designers should take care not to inject large currents into a ground plane because it can result in voltage drops that interfere with sensitive circuitry. This idea of a ground plane can be extended to create a voltage plane which offers similar advantages. The difference is that a voltage plane is dedicated to a power supply voltage. (Zumbahlen, 2012)

6.2.2 Component Segregation

When designing a PCB with both analog and digital signals there is one crucial consideration which must be considered when designing the physical layout of the board. Analog and digital components should be separated where possible to prevent crosstalk. Since digital signals such at TTL and CMOS rely on saturation logic, which produces relatively high noise in comparison with analog signals, if the two classifications of components are not adequately spaced apart the digital signals can greatly affect the performance of the analog signals. (Zumbahlen, 2012)

6.2.3 Decoupling

Certain electronic circuits, such as analog circuits, are highly sensitive to voltage spikes and rapid changes in voltage levels. Decoupling capacitors are often used in circuit design to prevent quick voltage changes. This is due to the capacitors acting as energy reservoirs. When there is a voltage drop the decoupling capacitor provides the energy needed to maintain a steady voltage supply. If the voltage spikes, the decoupling capacitor absorbs the excess energy, stabilizing the voltage. Additionally, decoupling capacitors can be used to allow DC components of a signal to pass while shorting the AC components to ground. Decoupling is typically done with a small capacitor (0.01 μF or 0.1 μF). Surface mount ceramic capacitors are ideal for use as decoupling capacitors because they have good high frequency characteristics. Decoupling capacitors should be connected directly to the ground plane. (Zumbahlen, 2012)

6.2.4 Trace Width

One part of PCB design that can be easy to overlook is the width of the copper traces that signals pass through. The width, in addition to the material the trace will consist of (typically copper) determines the amount of power the trace can pass in addition to the resistance of the trace. Since this project does not require especially high power or high frequencies, a trace width calculator which can be found with a simple google search was used in designing the PCB.

6.2.5 Thermal Management

Components in a PCB are typically physically small, resulting in the components having a low thermal mass. This results in the components heating up rapidly when even a small amount of energy is dissipated. Since the characteristics of electronic components can change with temperature, most notably semiconductor components such as diodes and transistors, we must take into consideration the potential thermal issues when designing a PCB. To ensure a long lifespan of the PCB, and thus the smart mirror, it is important to keep the ICs as cool as possible. Semiconductor devices have a specific temperature range that they are advertised as working in. This range is typically between 0 to 70° C. However, a semiconductors lifespan can be reduced even when operating at the upper end of the acceptable temperature range for extended periods of time. This is due to the semiconductors lifespan being inversely proportional to the temperature in which they operate.

There are several options which can be used to combat the increase in temperature of the components. The first and simplest method is by using a fan. By having a fan blow over the PCB we can remove the heat that would build up due to stagnant air. While this would be effective, the packaging and noise could pose an issue. The second method is to use heatsinks on the larger semiconductor components, such as the ICs. This is both effective and cost effective, however care must be taken to prevent unintended shorts on the IC when applying the heat sink.

6.2.6 The PCB Design Software

Computer aided design software (CAD) has become an essential part of designing any electronic circuit. Many CAD software have built in schematic editors in order to create the electrical connections for the circuits. Additionally, the software which was considered for use in this project typically had the capability for seamless transition from creating a schematic which deals with the electrical connections, to the physical layout of the PCB. This is due to the availability of the various libraries which house the all of the necessary information regarding the electrical and physical properties of each component. When specifically designing PCBs there are a multitude of options available, each with their own distinct advantages. The following table lists the various CAD software that was considered for use in this project.

Table 24 – CAD software which was considered

Software	**Specs**	**Cost**
Autodesk EAGLE Standard	99 schematic sheets, 4 signal layers, 160 cm^2 board area	$15/month
Autodesk EAGLE Premium	999 schematic sheets, 16 signal layers, unlimited board area	$65/month
Autodesk EAGLE Free	2 schematic sheets, 2 signal layers, 80 cm^2 board area	Free
Xpedition xDX Designer	Hierarchical search/edit capability, simulation support for various circuit types	$5000+ depending on package
DipTrace Starter	300 pins, 2 signal layers	$75
DipTrace Freeware	300 pins, 2 signal layers, non-profit use only	Free

The options listed in the table were considered because of both price point, except for xDX Designer, and their respective capabilities. xDX Designer was considered due to its use in large corporations, such as Lockheed Martin, making it a desirable software to be familiar with. However, due to the price it is not a viable option for student use.

After taking into consideration both the familiarity of our team members with the various software packages and the requirements for our project, it was decided that Autodesk EAGLE Free is best suited for the purposes of this project.

6.2.7 Autodesk Eagle

As mentioned in the research section of this paper, there are multiple different methods to designing a PCB, such as having a single-sided or a double-sided design. The EAGLE program has taken these into account and included these decisive components into the program. There is a function within the program to add the conductive foil within the top or the bottom of the circuit board **(jimb0, n.d.)**. One of the most important issue with designing a PCB is routing. Basically, it's how the conductive materials are connected from components to components. There is an option within the EAGLE program for auto-routing, which simply puts your required conductive connections from the schematic unto the board for you in a way that different routes do not accidentally connect with each other **(jimb0, n.d.)**. This function will save countless hours trying to think of the path for yourself. It's also worth noting that even though this function exists, it will be used with caution. The best way to layout a PCB is by hand and while the auto-routing function is great, it's not perfect and will be used sparingly if at all. With the addition of conductive paths, there are also copper pours included in the program **(jimb0, n.d.)**. This method is essentially used to create a ground in the circuit. There is also an option to add a surface mount for the microcontroller of our choosing. This includes doing a more advanced method in the program, but the basics are basically the same, the different connectors of the surface mount still need to be routed to its correct place. There is an added option to add silkscreen to the PCB design, which simply adds wording onto the circuit board as to what should go in each specific area **(jimb0, n.d.)**. This would make construction of the board easier, as well as being more user friendly for those trying to get a grasp of the board design. After the design is complete, we generate the Gerber files, which is a universal language for PCB design. The Gerber files simply contain the design description for each layer of the PCB **(jimb0, n.d.)**.

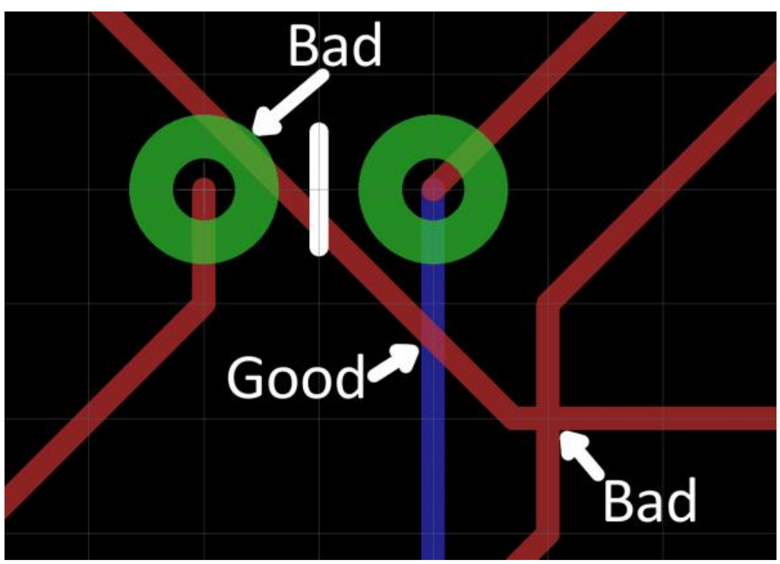


Figure 40 – PCB pathing example on EAGLE, Picture source: (jimb0, n.d.)

6.2.8 Manufacturing the PCB

After a series of thorough examinations on the design, the board will have to go through a manufacturer to get the physical component made. There are multiple decisions to make to decide which manufacturer to go with for our project. The first important factor is the overall quality of the PCB manufacturer. Should the product we receive be poorly made and non-functional it would drain both our time and money. The second important decision is cost, different manufacturers will have differentiating costs, as this project is funded from our own pockets, this will probably be one of the most important decisive factors. The third important decision to make is time, as in the length of time it would take for the manufacturer to ship the product to us. As we are already way limited in time for the creation and building of this project, we cannot afford a delay in our process from a lengthy production and shipping time. After all these factors are considered and a manufacturer is decided, then we simply send the required Gerber files to the manufacturer for production.

Table 25 – PCB manufacturers with pricing and time

Manufacturer	Price	Time
OSH Park (3 PCB per order)	2-layer prototype: $5/in.^{2} 4-layer prototype: $10/in.^{2}	>12 days shipping
Advanced Circuits (3 PCB for 2-layer) (4 PCB for 4-layer)	2-layer prototype: $33 4-layer prototype: $66 (max 60 in.^{2})	5 days turn
Gold Phoenix	2-layer prototype: $85 4-layer prototype: $200 (max 75 in.^{2})	hours turn

<u>PCB Design Considerations</u>
Some considerations must be considered while we are designing our PCB as will be listed below:

1. Shape
2. Power Traces
3. Mounting holes

The most important part of our PCB will be the shape and placement of components. Our PCB will be a Raspberry Pi hat which means it's meant to be directly mounted above the Pi as somewhat of an extension to it. The board shape will have to fit above the pi and the GPIO header will have to be placed correctly to be mounted above the pi directly where we want it to fit. This will also drive our design to be as small as possible and as such means we might have to use surface mount components in the PCB design. While these components are much smaller than regular through-hole ones, they're much more difficult to solder by hand.

While the design will have a slim and sleek profile, it will be much harder to assemble and test. We will be using 0805 size surface mount components so that they're as small as possible but also somewhat manageable when it comes to soldering them to the final PCB. However, the product will be a much more compact design than initially expected, which in turn will allow for the overall mirror design to be more compact. This will also in turn lighten the product weight and allow for the mirror to be mounted with less dangers of falling.

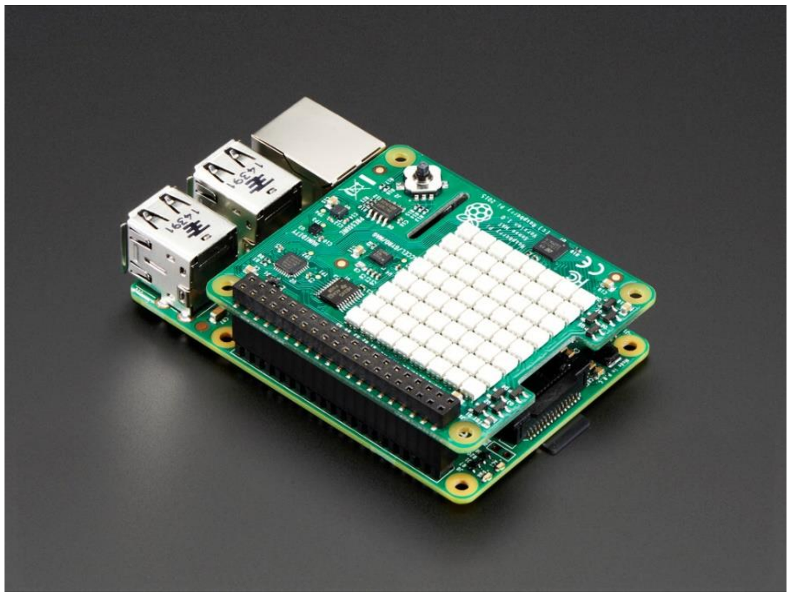


Figure 41 – Raspberry Pi hat from Adafruit, Source: (Adafruit, n.d.)

