Emotionally Intelligent Mirror

ECE 445 Final Report - Fall 2022

Project #15

Tala Aoun (taoun2), Apurva Chanda (apurvac2), Aishwarya Rajesh (arajesh4)

Professor: Arne Fliflet

TA: Akshatkumar Sanghvi

Abstract

The COVID-19 pandemic caused a major increase in the level of depression and people's mental health declined tremendously as people felt more lonely. A potential solution to this problem that our team built throughout the semester is an emotionally intelligent mirror. The mirror essentially analyzes people's facial expressions and responds by playing a message and a song that corresponds to the specific emotion recognized. The project consists of a double-sided mirror where you can see yourself as well as a display that is used to register or login into the program. A camera placed on top of the mirror captures live footage of the user's face and sends it to the raspberry pi where the model recognizes the expression and then plays a certain message and song relating to that specific emotion. In order to address the problem of providing help for people that might be struggling, after 30 uses of recorded Sad, Angry or Fear expressions, the screen displays numbers for hotlines and counseling centers in different locations.

Contents

1. Introduction

The emotionally intelligent mirror was built to address the problem of increasing feelings of depression or loneliness especially throughout the COVID-19 pandemic. The mirror is able to predict the user's facial expressions and therefore emotions based on a Convolutional Neural Network model. The mirror acts as a companion and uses messages and songs to reflect the user's emotions and make him feel better. The mirror is also able to provide counseling resources after it detects 30 uses of emotions such as sadness, anger or fear. Multiple profiles can be created on the mirror but the data in each user's profile is protected with a username and password that the user creates. In order to access your profile and start the model, there is a login/registration page that is displayed on the screen. The design of the mirror consists of 4 main subsystems: camera, user-interface, power and controls subsystem.

1.1 High Level Requirements

These are the high level requirements we set out to achieve with this project

1. The mirror will accurately identify if the user's emotion is negative, positive, or neutral 90% of the time and the specific emotion 80% of the time it is used.
2. After 30 uses of consistently negative emotions recorded on a user's profile, the profile will be flagged, because the user is exhibiting a downward trend in terms of their mental health. It will be flagged and resources like therapists and hotlines will be provided for the user.
3. The mirror will be able to identify one of the basic seven human emotions in under 10 seconds according to the goal accuracy levels above.

1.2 Subsystem Overview

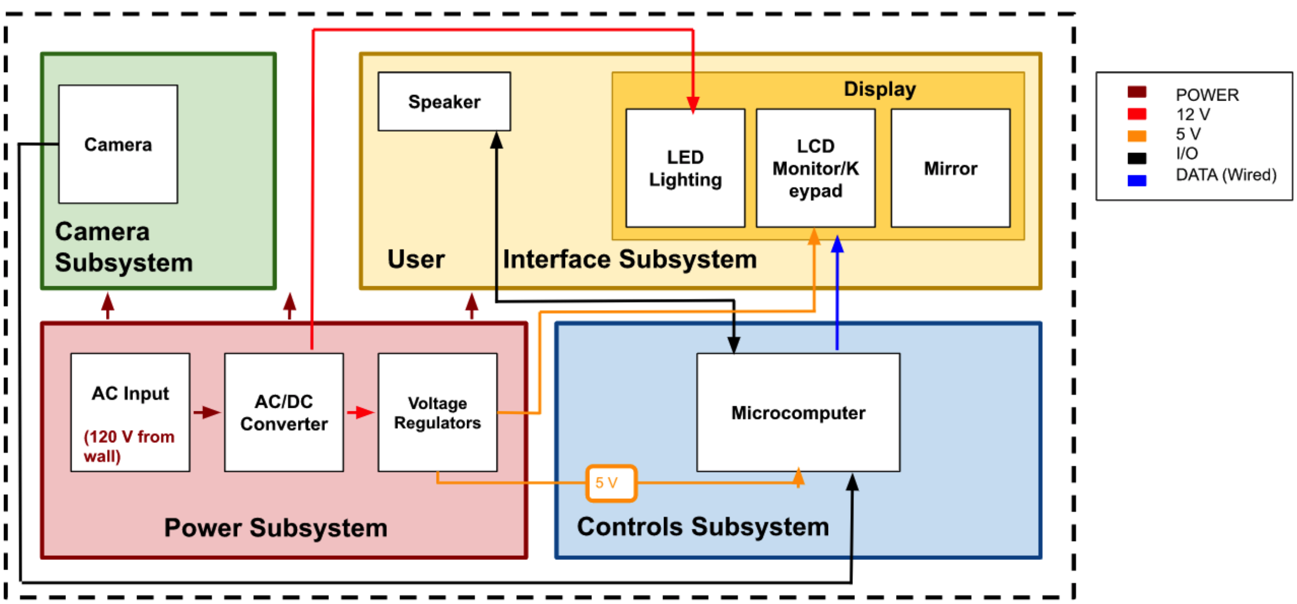

Figure 1: Block Diagram

User Interface Subsystem —

The user interface subsystem is the main aspect of our project. It consists of the following materials. The display is used to login/register their profile and also provides the user with resources when needed. It is attached behind the two sided mirror, so the user can see both themselves and the display. The speaker is used to play messages and songs to the user. To reduce overall power consumption from the external wall source on the PCB, the LED lights are used to provide the user with better lighting and an aesthetic feel as if it is in the bathroom. The user interface subsystem receives data from the controls subsystem as all data and I/O is routed through the Raspberry Pi. It will interact with the power system to stay running.

Camera Subsystem —

The camera subsystem contains the high quality camera that is used to capture the user's face and sends the picture to the controls subsystem to be analyzed. While it may seem rudimentary, having the camera as its own subsystem is important to this project since the camera will be providing the input to the microcomputer. Therefore, the camera is one of the most important aspects of our design, since without it we would not be able to analyze and react to the emotions of the users. The camera will provide the live picture of the user's face to the microcomputer which will be used to determine what emotion the user is feeling. This will be done using a CNN algorithm which is discussed in detail in the Software Design section of this report. The camera subsystem will only provide input to the controls subsystem but will never receive input from any other subsystem. It will interact with the power system to stay running.

Controls Subsystem —

This subsystem consists of the microcomputer, Raspberry Pi, that receives input from the camera subsystem and sends data to the user interface subsystem. The controls subsystem runs the prediction model and decides what song or message to play to the user. The microcomputer will be considered one subsystem that we will call the controls subsystem. The microcomputer is used to support graphic outputs on LCD displays, handle multiple 10 processes, work with a camera, and communicate serially. This subsystem will interact with all other subsystems both sending data and receiving it. As it is the brain of our project, it'll be a key focus.

Power Subsystem —

The power subsystem connects to all other subsystems. In order to have the whole project functioning, the power subsystem will connect to all the other subsystems through various physical connections. From the wall, the AC input will be directed to an AC to DC converter to switch the type of current. There will be a power loss of about 5-20%, so the diode and capacitor will be chosen accordingly. If we choose to add a regulator, though not technically necessary, we would use a switching or linear voltage regulator to get the voltage amounts we need for different subsystems. Finally, we would use wire connections to connect the controls system to power all the components.

2 Design

2.1 Physical Design

2.1.1 Electrical Components

Over the course of the semester, the physical design changed drastically based on lessons learned and general feedback. A 120 V power supply through an AC to DC adapter wall adapter that brings it down to 12 V. The LM7805, a 12 V to 5 V Linear Regulator, was used to step down the voltage to the 5 V power rail. Within this system, there is a 1 uF capacitor and 0.1 uF capacitor connected in parallel with ground. The first capacitor is connected to the input pin, ground is connected to the device ground, and the second capacitor is connected to output. Originally, the plan was to use a buck converter and then a linear regulator to smooth out any fluctuations in the output voltage of the first regulator, however the 5 V output was not stable enough to be connected to the Raspberry Pi. Using a linear voltage regulator provides a steady voltage to the other subsystems. If we went with the 3.3 V power source, we would have followed a similar design thinking and the circuit in the diagram below. This hardware design provides a simple and effective way to power our project with a 120 V DC power source, with the added protection of the capacitors to ensure that everything is operated safely and reliably.

An additional component that was on the breadboard was 20 mm burg pins. When comparing the pros and cons of male versus female connectors, it was not clear which would work better since they have the same functionality, initially. For that reason, both sets were ordered and tested with. Ultimately, we went with the female connectors as they allow for more versatile connections.