The second consideration is designing the width of the PCB traces used for distributing power throughout the board. Since the traces going to components such as the IR LED's will be carrying much more current, we must use more wide traces to handle the amount of current that will be passing through them.

The final consideration is designing the mounting holes on our board to fit perfectly over the same mounting holes on the pi. This will require that we either measure the holes on the pi or find a board schematic with the dimensions we need to make the mounting holes fit correctly.

6.2.9 Soldering Techniques

In our PCB design, we will be using surface mount components in some cases to save space and make the board more compact. Surface mount components come in a variety of different sizes ranging from easy to solder and going to almost impossible. It's important that we pick a size that will be easy to solder but also give us the sleek and small profile we want our circuit board to have when it's finished.

Table 26 – Surface mount package sizes

Package (Imp.)	Approximate Dimensions
0402	0.04 x 0.02 inches
0603	0.06 x 0.03 inches
0805	0.08 x 0.05 inches
1008	0.10 x 0.08 inches

In the table above are some common SMD package sizes. We will be using the 0805 packages because while they're fairly small, the soldering is still manageable with a good technique. SMD packages aren't really designed to be soldered by hand so each one requires a different technique to do by hand and some are downright impossible. Passive components come in a 0805 that looks like the following figure:

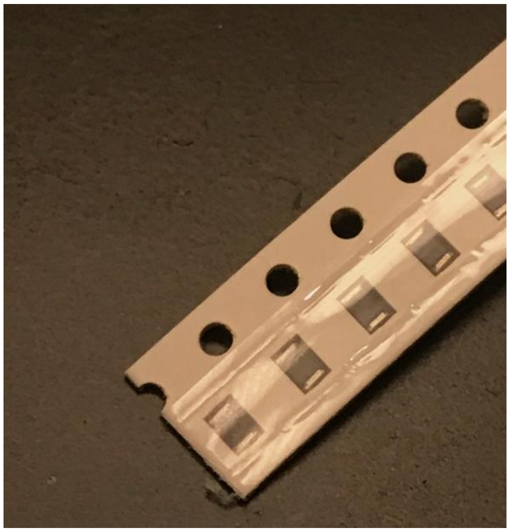


Figure 42 – 0805 SMD Package

The best technique I've learned for soldering this is by first "tinning" one of the pads which means applying solder to one size on the PCB. Once the pad is tinned, the component can be placed and held in place using tweezers. Then the soldering iron is applied to the pad, with some solder on the tip, and that side of the component will then be soldered into place. Now that one side is locked down, simply solder the other side and the job is done. Now this will work for the 0805 passive components we have but our microcontroller and multiplexers come in different SMD packages.

Surface Mount chips come in a variety of different sizes, but I will list some in the table below:

Table 27 – SMD Package types

Package Type	Description	Difficulty
SOP	Small-Outline Package	Easy
TSOP	Thin Small-Outline Package	Medium
QFP	Quad Flat Package	Hard
BGA	Ball Grid Array	Impossible

Soldering these packages goes from easiest to impossible by hand. The packages we will be using range from SOP-QFP. All solderable by hand, using a good technique. The best way to solder these packages by hand is first to add soldering flux to the PCB pads and then placing the package on the pads using tweezers. Then solder down a pin on the very corner to lock the chip down in place, making sure it's pins are on all their corresponding pads. Next add an excessive amount of solder to the end of the soldering iron and drag it across the pins on one side of the chip. Typically, this will get solder on all the pads without creating too many jumpers across any. This may require a couple passes of the iron and also some touch up on individual pins. Below is what a QFP package looks like for reference:

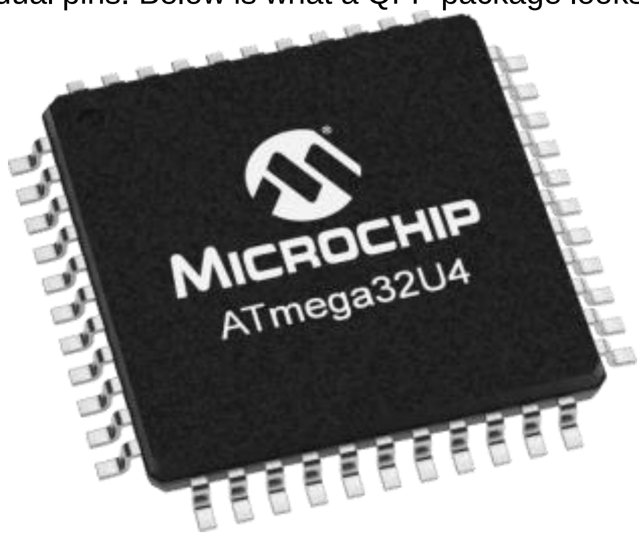


Figure 43 – ATMega32U4 in TQFP Flat Package, Source: (Atmel)

As mentioned above, you can better see how this process might be applied to this specific chipset. The image is also the microcontroller we will be using in this project for its slim form factor and Arduino compatibility.

6.2.10 Crystal Oscillator

When using microcontrollers, ideally it will need a clock source to determine at what speeds instructions can be implemented. To get this clock source, a Piezo-electric oscillator is typically used, and the most common being a crystal variant (Keim, 2016). There are internal and External clocking mechanisms, the one we will use, the crystal oscillator is an external clocking mechanism. Figure 43 located in the Schematic Design section shows how we plan to connect the crystal oscillator and the corresponding load capacitors. Pin 16 and 17 connects the crystal oscillator to the microcontroller and then connects the oscillator to its coupling capacitors which are then grounded.

Despite all the other clocking mechanisms, crystals are by far the most precise and stable (Keim, 2016). The microcontrollers usually have a built-in oscillator but to run faster clocks than available from the internal clocking mechanism we must use an external oscillator, in the case of the ATMega32u4 the max clock speed is 8MHz . In our case, based on the datasheet, the maximum external clock that we can use for the ATMega32u4 microprocessor is 16MHz. The clock speed doubles using an external clock mechanism. The following equation will be used to find the required load capacitance value.

Equation 4 – Load capacitor equation

$$CT = [(C1 \times C2) \div (C1 + C2)] + Cx$$

The CT is the capacitance of the crystal oscillator we will be using, which we will put down as 16MHz (based on 16MHz Crystal from Sparkfun). In our case the CT = 20pF, as for the Cx, that refers to a parasitical capacitance and usually it is safe to assume a value of 5pF for that. After doing the math, you get the coupling capacitors, C1 and C2, to be (16pF – 5pF) x 2 = 22pF. Sparkfun also has a 22pF ceramic capacitor that is recommended along with the crystal oscillator.

6.2.11 Clock Configuration

Now that we have decided on the required crystal oscillator and ceramic capacitors to potentially increase the clock speed, we still must choose a clock configuration that would best fit our project. There are two types of clock configuration for the crystal oscillator, the low power and the full swing.

The low power configuration, as the name suggest would help to lower power consumption. Ideally, since we are connected to an outlet as a power source this doesn't really matter as much. Also, the clock speeds of the crystal are susceptible to noise. As with any electrical devices there are bound to be noise included with it, usually it would not matter much, however since we are dealing with the clock speeds the noise would affect it in a way that would make it less than the most efficient setup.

The full swing configuration does exactly the opposite as the low power configuration. It is not susceptible to noise, but it consumes a lot of power. Even though this configuration consume way more power than the last configuration, this configuration would keep the clock speed running at the most efficient, which would mean things get processed as fast as intended. Not only that, the overall stability is also improved, since the device isn't susceptible to noise it runs as intended therefore keeping its stability. This makes the full swing configuration the best choice to use for our project.

6.2.12 Schematic Design

IR Touch Sensor Details

The most crucial component of the smart mirror is the custom PCB which will be used to take input from the optical grid for the user to interact with the smart mirror. As the optical grid will be the main method with which users provide input to the smart mirror, special care was needed when designing the circuit.

From the 12V input which will be supplied by a standard laptop charger LM7805 voltage regulators are used to provide a constant 5V output to power both the ATMega32u4 microcontroller and the 940 nm LEDs which will illuminate the photodiodes, so we can properly process input.

Due to constraints on the available I/O on the microcontroller, two multiplexers are connected to the photodiodes to allow enough photodiodes to be connected to the smart mirror. Each multiplexer will provide input to the microcontroller corresponding to one of our two axis, horizontal or vertical. By connecting the output of the CD4051 multiplexers to an analog I/O pin, due to the photodiodes providing an analog signal, and the select pins to digital pins, we are able to poll the multiplexer to constantly check for input. With the digital pins on the microcontroller assigned to the select pins on the CD4051 we are able to count through the various inputs and check the signal of the corresponding photodiodes.

When a photodiode is not receiving adequate light and thus no signal is passing through, the microcontroller will determine where the user is providing input by correlating the location on the mirror to the location of the photodiodes.

An issue that comes to mind is when the user is using two fingers to press on two different inputs. Whether the earliest photodiodes that are not receiving signal will access and rendering the other input by the user useless or whether none of the inputs will be processed. This part of the project is still under discussion, but we are leaning towards making it access the first photodiode to lose signal.

Microcontroller & Reset Schematic

This section will discuss the microcontroller and the reset schematic in detail. That includes all the visible components attached to the microcontroller as well. The microcontroller is the most important portion of the whole schematic, it is the brain of this project responsible for processing data from all user inputs like the gesture sensor and the IR touch sensor. This design is going to be used for the prototype, so it might be changed in the finalized design.

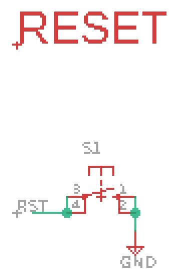


Figure 44 – Reset for microcontroller

In case of any foreseeable errors in the future in regard to the microcontroller, a simple reset switch has been added using a momentary switch that will reset the microcontroller by connecting the reset pin to ground. This will cause for the microcontroller to boot back to its first set of instructions.

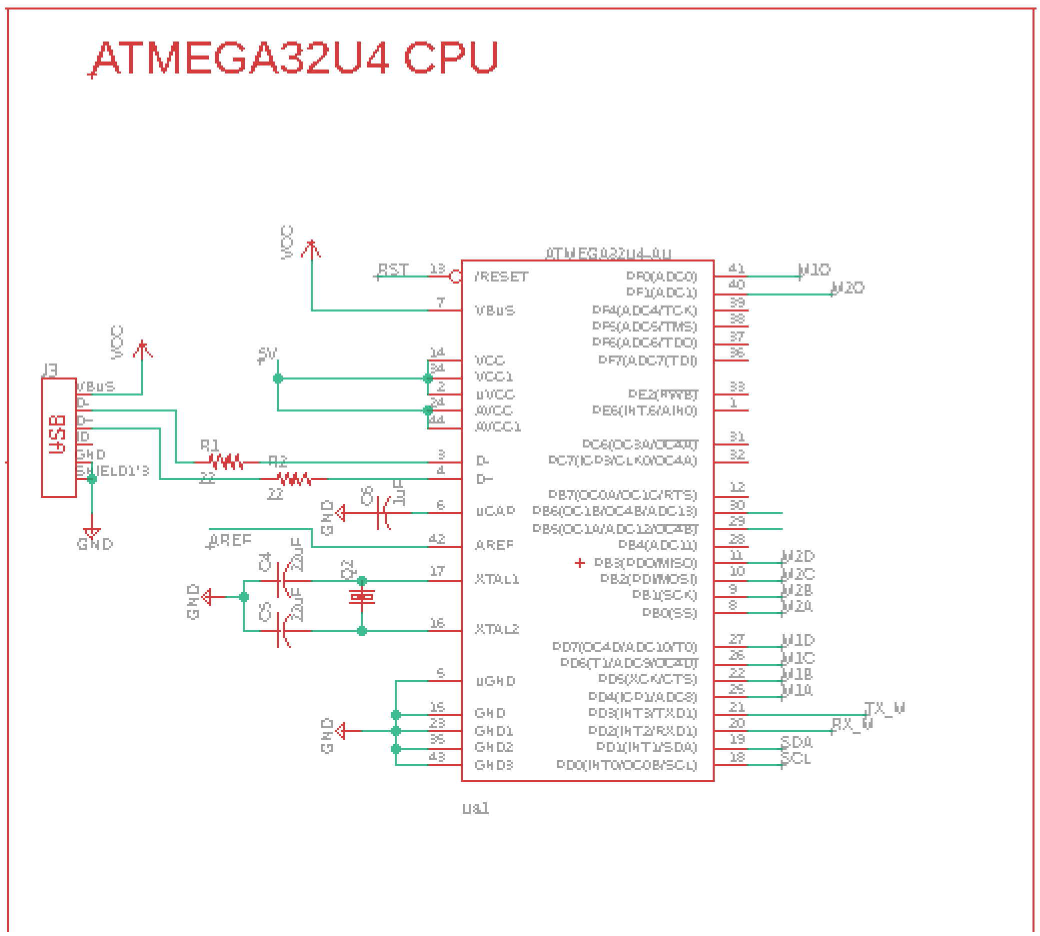


Figure 45 – Microcontroller connections

As seen from above, all the varying VCCs on the microcontroller are connected and then connected to 5 volts DC. All the ground sections are connected to ground. In short, the VCC is the voltage that will be delivered to the microcontroller in relation to ground to activate it. Pins 16 and 17 indicate where the crystal oscillator will be located including the two coupling capacitors which are then located to ground. The crystal oscillator is an external clocking mechanism, which will increase the speed of the microcontroller because it is faster than the internal clocking mechanism. Pins 3 and 4 indicates a connection to a USB port. This will be used to program the microcontroller by connected a male-to-male USB cable that will then connect to the computer. Pin 6 connects to a lone 1 microfarad capacitor which then connects to ground. This connection was specified to be done by the microcontroller datasheet.

Photodiode & LED Wiring

Below are how the photodiodes will be wired to create a voltage that can be read by the analog input pins on the microcontroller. There's also a method to help connect the LEDs in such a way that broken LEDs won't trigger a domino effect.

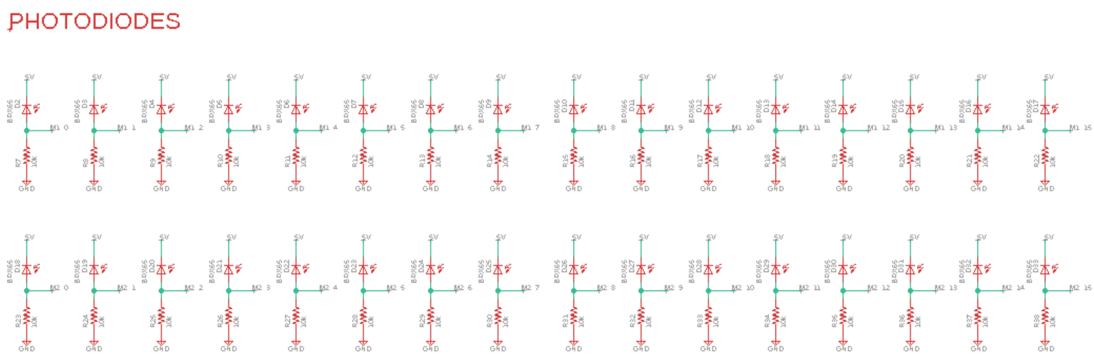


Figure 46 – Wiring of photodiodes

Each photodiode is connected to the 5-volt rail and feeds to a resistor going to ground. The resistor will create a voltage based on how much current is let through by the photodiode. As more light is shined on the photodiode, the current will increase and so the voltage across the resistor increases. The resistor voltage is connected to one of the multiplexer inputs and then can be read by the microcontroller when that input is selected. The default state should be excited as the diode will have a constant source of light on it at most times. So, when a hand is then passed and blocks the IR light from reaching the photodiode, the voltage across the resistor will drop and so that is how the microcontroller will know where a hand is on the display.

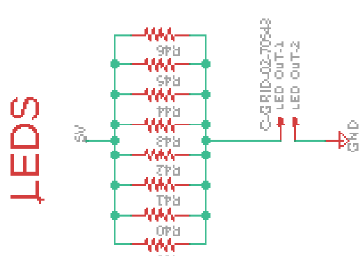


Figure 47 – LED wiring schematic

Since the resistors cannot pass a large amount of current through them, this is our method to help counter it from breaking. Simply connecting many resistors in parallel will allow for the current to be split off and recombine back into the LEDs which are also connected in parallel, thus splitting the current once more. This method does not only allow us to use cheaper resistors that can only handle a little amount of current but also save the other LEDs if one should break since the current will be dispersed by the resistors instead of going through the other LEDs and breaking them as well.

Communication Section

The Serial Communication of the circuit board includes the raspberry Pi GPIO connector and the logic level shifters for the microcontroller to communicate to the pi over serial.

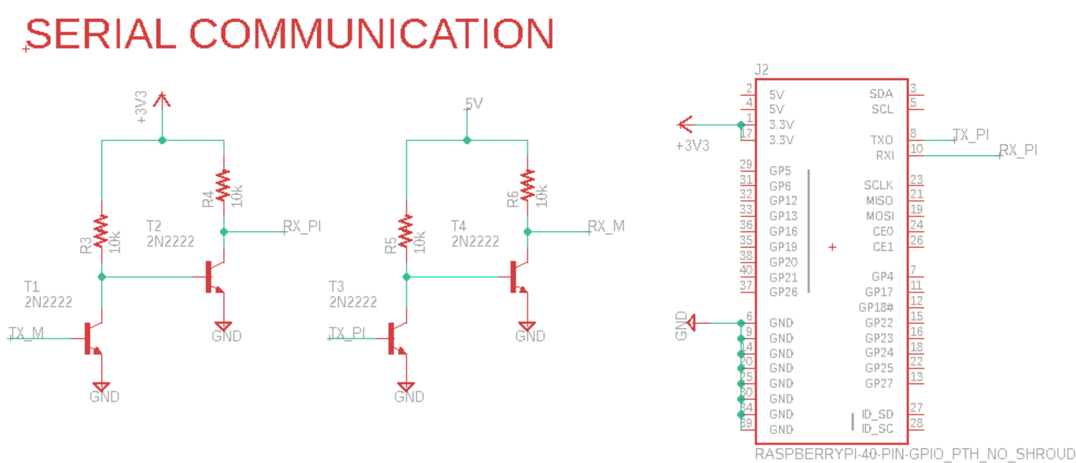


Figure 48 – Serial communcation section of the schematic

The logic level shifters will allow the 5-volt logic levels of the microcontroller to be read by the Raspberry Pi without damaging it and the same goes for the 3.3-volt logic of the pi when being read by the microcontroller. As display above, the 5-volt serial transmission from the microcontroller will be applied to the base of T1, driving it into saturation. Since T1 will be conducting current, a large voltage drop will happen at the collector resistor and so the collector voltage of T1 is small, close to 0.2-volts. In this case the base of T2 is assumed 0 and that transistor will be off. With no current running through the collector resistor of T2, there is no voltage drop across it. So, there will be a collector voltage on T2 of about 3.3-volts. So, the circuit to the left successfully converts 5-volt logic to 3.3-volt as desired. The circuit on the right just does the opposite and converts a 3.3-volt logic to the desired 5-volts.

Multiplexer Section

The multiplexer section of the schematic is straightforward, using two 16x1 multiplexers to read 32 photodiodes using two analog pins. We have decided to go along with this method as it was the easiest way that we've thought of to see whether or not the LEDs rays to the photodiodes have been blocked. We also go into detail later on as to why we decided to use two multiplexers as supposed to one large multiplexer. Setup as follows:

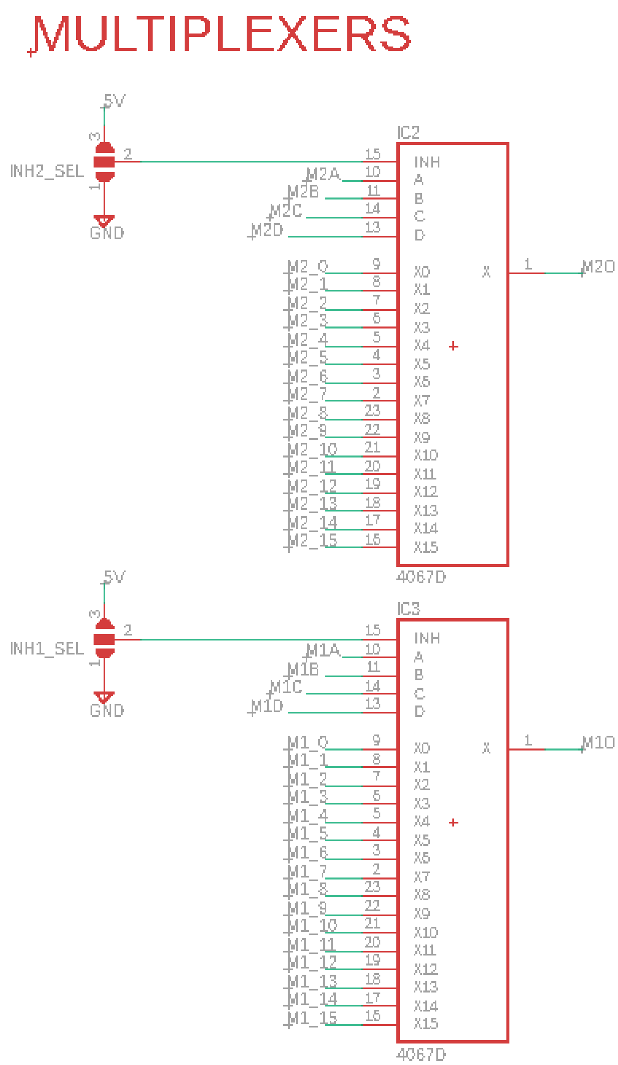


Figure 49 – Multiplexer section of the schematic

The inputs of the multiplexer are the 32 photodiodes shown above. 8 digital outputs of the microcontroller are used to control both multiplexers and pick one out of the 32 inputs to be read by the microcontroller. In the current design a jumper is connected to the chip inhibit pin for flexibility in our design. What this does is allow us to choose any compatible multiplexer, whether it's active high or active low. If we decide to change our multiplexer chip, a jumper can be used to easily change that condition.