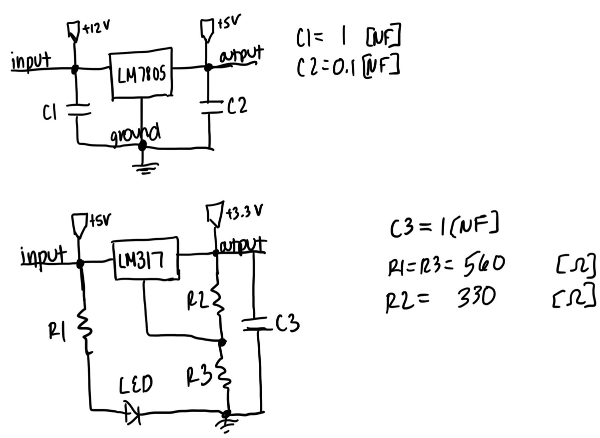

Figure 2: Regulator Circuits

2.1.2 Mechanical Components

Enlisting the help of the ECE Machine Shop, we were able to assemble all of our parts in one, cohesive display. The wooden holder encases the two sided mirror and IR frame and comes with a stand. There is a small portion near the top for easy access to the camera for the user. As a special touch, we painted it a nice, glossy black to pull in the whole ambience as this product is designed for an intimate room like a bathroom.

Putting together all the components, we came up with the following project. Below, the picture of the front and back of the mirror showcases how everything came together in the final iteration.