Currently we're also using two individual multiplexers for ease of use when coding. Connecting the multiplexers would make a single 32x1 mux and this would only use 5 digital pins and save 3 for another purpose. Currently we don't have a purpose for those extra pins and so they're being used to drive two separate multiplexers individually.

Power and Filtering

The power part of the schematic provides a filtered 5-volts to the microcontroller and the rest of the board that will need to use 5-volts. The 47uF capacitors are used for the filtering and will remove any ac noise in the dc signal after the regulator converts the input voltage to 5-volts.

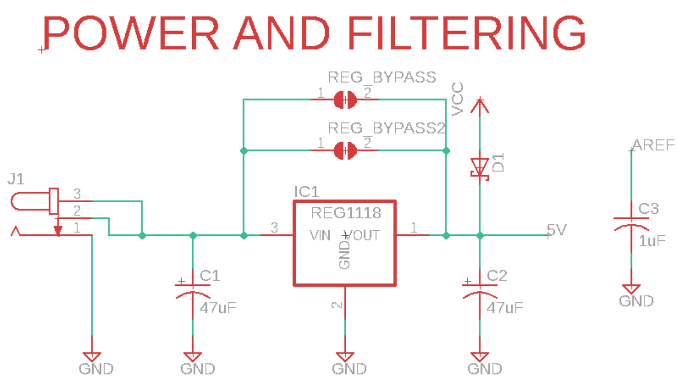


Figure 50 – Power and filter section of the schematic

Included in this is the diode that provides power from the USB connector. The purpose of this diode is to provide 5 volts when the USB is connected but it won't let current travel back to the USB port and damage it. A MOSFET could also be used for this purpose but that is unnecessarily complicated for this purpose. We also including two jumper pads for bypassing the 5-volt regulator in case an exterior power source is used instead. Discussion of a 5-volt switching regulator was mentioned and so that can still be used by just added a solder jumper across the SMD pads. The coupling from the analog reference to ground is also here as specified in the schematic for our microcontroller if it's not used.

Overall Schematic

The figure below shows the schematic design for the smart mirror project, including the LEDs, the photodiodes and the gesture sensors wiring to the microcontroller. This section also exhibits a table to show what the pins in each of the microcontrollers are doing.

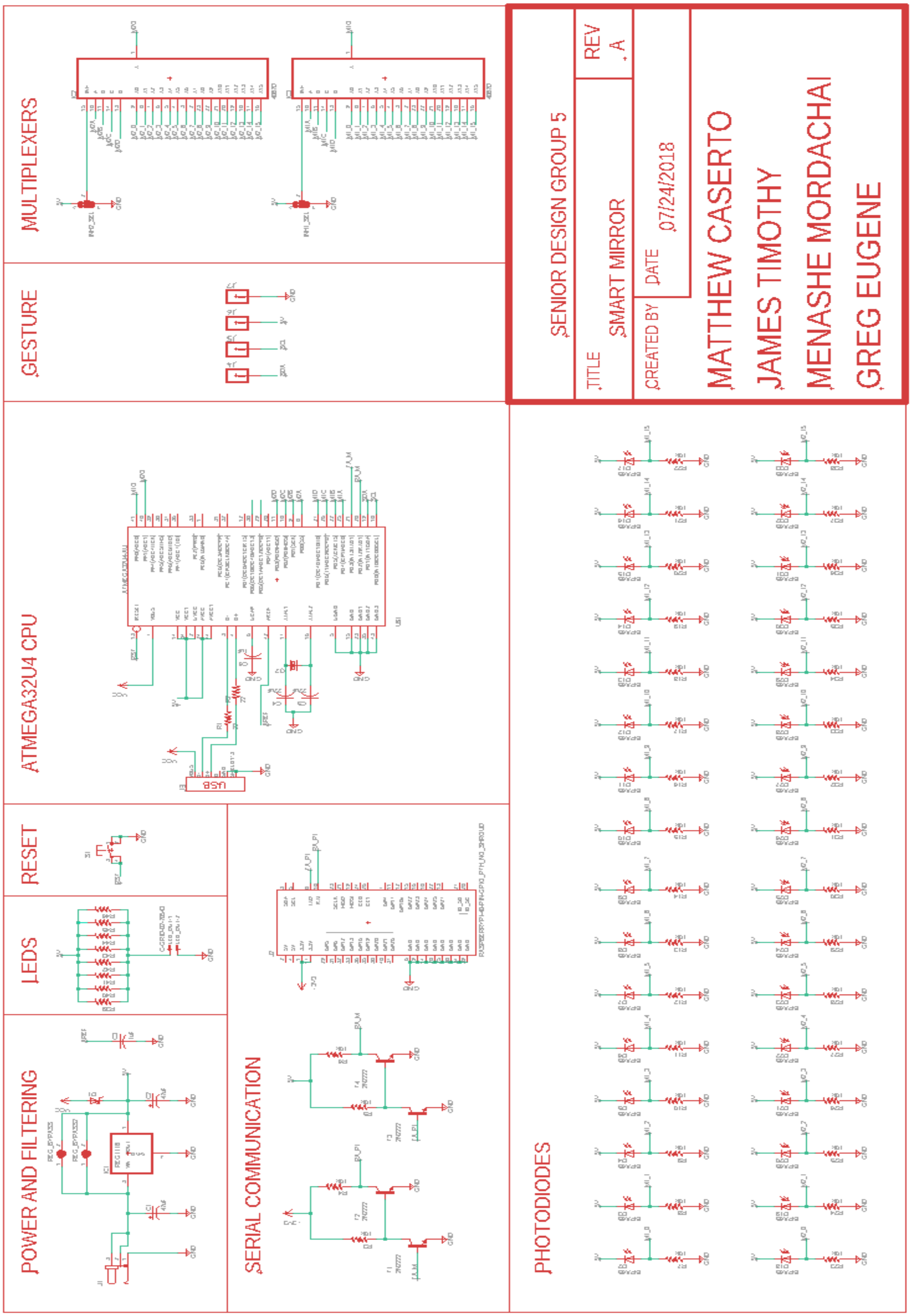


Figure 51 – Full schematic design for the smart mirror

Table 28 – Use of the ATMega32u4 I/O

Smart Mirror ATMega32u4 Pin Outputs	
Pin #	**Description**
3, 4	USB port to program the microcontroller
13	Reset for the microcontroller
7	Vcc input
5, 15, 23, 35, 43	GND
16, 17	16 MHz crystal oscillator and corresponding coupling capacitors
2, 14, 24, 34, 44	+5v input
6	1µF capacitor, (specified by datasheet)
42	Connection to power and filtering
41	First multiplexer output
40	Second multiplexer output
8, 9, 10, 11	Second multiplexer input digital pins
22, 25, 26, 27	First multiplexer input digital pins
21	3.3v to 5v serial communication output
20	5v to 3.3v serial communication output
18, 19	Connection to the gesture sensor

7 Project Prototype Testing Plan

The following section will contain the steps on which we plan to test our prototype to make sure that the outcome of the project will function as planned. Some parts will be tested individually, perhaps using different components for the purposes of testing the concepts. It will also include not just the hardware parts testing steps but also the software testing methods.

7.1 Software Test Methods

We decided between three development method that we like to implement for our project. In Software Development Life Cycle or SDLC is an outline that is utilized to structure and plan the process of developing a software system. or SDLC is a sequence of stages that specify common modalities or best practices of the software development process. The goal of the SDLC process is to provide a detailed definition of what the system requirements are. This is needed to make sure that everyone involved in the process has a clear understanding of the tasks assigned to them and how every task should be implemented. There has been a significant expansion in regard to the variety of models. This system diversity can be attributed to the wide variety of product types developers can encounter. starting with a simple website to a complex medical software. An important thing to note is that regardless of the model that is chosen, it should be adjusted to fit the scope of the product, project, and company.

7.1.1 Waterfall

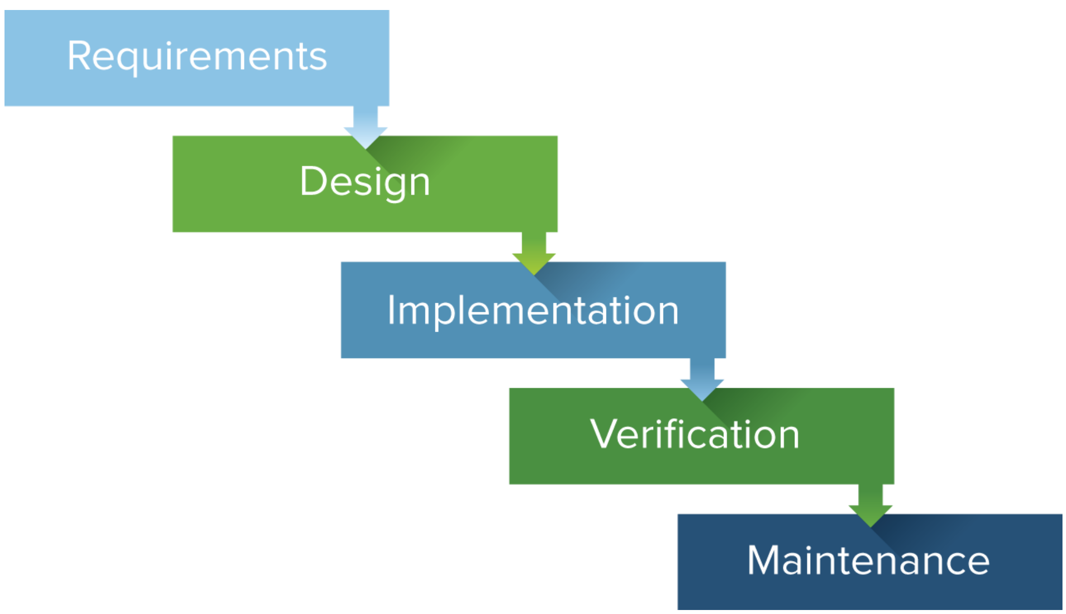


Figure 52 – Waterfall development method

The Waterfall software development model is a sequential approach in which development process is structured as progressively flowing downwards system through the different stages of t analysis, design, implementation. The development process is usually segmented into sequential stages, that will have some overlap acceptable between the stages. The emphasis is placed on planning, schedules, and the overall implementation of the entire simultaneously. Written documentation is a vital part of the development model.

7.1.2 Agile

Agile software development is a development methodology that is based on an iterative/incremental approach to software development. In this particular model the requirements for the project and the manner in which they are solve will evolve over the course of the development process. By collaboration between development teams this model promotes an adaptive approach to planning, with regularly evolving development and delivery schedules, and an iterative approach, this encourages a rapid and flexible response to development modifications.