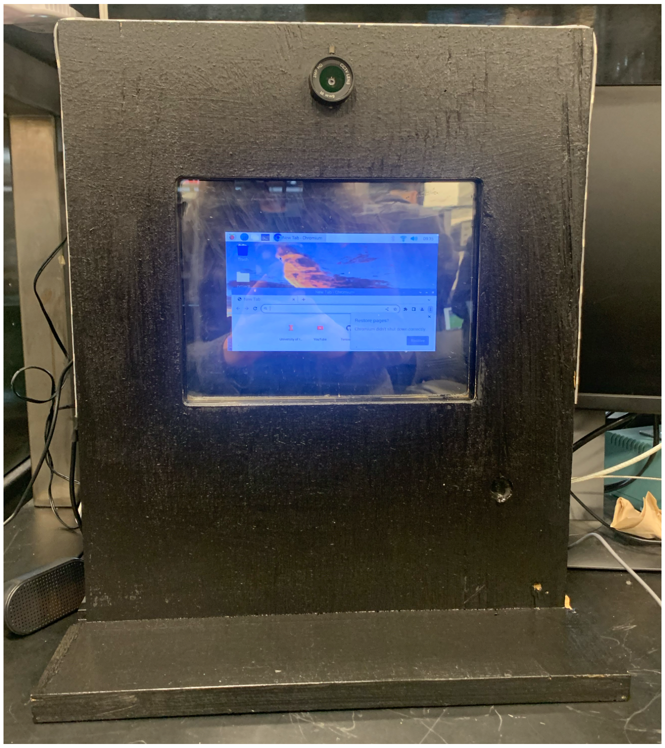

Figure 3: Mirror Design - Front

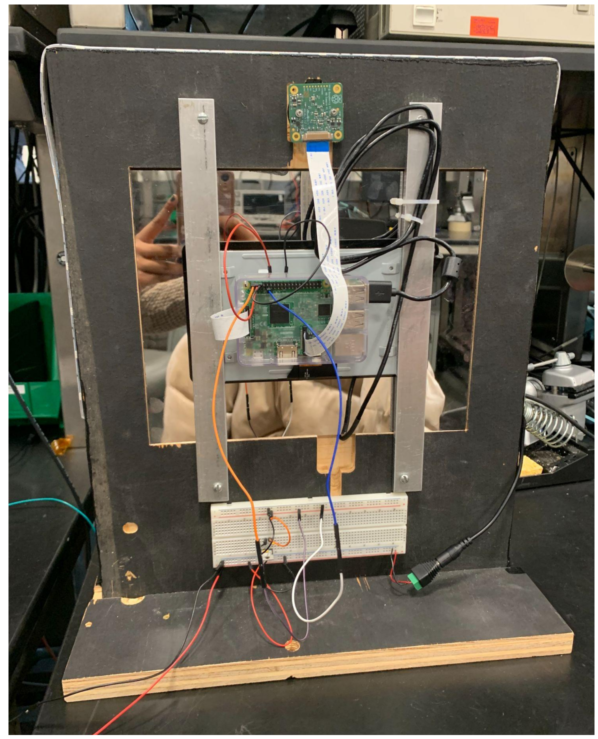

Figure 4: Mirror Design - Back

2.2 Software Design

2.2.1 CNN Model

For the software design, we used a convolutional neural network called VGG16. A convolutional neural network or CNN is a deep learning algorithm that differentiates between images by assigning weights to various objects within the image. We used this model to differentiate between the 7 different human emotions: Happiness, Sadness, Anger, Disgust, Surprise, Fear and Neutral. VGG16 is a convolutional neural network with 16 layers. In VGG16 there are 13 convolutional layers, 5 Max Pooling layers and 3 Dense layers. Even though that sums to 21 layers, only 16 layers are assigned weight. We did not build the VGG16 model from scratch but instead we used Transfer learning. Transfer learning means using a pre-trained model since those are trained on much larger datasets. We used a pre-trained model trained on the ImageNet dataset. ImageNet is a really large dataset for research purposes which includes millions of images. After loading the model, we included it in the CNN model we built which contained 3 Dropout layers, 4 Batch Normalization layers, 4 Dense layers and 3 Activation layers. The dropout rate we used is 50% and the activation function used is the rectified linear unit activation function (ReLU). This function is a piecewise function which is zero for negative input values and equal to the input when the input is zero or larger than zero. A pooling layer calculates the maximum value for patches of a feature map and uses it to create a downsampled feature map. A dense layer is a layer that is deeply connected with its preceding layer which means the neurons of the layer are connected to every neuron of its preceding layer. A Dropout layer is a mask that nullifies the contribution of some neurons towards the next layer which helps prevent overfitting. Batch Normalization is a technique done between the layers of the neural network. It is done along mini-batches instead of the full data set. Adding Batch normalization to our model speeds up the training and uses higher learning rates. We then trained this model on the FER 2013 dataset. After training the model for 5 epochs, the model was saved to the Raspberry Pi. We plotted 3 graphs for Accuracy, Loss and AUC. AUC stands for Area under the curve and it is the measure of the ability of a classifier to distinguish between classes. If the AUC is high then the model is performing well.

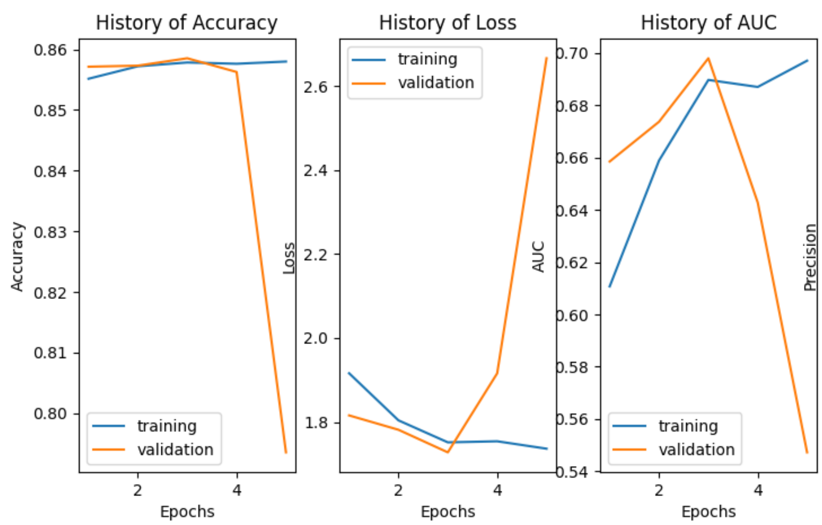

Figure 5: Plots of the metrics of the model's performance

To detect the position of faces, we are using Haar-cascade. The Haar cascade algorithm is a sliding window algorithm that detects objects based on its features. It employs different types of features to detect faces such as the size and location of facial features like the nose bridge, mouth line and eyes. We are using an xml file that contains a pre-trained model able to recognize faces from the camera. After we detect the face, we need to resize it to the size of an input image that the model can understand. We convert the image to grayscale and normalize it then we can have the model predict the emotion.