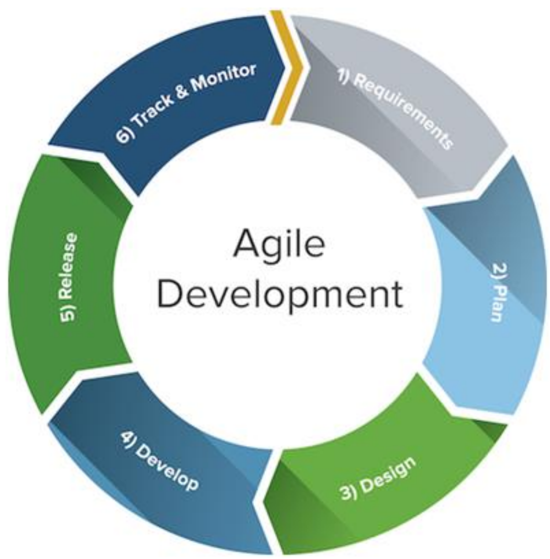


Figure 53 – Agile development method

7.1.3 Spiral

Spiral software development combines elements of both the design and prototyping stages of SDLC. This is done in an effort to take advantage of both the benefits of top-down and bottom-up approach. This model of development combines the features of the prototyping model and the waterfall model. The spiral model is the preferred method of development for large and complex projects. This model uses a lot of the same stages as the waterfall model, in the same order, separated by planning, risk assessment, and the building of prototypes and simulations.

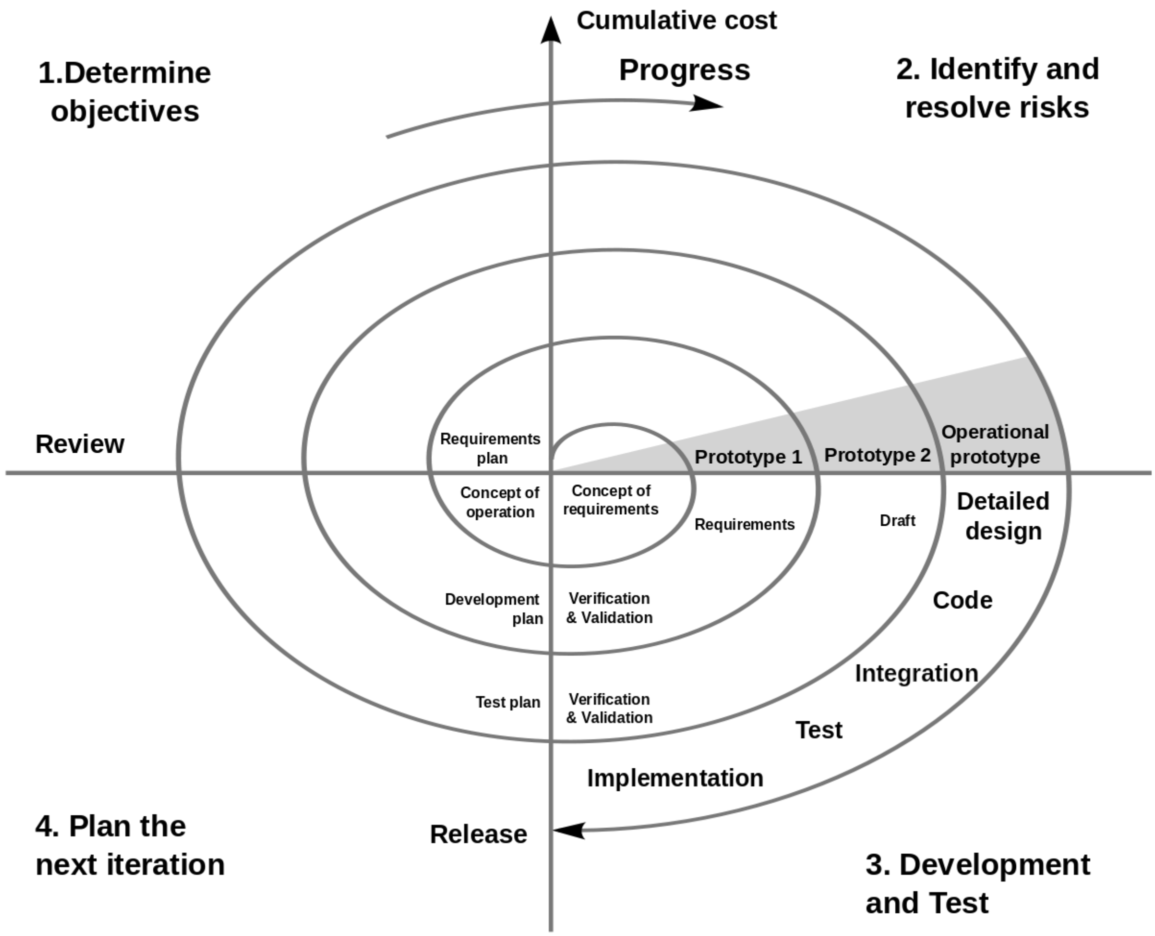


Figure 54 – Spiral development method

7.2 Hardware Testing

Hardware testing of the various subsystems of the smart mirror will allow us to know everything is working before we finalize our circuit board design and send it off to be shipped to the fabrication house. This step is debatably the most important step because it's essential to have our circuit board design correct or our project could be set back weeks if not more by waiting for another circuit board. Hardware testing will be done in Multisim first if possible and then on a breadboard.

After the PCB has been delivered, more testing has to be done on both the software and hardware sections to ensure that the PCB is functioning like it should.

Also, testing the hardware and software on the PCB would test compatibility of the object/software with the PCB.

Objective:

The objective for testing is verifying that every subsystem in the smart mirror design works and if it doesn't work as expected, a different part will be ordered and tested. Testing on a breadboard will be like testing a prototype before getting to the final stage of the design. Even if parts do work as intended, some features may cause for us to switch the part if we deem that it may bee too difficult to implement over another part that does similar functions.

Environment:

The hardware testing will be performed in the UCF Senior Design lab where there is access to a variety of power supplies and measuring equipment including:

- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator, 25 MHz
- Tektronix DMM 4050 6 ½ Digit Precision Multimeter
- Agilent E3630A Triple Output DC Power Supply

Procedure:

1. Power Arduino microcontroller and wire various connections to the power supply and sensors.
2. Write code to test gesture sensor and light up LEDs depending on the direction swiped.
3. Write code to illuminate LED from Raspberry Pi to test GPIO output.
4. Lastly, connect Raspberry Pi to the Microcontroller and make sure both can communicate over Serial UART.

7.2.1 Microcontroller Testing

First step in testing the microcontroller was writing some code to blink the included LED on the Arduino Uno board. This was to make sure that the board is working correctly, and code can be uploaded to the microcontroller without any issues. This was simple and worked the first try so I know the microcontroller is good and now I can write code to talk to the gesture sensor.

7.2.2 Gesture Sensor Testing

The Gesture sensor we have communicates over an I^2C bus to the microcontroller to send various commands. The sensor can be used to detect ambient light, gestures, and distance up to 4 inches. Our use is for the gesture detection alone.

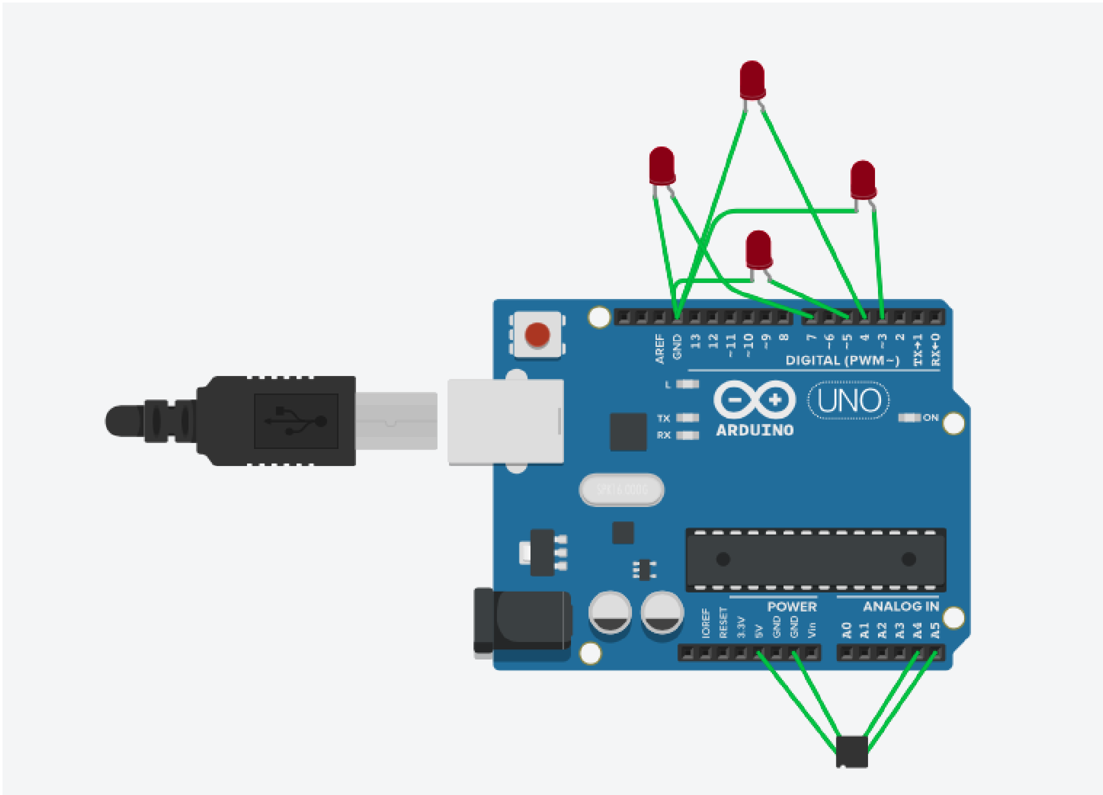


Figure 55 – Gesture sensor test setup

Here is the circuit configuration used to test the gesture sensor setup. First the gesture sensor was connected to the microcontroller using the two I^2C pins which on the Arduino Uno are analog Pin 5 and analog pin 4. Next the sensor needs power, so it's wired to the 5 volts output and ground on the Arduino board. Testing is difficult without any output to see so I wired up 4 LEDs to 4 digital pins on the Uno and used those to signal the output of the gesture sensor. When a left swipe is detected, the left LED lights up, right swipe lights up the right LED, etc. This made it very easy to automatically see if the circuit was working without the Serial monitor. The sensor worked up until about 5 inches and then wouldn't sense any gestures as far as I could see during testing.

7.2.3 Microcontroller-Raspberry Pi Communication Testing

The next piece of hardware that needs testing is communication between the Raspberry Pi and Microcontroller. This is essential because all the input methods will need to be communicated to the Pi so that the user interface can be updated accordingly. Doing this required me to write an application for the Raspberry Pi so I could receive and send Serial messages through the Pi itself. I decided to write the applications in Java because it can run on multiple operating systems.