2.2.1 User Interface

In terms of software, our project also had a GUI for login/registration and the information from that was stored in a SQL database. The messages and songs we are picking from to play to the user are also stored in SQL databases. The user interface was created using the Tk interface in Python. The user interface has two buttons: Register and Login. When Register is clicked, a new window opens where the user can enter his name and password, this data is then saved to the SQL database. For login, when the user inputs his name and password, this information is compared to all entries in the database to see if one entry matches this exact information. If there is one exact match that is found in the database then the user is able to login and the user will hear a personalized welcome message. For security purposes, a user is not allowed to create two profiles with the same username. After the welcome message is played through the gTTS module then the camera is enabled and the model will start predicting the user's emotion. The emotion with the highest confidence detected is saved in the database to track the user's history. Then a random song associated with that emotion is selected and played from our song database. In the case where the user has more than 30 recorded uses of negative emotions (Sadness, Anger, Fear) then resources will pop up on the screen such as numbers for hotlines and counseling centers in your area.

3. Design Verification

3.1 Physical Verification

In order to test our results we conducted tests of our designs using the benchtop equipment and other materials found in the lab. As the first step of building up our hardware, we created a breadboard that would have a 12V, 5V, and 3.3V rail. As the hardware was designed primarily as a power management system, ensuring these three values worked was our primary focus. Once we built the multiple breadboards, we realized because of the way we routed our components in the other subsystems, we did not need a 3.3V value. With this being the case, we focused on the 12V and 5V power supply. Below, there are pictures of the breadboards' voltages we tested successfully. At this point we connected our created power supply to the mirror display and powered up the devices.

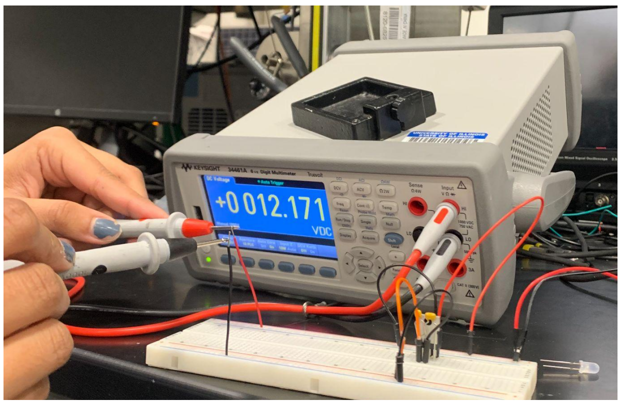

Figure 6: 12 V Power Rail

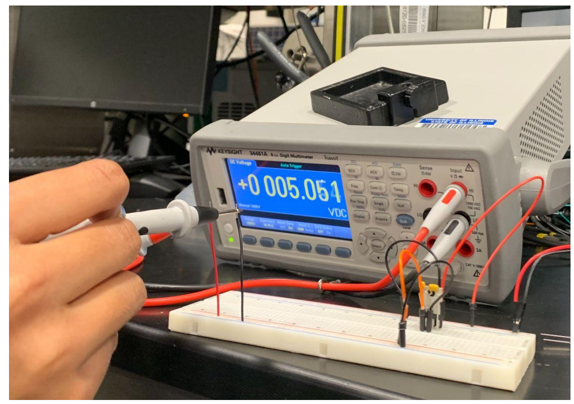

Figure 7: 5 V Power Rail

3.2 Software Verification

The main part of software testing involved getting the 80% accuracy goal for the trained CNN model. To test, we had a 10 second period when the model was analyzing the user's emotion. Each second, the model recognized an emotion on the user's face and each recognized emotion had an associated confidence level, which we used as a measure of accuracy. At the end of the 10 second period, the emotion that had the highest associated confidence level was determined to be the user's emotion. The model was refined enough that all emotions seen in the 10 seconds had an accuracy above 80%, seen below. The accuracy met our high-level requirements for all of the seven basic emotions we had set out to recognize.

```
1/1 [==============================] - 0s 35ms/step
1/1 [==============================] - 0s 38ms/step
Angry
90.65038561820984
```

4. Costs and Schedule

4.1 Parts

Table 1 - Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Two Way Mirror	Amazon	27.63		30.12
IR Frame	Walmart	52.69		52.69
Raspberry Pi Microcomputer Model 3B	Raspberry Pi	35		0
ATmega32PU Microcontroller	Atmel	4.77		9.54
Waterproof IP65 LED Flex Strip	LED Supply	9.99		9.99
5” Raspberry Pi DSI Touchscreen	DFRobot	44.90		44.90
HQ Camera	Adafruit	50		50
6mm Lens for HQ Camera	Adafruit	25		25
Wooden frame + parts to assemble	ECEB Machine Shop	0		0
Mini External USB Stereo Speaker	AdaFruit	12.5		12.5
3.3V 1.5A Linear Voltage Regulator LM317 TO-220	onsemi	0.78		0.78
5V 1A Linear Voltage Regulator LM7805 TO-220	Texas Instruments	1.97		1.97
2.54 mm Male Connectors	Amphenol ICC	0.43		0.43
2.1mm DC Barrel Jack	DIKAVIS	1.07		1.07
Total				**238.99**

4.2 Labor

Table 2 - Labor Costs

Name	**Hourly Rate ($)**	**Hours**	**Total ($)**	**Total x 2.5 ($)**
Tala Aoun	30	300	9000	22500
Apurva Chanda	30	300	9000	22500
Aishwarya Rajesh	30	300	9000	22500
Total				$67500

4.3 Total

Table 3 - Total Costs

Category	**Total**
Labor	$67,500
Parts	$238.99
Total	$67,738.99

4.4 Schedule

Week	Task	Person(s)
Week of 10/03	Finalize physical + PCB design	Aishwarya
	Order parts for prototyping	Everyone
	Create + test user interface subsystem prototype	Tala
	Conduct research to implement software	Apurva
Week of 10/10	Continue board assembly	Aishwarya
	Pass Audit + PCB Order 10/11	Everyone
	Make BOM and order electronics	Everyone
	Write code to extract landmark points from face.	Apurva + Tala

Week of 10/17	Integrate microcontroller/microcomputer + Begin testing individual subsystems	Aishwarya
	Write Convolution layer + Train model	Apurva
	Write Pooling layer + Train model	Tala
Week of 10/24	Revisions to PCB Design	Aishwarya
	Integrate input subsystem with user interface	Tala & Apurva
Week of 10/31	Finalize assembly	Aishwarya
	PCB Order 11/01	Everyone
	Software Integration + Testing	Apurva + Tala
Week of 11/07	Testing	Everyone
Week of 11/14	Mock Demo	Everyone
Week of 11/21	Final modifications + Fix minor bugs	Everyone
Week of 11/28	Final Demo	Everyone
Week of 12/05	Final Presentation + Final Paper	Everyone
	Final Paper	Everyone

5. Conclusion

5.1 Accomplishments

All high level requirements were successfully met. We were able to predict one of the 7 basic human emotions in under 10 seconds with over 80% accuracy. We were also able to provide the user with resources if he exhibits a trend of negative emotions over more than 30 uses of the mirror. The mirror we built is an accessible technology that is portable and could be placed anywhere in the user's home. The first thing the user sees is a login screen, after he registers a new user or logs in using an existing account then a welcome message is played and the model is started. The emotion predicted with the highest level of confidence is then chosen and a message and song are played accordingly.

5.2 Uncertainties

While there is always room for improvement, our project completed the high level requirements we designed. Specifically, in terms of the software. Our model was able to achieve the accuracies we predicted at the beginning of the course. The model was able to accurately predict the seven basic emotions with 80% accuracy or higher. We were also able to predict one of the seven basic human emotions in less than 10 seconds. Even though we achieved our goals in terms of software, we still faced challenges dealing with the Raspberry Pi since the model we used had some integration issues with our model and the camera. In any future iteration, we would choose to work with a newer version of Raspberry Pi.

In terms of the hardware, our circuit design worked when breadboarding. The 12V, 5V, and 3.3V rails worked in functionality individually and powered up our components. When we extended the design to the PCB, we did not have as much luck. As this was our first time designing and testing one, there was quite a bit of a learning curve. In addition, while we designed our PCB one way, the order was messed up and the 12V barrel jack input ports were messed up. Despite all of our efforts to salvage our board before the presentation, we were unable to get it working. Moving forward, we will spend more time researching before implementing a PCB and now have the experience to do so more successfully.

5.3 Ethical considerations

After reviewing the IEEE Code of Ethics and the ACM Code of Ethics, we do not think our project will raise any ethical concerns. We do want to highlight that we are dealing with people's mental health information which must be kept confidential under all circumstances (ACM Code of Ethics and Professional Conduct Section 1.7). We also researched HIPAA laws but we have concluded that won't be applicable to the project since we are not collecting patient information through a healthcare plan. However, we are still dealing with people's mental health so our program needs to be safe so that the user's information is protected which is why we implemented a secure login system. In building this project, we also have a moral duty to provide resources to users that display a deterioration in their mental health. In terms of safety, there are no big concerns relating to the use of the mirror. We are not using significant voltage or battery power therefore users are not put at risk by using the product.