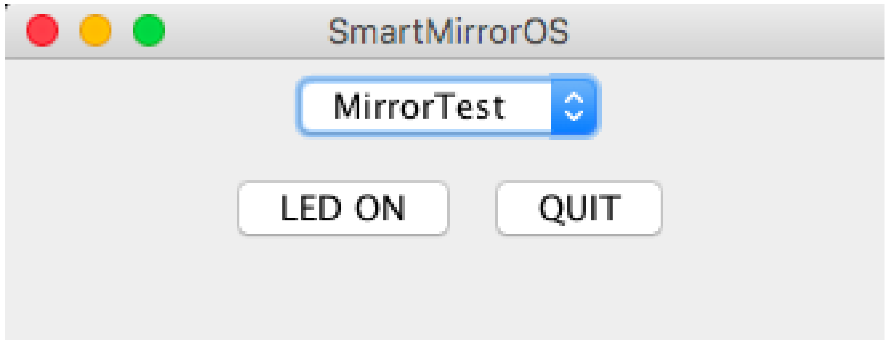


Figure 56 – Java application for the Raspberry Pi

Using the WiredPi library, I was able to control a GPIO pin of the Raspberry Pi to turn on and off an LED. Now that I've figured out how to write java apps and get them working on the Pi, it's time to test the Serial Communication capabilities.

Our Microcontroller cannot simply be connected to the Raspberry Pi though, there's an issue with doing that. The Pi operates on 3.3-volt logic while our Microcontroller uses 5-volt logic. This imposes an issue when you want to communicate between the two. There is two options to make them compatible though and they're both fairly simple:

1. Buy a level shifter
2. Build a level shifter

Both options are simple enough but what will be the main difference? The only sacrifice will only be size. There's logic level shifter integrated circuits in the market and they're quite small but if we have the space for it, designing our own isn't too hard. It only requires one transistor and a few resistors to build. Here is the circuit and simulation:

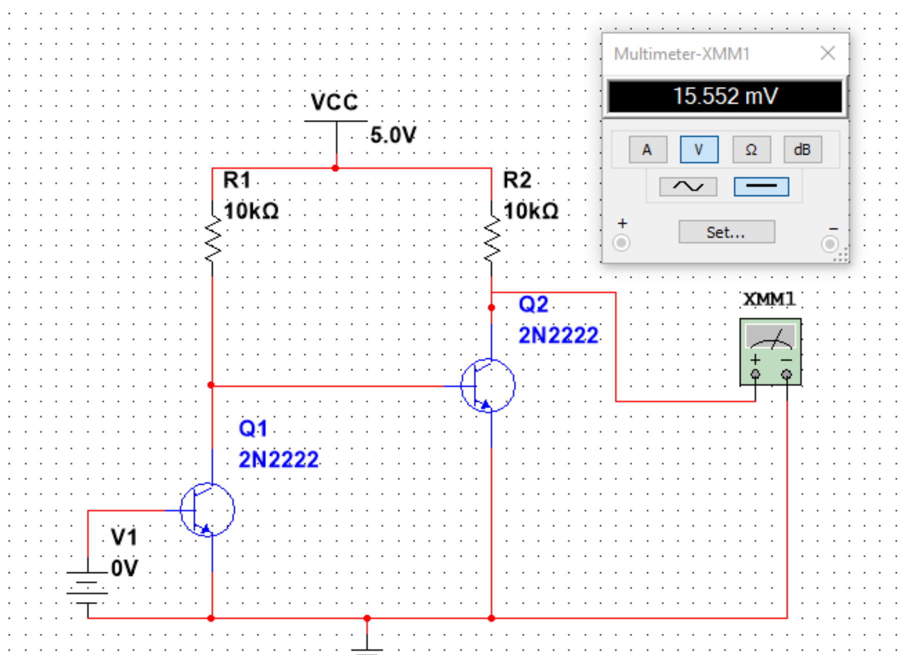


Figure 57 – Level shifter simulation with a 0 V input

This circuit is quite simple in its construction and uses parts we already have so it won't use any of our budget and that is one of the reasons we will be building our own logic level shifter. The operation is as follows: The input is on the base of the first transistor, Q1, and when that is zero volts, so the transistor is turned off. Since no current is then flowing through the collector resistor, the voltage at the collector of Q1 is 3.3 volts and this will bias Q2 to be in saturation. Since Q2 is in saturation, the voltage across the transistor will be about 0.2 volts and so the collector voltage for Q2 will be about VCC or five volts. Using two of these will allow us to send data between our Microcontroller and Raspberry Pi without damaging anything. The above figure shows the simulation result for an input of zero volts, following is the simulation for a 3.3-volt input:

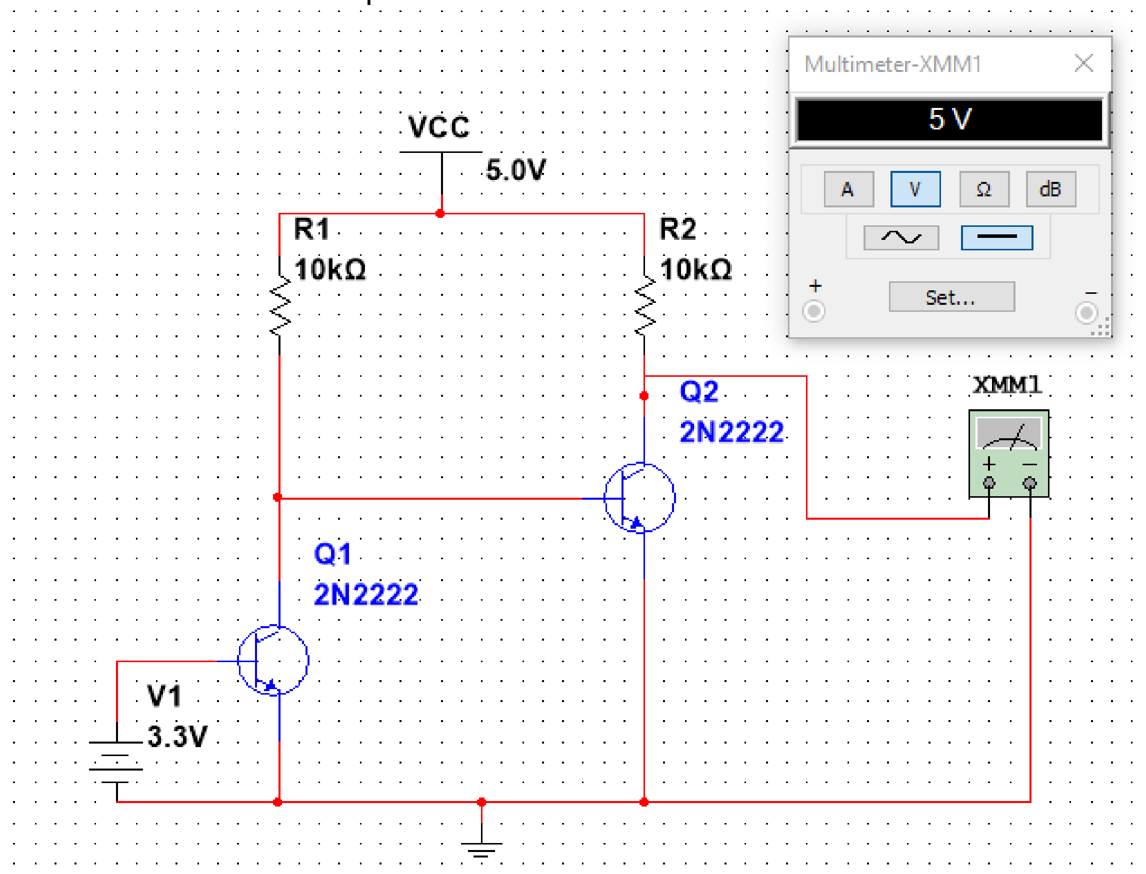


Figure 58 – Level shifter simulation with 3.3 V input

As you can see, the level shifter works as expected with just two transistors and a few resistors. Unfortunately, this circuit won't work both ways, but the same circuit can be made into a 5-volt to 3.3-volt level shifter by changing VCC to 3.3-volts.

Now that the level shifting is handled, it's time to setup a test that demonstrates the ability for the Raspberry Pi and Microcontroller to communicate to each other. The first step is connecting the Pi and the microcontroller and that will only require two wires for both a Tx and Rx line. The Tx will be the transmit of the Microcontroller and that feeds into the Rx, or receive, of the Raspberry Pi. Then the Pi Tx will be connected to the Rx of the microcontroller.

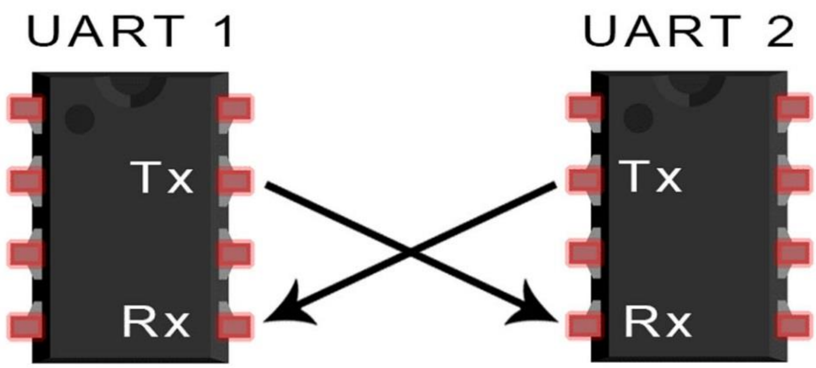


Figure 59 – Serial UART, Source: (Circuit Basics, n.d.)

I will be writing a program that allows a button to be pressed in a raspberry Pi java program and the microcontroller will that light an LED depending on the button pressed. This will test if communication works and give a visual notice that the software and hardware is working. Eventually all of this will lead to the test of the whole system, but it is important to start small and work up from there. Following is the software diagram:

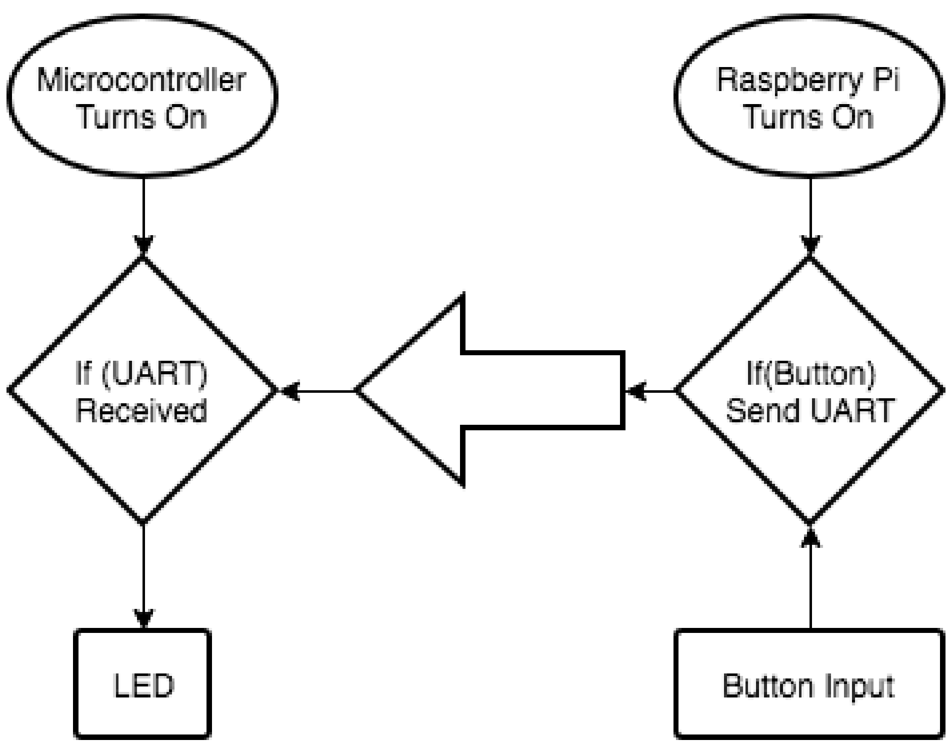


Figure 60 – Communication software diagram

As detailed in the diagram, the program starts with both the microcontroller and Raspberry Pi starting up. The Microcontroller will be in a loop just waiting for a Serial input to happen and when it does it'll activate the digital pin that outputs to an LED. The Pi does the same in that it is waiting for a software button to be clicked and once that happens, it'll send a Serial Command to the microcontroller to be acted upon. This will very much show proof of concept for what the whole system will be like when complete because this communication is essential in making the project work correctly. Especially for relaying information such as the Gesture controls.