5.4 Future work

Through our market and design research, it is evident there is a market for such a product to help people of all ages. People's mental health has become very concerning, especially in the United States, after COVID-19 and general high levels of stress. There are various potential areas of growth from conducting further research to refine the project scope to specialized applications to an ecosystem of affective companions. In terms of the technical aspect of the mirror, we could add additional features such as a more involved display, multilingual support, and customizability.

References

[1] *Activation Functions in Neural Networks - towards Data Science*. https://towardsdatascience.com/activation-functions-neural-networks-1cbd9f8d91d6.

[2] Bhandari, Aniruddha. "AUC-Roc Curve in Machine Learning Clearly Explained." *Analytics Vidhya*, 14 June 2022, https://www.analyticsvidhya.com/blog/2020/06/auc-roc-curve-machine-learning/.

[3] "The Code Affirms an Obligation of Computing Professionals to Use Their Skills for the Benefit of Society." *Code of Ethics*, https://www.acm.org/code-of-ethics.

[4] Learning, Great. "Everything You Need to Know about VGG16." *Medium*, Medium, 23 Sept. 2021, https://medium.com/@mygreatlearning/everything-you-need-to-know-about-vgg16-7315defb5918.

[5] Vikas Gupta Anastasia Murzova, et al. "Keras Tutorial : Using Pre-Trained ImageNet Models." *LearnOpenCV*, 5 May 2021, https://learnopencv.com/keras-tutorial-using-pre-trained-imagenet-models/.

[6] Bethune, Sophie. "Demand for Mental Health Treatment Continues to Increase, Say Psychologists." *American Psychological Association*, American Psychological Association, 19 Oct. 2021, https://www.apa.org/news/press/releases/2021/10/mental-health-treatment-demand.

[7] Author Cadence PCB Solutions, et al. "PCB Layout Guidelines for Switching Power Supplies." *PCB Layout Guidelines for Switching Power Supplies*, 13 Oct. 2022, resources.pcb.cadence.com/blog/2021-pcb-layout-guidelines-for-switching-power-supplies.

[8] C. A. Tămaş, N. D. Codreanu, C. Grecu and I. Marghescu, "Investigations on silicon and PCB ground system design for new 1.2V DDR4 power sources," Proceedings of the 2014 37th International Spring Seminar on Electronics Technology, 2014, pp. 385-389, doi: 10.1109/ISSE.2014.6887630.

[9] Genereaux, Ben. "High Voltage Seminar ." *Texas Instruments*, Texas Instruments, www.ti.com/lit/ml/slyp762/slyp762.pdf?ts=1667365098243&ref_url=https%253A%252F%252Fwww.google.com%252F.

[10] Group, Matric. "In-Circuit Testing and 6 Other PCB Testing Methods." *In-Circuit Testing and 6 Other PCB Testing Methods*, blog.matric.com/pcb-testing-methods.

[11] *IEEE Pes Power Quality Subcommittee*, cmte.ieee.org/pes-pq/resources/.

[12] Person. "Multirail Power Supply Design for Successful Application Boards-Part 2: Layout Tips and Tricks." *Multirail Power Supply Design for Successful Application Boards-Part 2: Layout Tips and Tricks | Analog Devices*, www.analog.com/en/analog-dialogue/articles/multirail-power-supply-design-for-successful-application-boards-part2.html.

[13] Peterson, ZM. "How to Add the Raspberry Pi Microcontroller to Your PCB." *Northwest Engineering Solutions LLC*, Northwest Engineering Solutions, 22 Jan. 2021, www.nwengineeringllc.com/article/how-to-add-the-raspberry-pi-microcontroller-to-your-pcb.php.

[13] "TPS54386: Dual Power Supply, Vin 12V to VOUT 5V & 3.3V Design Issue." *TPS54386: Dual Power Supply, Vin 12V to Vout 5V & 3.3V Design Issue - Power Management Forum - Power Management - TI E2E Support Forums*, e2e.ti.com/support/power-management-group/power-management/f/power-management-forum/705151/tps54386-dual-power-supply-vin-12v-to-vout-5v-3-3v-design-issue.