The tested circuit and program worked as expected and now can be used in the final project as a reliable way to communicate between the Microcontroller and Raspberry Pi. The pins used on the Raspberry Pi and Microcontroller are as follows:

Table 29 – Microcontroller pins used

Pin	Purpose	Connection
Analog Pin 4	I^2C Bus	Gesture Sensor
Analog Pin 5	I^2C Bus	Gesture Sensor
Digital Pin 1	UART	Raspberry Pi
Digital Pin 2	UART	Raspberry Pi
Digital Pin 3	Digital Output	LED
Digital Pin 4	Digital Output	LED
Digital Pin 5	Digital Output	LED
Digital Pin 6	Digital Output	LED
Ground	Common GND	Connect all references
5-Volts	Sensor Power	Power Gesture Sensor

Table 30 – Raspberry Pi pins used

Pin	Purpose	Connection
14	UART	Microcontroller
15	UART	Microcontroller
2	5-volts	Logic Level Shifter
1	3.3-volts	Logic Level Shifter
40	Digital Output	LED

Much of these pins will also be used in the final design and even more as the full set of Photodiodes are connected to the microcontroller. A small issue encountered during testing is with the UART module on the Raspberry Pi 3. Since Bluetooth was added to the Pi 3, it uses the UART module that was previously free for use with any programs written on the device. A small software dependent UART was installed for user programs and it can be less reliable and cause problems because it uses the CPU clock which is variable. The solution to this was to lock the CPU clock to one value so that it doesn't change and the UART is stable. There is a small decrease in performance, but it is barely noticeable and must be done if we want stable communication. There is a second fix as well and that is by disabling the Bluetooth module but since we plan to integrate Bluetooth functionality, that isn't an option for our project.

The microcontroller has been prototyped using an Arduino Uno board because it uses the same microcontroller as we plan on using.

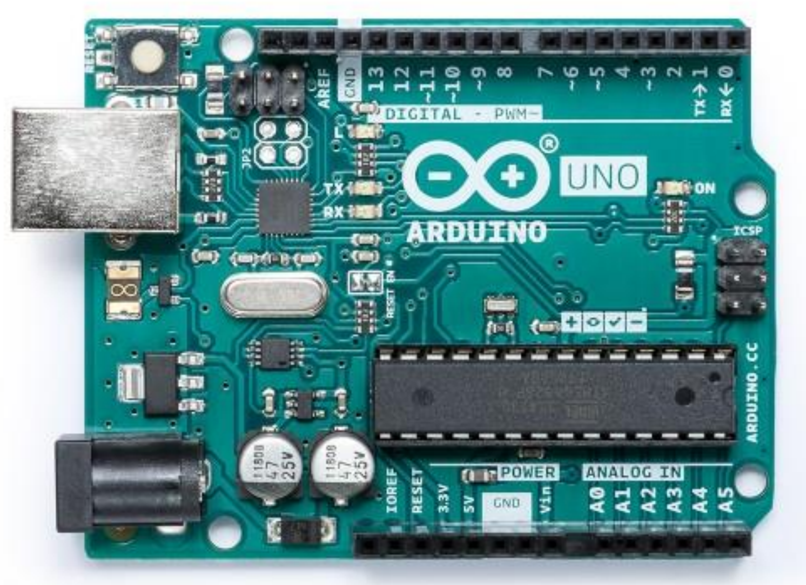


Figure 61 – Arduino Uno Board, Source: (Arduino, n.d.)

It's a very robust board with a lot of digital and analog pins available for use on the microcontroller. It's also easily programmable through USB and the Arduino IDE. The Arduino IDE will allow us to use a plethora of libraries made just for the Arduino platform and integrate them into our project, making it much easier.

Using the Arduino Uno also provides us another benefit for our project. Once the PCB's are made and we have our own board with an integrated microcontroller, the Uno can be used as a programmer for the chip. A programming application can be uploaded to the Uno and once that's running on it, we can upload a bootloader to our own chip using it. It's a straightforward process and just means we will have to take care to break out the serial pins on our custom PCB. The chip will be programmed over serial using the SPI pins of the microcontroller.

Since we are now using the ATMega32u4, we will no longer need the Arduino Uno as a programmer. Although it will still be used as a backup plan just in case the USB doesn't work or fail. This will act as a failsafe measure and also has the benefit of having a way to program the device from a different angle since the USB port and SPI interface will be facing different directions on our board.

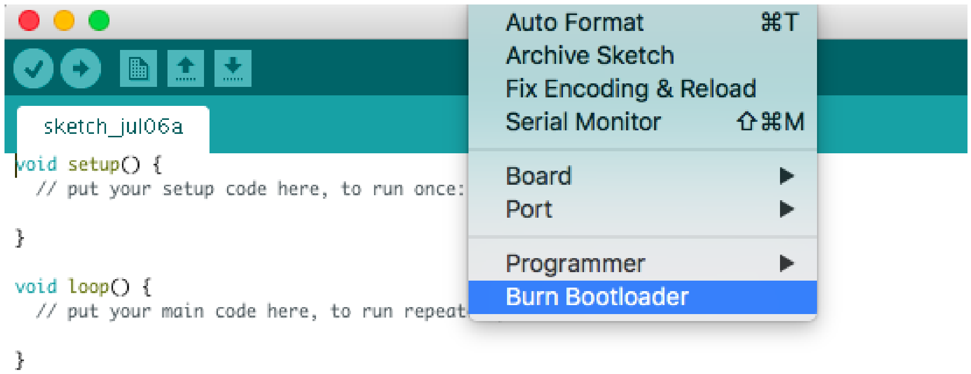


Figure 62 – Arduino IDE with programming options

Once the Uno is setup as an ISP(in circuit programmer), it's as simple as pressing a button. Once the bootloader is on our own ATMega32u4 chip, we can simply upload our code to the board. During current testing we've been programming the Arduino board through USB because it has a specialized chip for converting USB signals to Serial SPI that the microcontroller uses. Our final circuit won't use this chip so programming through USB won't be an option and so a program will be used that turns our testing device, the Uno, into an ISP (in circuit programmer). So, in the final circuit a 6-pin SPI cable can be connected between the two devices and our microcontroller will only be programmed through the Uno device.

Table 31 – Programming pins and their corresponding digital pins

Pin	**Name**	**Purpose**
Digital Pin 13	SCK	Serial Clock
Digital Pin 12	MISO	Master In-Slave Out
Digital Pin 11	MOSI	Master Out-Slave In
Digital Pin 10	SS	Chip Select

Although these programming pins use digital outputs, we can still use them in our own code. Once the circuit is programmed these pins are free to use for whatever purpose we require. The other two pins on the 6-pin connector will be VCC and Ground. VCC is needed to power the microcontroller while it's being programmed, and ground is also for that and to have a common reference for both boards.

7.2.4 Optical Components Testing

The optical components will be tested by creating a simple electrical circuit and testing the functionality of each component. Since the IR light sources and photodetectors will not be mounted onto a PCB we are able to buy through-hole components for both testing and use in the final product. This is possible due to the components being embedded in the frame of the mirror. We will have wire running from the optical components to connectors on the board for two reasons. The first being that, by having a connector between the optical components and

PCB we are able to easily switch out the PCB should we discover a hardware bug or accidentally destroy it. This will save us time if such an event occurs since it will not require the disassembly of the entire smart mirror. Additionally, since the optical components will be tested before they are mounted in the mirror, we can use sturdier and more permanent mounting solutions since they will not need to be removed should the PCB fail. For the light source it will be done by creating the electrical circuit shown in the following figure. Note that the IR LED cathode and anode will be connected in reverse to what is shown in the figure

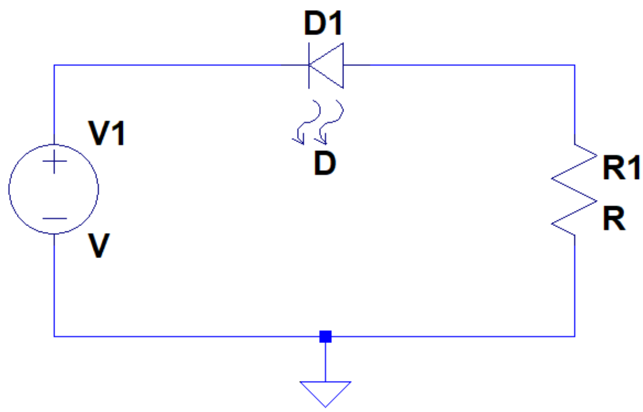


Figure 63 – Test circuit for IR LED and photodiode

Once the circuit is built onto a breadboard and enough voltage is provided to push the semiconductor source above the threshold voltage and turn on, we will use an IR card to ensure that the source is emitting light as expected. If we are unable to see any light appear on the IR card after power is applied and we have verified the electrical connections with a multimeter, we can be certain that the IR light source is defective.

Once the functionality of the IR light source has been confirmed, we will create an identical circuit on another breadboard, however the IR light source will be replaced with the photodetector. With the IR light source positioned to emit light onto the surface of the photodetector and power provided to both circuits a multimeter will be used to measure the current flow through the detector circuit. If current is flowing, then the photodetector is operational. However, if that is not the case and we have confirmed that surface of the photodetector has been exposed to IR light by using the IR card we can be certain that the photodetector is defective.

7.2.5 Voltage Regulator Testing

Other than the ATMega32u4 microcontroller and Raspberry Pi, there are several circuit components that need testing, such as the LM7805 voltage regulators. In order to test the LM7805 voltage regulators we connected the input pin to the positive terminal of a DC power supply and the ground pin to the negative terminal of a DC power supply. With the power supply turned on, we increased the voltage above the regulated output levels, which for the LM7805 can range from 4.8V to 5.2V, but within the appropriate voltage levels for the device. Using a multimeter, we measured the voltage between the input pin and ground pin to make sure an adequate electrical connection was made, followed by measuring the voltage between the output pin and ground pin. Once we saw that the output is providing a voltage between 4.8V and 5.2V, we were able to confirm that the LM7805 voltage regulators we ordered were properly working.