Appendix A: Requirement and Verification Table

3.1 User interface subsystem

Table 4: Requirements and Verification for the user interface subsystem

Requirements	Verification
1. When the user starts the mirror, they will be able to log in within five seconds (excluding user delays) and experience no operational delays.	1. The mirror will turn on immediately and the script will run once it's powered on. 2. The speaker will ask the user to press 'Create an Account' (indicating an new user) or 'Log In' for existing users. 3. The user will choose the appropriate option on the display monitor. 4. If this user chooses 'Create an Account', they will be prompted to enter a password and confirm it. The prompts will be received through the display monitor. 5. If this user chooses 'Log In', they will enter their password and log in. Their confirmation of login will be an screen that says 'Login Sucessful'
1. The speaker should be able to speak to the user after at most ten seconds of the user standing in front of the mirror, after the footage is taken.	1. Post-log in, the camera subsystem* will send the footage to the microcomputer within the controls subsystem. 2. The script will show how long the microcomputer running the CNN algorithm takes to identify the emotion the user is feeling, and it will be under 10 seconds.
1. The speaker should say something to the user and play music that is relevant to the way the user is feeling.	1. For each emotion, associated songs will precede the message. Each emotion has an array of songs to match it, and a randomly chosen song for that specific emotion will play for ~15 seconds. 2. If the emotion detected has a negative connotation (fear, anger, disgust, and sadness), the speaker will deliver uplifting messages to improve their mood. These messages will cater to each of the specific negative emotion identified. 3. If the emotion detected has a positive connotation (joy), the speaker will deliver a message that recognizes the user's positive state of mind 4. If the emotion detected is neutral (neutral, surprise), the speaker will acknowledge

	their current mood and suggest fun activities for them to make it better.
1. Mirror should display resources to the user if his/her mental health starts to deteriorate over time.	2. Display mental health resources, both online and in-person ones after 30 negative emotions have been detected in a row. 3. If resources do not display successfully on the computer, debug software 4. If resources display successfully on the computer, debug hardware connections

3.2 Camera subsystem

Table 5: Requirements and Verifications for the camera subsystem

Requirements	Verification
1. When the user stands in front of the mirror, the camera should be able to capture live footage of the user's face within four seconds and send it to the controls subsystem.	1. The user will stand in front of the mirror with the light on in their background. 2. If the user is centered, the camera will start recording the user's face. 3. Recording will begin within four seconds and the user will be realize their emotion has been recognized by the appropriate message and song playing. 4. Photos taken will be sent to the microcomputer to store.
1. For the image to be processed correctly, the image resolution has to be at least 20 x 30 pixels.	1. After the camera takes the picture of the user, we will calculate its image resolution in Python. 2. If the resolution is below 20 x 30 pixels, display an error message on the monitor. 3. Inform the user that he needs to take another photo. 4. Take another photo.

3.3 Controls subsystem

Table 6: Requirements and Verification for the controls subsystem

Requirements	Verification
1. Ensure power and functionality of the microcomputer	1. Ensure all connections are secured correctly, especially the grounds. Connect

	AC to DC convertor to PCB. 2. If there's any data on the microcontroller, erase it. Power up and verify the oscillator is producing a good waveform. 3. Measure voltage at the 12V pin of LED strips. Measure 5V and 3.3 V linear regulator using a multimeter. 4. To further check, program one of the inputs to blink an LED.
1. When there is a controls subsystem communication failure, the subsystem must shut down the system	1. Ensure the mirror display system is at an idle state such that the user is not communicating with it 2. Under "normal operating conditions", have the user activate the mirror using the display and confirm behavior

3.4 Power subsystem

Table 7: Requirements and Verification for the power subsystem

Requirements	Verification
1. Must be able to regulate voltage to power components throughout the operation of the system that require 12V and 5V and automatically cut out power when voltage supply drops too low/high	1. Connect input of voltage regulator to voltage supply. Connect output of voltage regulator to variable, testable load. Set voltage supply to maximum voltage, 5 V. 2. Check voltage reading with multimeter to make sure output is within the range of 3.3V $\pm$ 5% with full/no load. Repeat this with lower values multiple times until the output 0V between 3.0 V and 3.6 V
1. Must be able to regulate voltage to power components throughout the operation of the system that require 3.3V and automatically cut out power when voltage supply drops too low/high	1. Check voltage reading with multimeter to make sure output is within the range of 3.3V 2. $\pm$ 5% with full/no load. Repeat this with lower values multiple times until the output 0V between 3.0 V and 3.6 V