7.2.6 CD4051 Multiplexer Testing

When testing the CD4051 multiplexer we connected +5V to the inputs of the multiplexer and made sure that the appropriate voltages were being applied to power the device. Once this was done, we applied voltage to the select lines in order to select the input pin which had voltage applied to it. Using a multimeter, we measured the output relative to ground to make sure that a voltage was being outputted. The following figure shows the schematic for testing the CD4051 multiplexers.

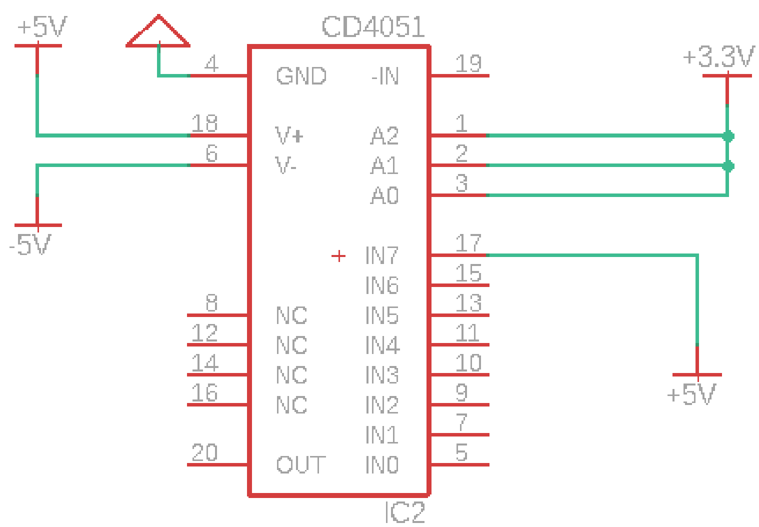


Figure 64 – Circuit used to test CD4051 multiplexers

7.2.7 Raspberry Pi Camera Module Testing

For this part, we are planning to use the camera module mainly for facial recognition. This part of the test mainly depends on the software portion, we used a simple computer webcam to test the software function. We confirmed that the software functions using the webcam, transferring the software to the Raspberry

Pi would not impede the function. We have confirmed however, that the camera module is indeed working as intended. The command (raspistill) was used to take a still image using the camera. The output picture came out great in high detail. One of the concerns that came up with the testing of the camera module is the length of the ribbon cable. Ideally, we would want to have the camera mounted on the top middle section of the smart mirror. However, to deal with the issue, we will just have to design the layout of the smart mirror so that the Raspberry Pi 3 model B is mounted somewhere near the top middle section to have the intended design stay the same.

8 Integration & Improving the Design

Once the PCB design has been sent out to be manufactured the team intends to begin the final construction of the smart mirror. Connectors will be used to connect the wiring from the LEDs and photodiodes embedded in the frame of the smart mirror to the custom PCB in order to allow for easy removal of the board if tweaking or a rework of the circuit design is needed.

When all the components have been assembled into the initial smart mirror design, testing will begin. This will be done by first confirming that the hardware works both as intended and reliably to allow for a seamless user experience. To confirm that the hardware is working properly the team will repeatedly provide inputs through the various methods available, such as facial recognition, using the gesture sensor, and using the optical touch grid. Using an oscilloscope with probes connected to the various parts of the circuit board we can view the signals as we provide inputs in order to ensure that there is no excess noise somewhere in the signal path.

Once the hardware bugs have been ironed out, the team will begin testing the software. Software testing will be done by first checking the connectivity of the smart mirror by connecting it to various smartphones of various brands and operating systems via Bluetooth. This will allow us to confirm that we are able to obtain a consistent and reliable connection. Additionally, the Wi-Fi will be tested by making sure that the smart mirror is pulling relevant and accurate information for viewing, such as the local weather.

The inputs to the smart mirror must also be checked. Although by this point we will have already confirmed that the signals are propagating as intended, we must still make sure that the user interface responds appropriately and that there are no bugs in the software which would cause the input to be misread by the smart mirror.

The final stage of testing will consist of either a team member or a close friend of one of the team members using the smart mirror in their daily lives. This will provide us with feedback and constructive criticism regarding the features and user interface implemented.

9 Administrative Content

This section will be where the management portion of the project can be found. This section will discuss the current project schedule as well as the desired milestones and budgeting. It is important to note that this portion, like the rest of this document, is subject to change as the project evolves.

9.1 Budget & Funding

Our project will be self-funded and based on the research we have done, and will continue to do, as we progress with this project and improve the design. Currently we believe that it is possible to keep the total cost of the components under $550.

Table 32 – Smart mirror budget

Device	**Quantity**	**Cost estimate**
Two-Way Mirror	1	$50 - $100
Monitor/Tv	1	$150 - $200
Processor/micro-controller	1	<= $10
Camera	1	<= $20
Wifi chip	1	<= $10
Bluetooth Chip	1	<= $10
Optical Touch Grid	N/A (multiple light sources)	$75 - $100
Gesture Sensor	1	<= 20
Custom PCB	3	$30 - $50
Power Supply	1	$15 - $30
Total Cost	**N/A**	**$390 - $550**

9.2 Project Milestones

These project milestones are tentative as we continue to improve our design and update our estimates for both cost and time to completion. It helps us keep track of our project timeline and see whether or not we are falling behind. These milestones will be used as an estimation, however, finishing the project early will leave more time for testing and fixing errors. Therefore, it is essential that we save as much time as possible on this project. We have also considered to continue work on this project over the two-week holiday between the semester.

Table 33 – Project milestones

Milestone Name	**Duration**	**Week**
Senior Design 1		
Brainstorm for project ideas	3 weeks	5/14 - 6/4
Divide and conquer project report	5 days	6/4 - 6/9
60 page documentation report	~ 4 weeks	6/9 - 7/6
Design PCB & order all necessary items for project	~ 2 weeks	7/6 - 7/30
100 page report	~ 2 weeks	7/6 - 7/20
120 page final report	~ 1.5 weeks	7/20 – 7/30
Senior Design 2		
Building project prototype	~ 4 weeks	8/20 - 9/20
Test and adjust prototype	TBA	TBA
Finalize prototype	TBA	TBA
Peer presentation	TBA	TBA
Final report	TBA	TBA
Final representation	TBA	TBA

9.3 Division of Labor

The figure below shows the current division of labor. Tasks have been divided based on hardware and software tasks and everyone's respective strengths. This is subject to change depending on how the project changes as we get further into the building process. The division of labor shows what each person will be held responsible for. Since many of these components are dependent on each other there will be collaboration between the team members, even on components where there is a single individual responsible for its completion.

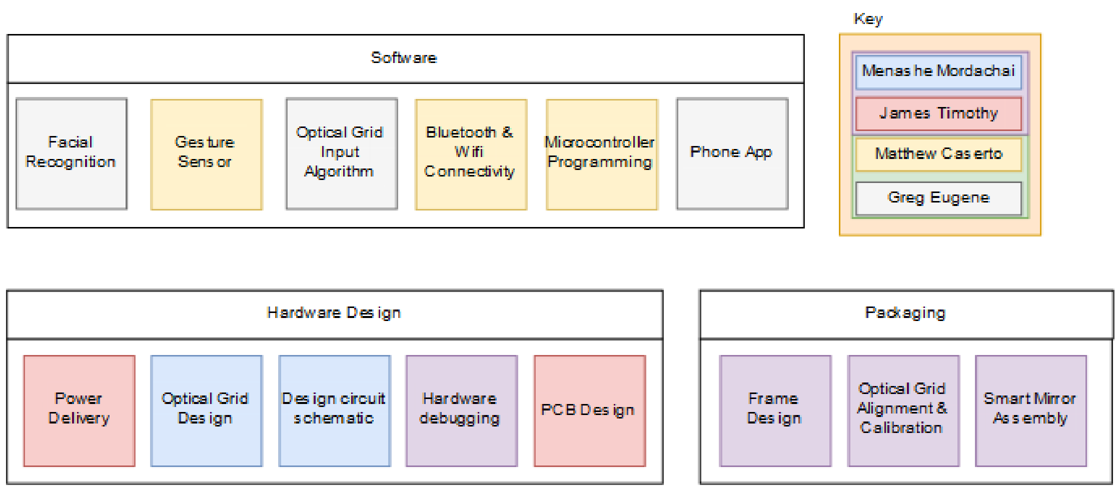


Figure 65 – Current division of labor

10 Conclusion

During the research and design of our smart mirror, many ideas have come together to create a full feature set for a mirror we believe will be very functional, useful, and unobtrusive. Every decision was made with the opinion of all group members to create something we could all contribute to from the IR frame to the PCB and software. All this technology will come together to create something that should resemble a final product that could be found on a store shelf. It is of course still a prototype and might still resemble one in some ways since some parts, such as the frame, will be hand built.

Every step in the decision process involved one simple idea, that good technology shouldn't be noticeable or invasive. Our project was designed from the ground up to exist when it is needed but only be a regular mirror when it is not. Everything from the IR elements hidden behind the frame to the gesture sensor behind a sleek piece of translucent plastic. Since it is meant to be inside a home, it must look nice and have the appearance of something people might want to place in their bathroom or bedroom. The aesthetics of our project might arguably be the most important part and difficult from a design perspective.

Privacy is also a very big concern to us, especially considering that the mirror will have a camera when it is designed to be in any environment, including a bathroom. That's why when we designed the camera system, the power to the camera must be turned on using a transistor in software and a red led will sit behind the mirror to let users know the camera is activated. The LED can't be deactivated in software and that's an important distinction when it comes to the security of the mirror.

Our design has been optimized to evenly distribute the workload between team members and make it so that everyone has a fair amount of work. The varying feature set will allow us to widen our scope and learn more about different technologies and software we haven't used while in school. Ideally this project should push us all out of our comfort zones and force everyone in the group to learn new skills while working through the two semesters that this class takes place.

Additionally, the final mirror included most of the design considerations brought up in this paper. These include the touch IR Frame, Bluetooth connection, multiple applications, and more. One feature that didn't make it though was the gesture sensor because as the design with the IR frame advanced, it became a superfluous method of input.

11 Appendix A: References

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12 Appendix B: Permission Requests

Sparkfun

James Timothy <jatimothy11@gmail.com> 5:44 PM (3 hours ago)

to support

Hello,

I am a student from the University of Central Florida, there is a couple of images from your site that we wish to use for our senior design report. This report is for educational purposes only and will not be used for profit. The images we wish to use are the PCB layers images and the PCB routing example from the tutorial given here:

https://learn.sparkfun.com/tutorials/using-eagle-board-layout

Best regards,
James Timothy

Jenn M replied:

Good evening!

You are welcome to use our images for your project, just please provide the photo credit to us.

Let me know if you have any other questions. Thanks!

Best regards,

Jennifer Miller

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James Timothy

jatimothy11@gmail.com

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Best Regards, James Timothy

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