Emotionally Intelligent Mirror

ECE 445 Design Document - Fall 2022

Project #15

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1. Introduction

1.1 Problem

These past few years have highlighted the need for strategies alleviating mental and physical health issues (Source) especially during COVID-19 (Source). In particular, many who live alone face loneliness and seek comfort/companionship. A potential solution to provide accessible technology to all is an emotionally intelligent mirror that can understand your emotions in real-time and communicate with you. The mirror should also be able to track a user's emotions on a long-term basis to see if any improvements or deteriorations are occurring. Our end goal is to give the user a better understanding of their mental health patterns and be able to take actions to keep themselves healthy.

1.2 Solution

The mirror will be able to understand the user's emotions such as happiness, anger, sadness and neutral and respond accordingly to each emotion by reciting comforting words, playing music and sympathizing with the user. Every morning, the user could start his day looking at the mirror which would give him daily affirmations and would boost his mental well-being. The user will also be able to see motivational messages on a monitor. On a long term basis, the mirror will store information about a user's mental health that has been gathered from facial expressions and emotions to track a user's progress and see if any improvements or deteriorations are occurring. If a user's emotions are obviously getting worse in the long term, the mirror would be able to provide resources like crisis hotlines or telehealth to help the user. The mirror would alleviate the stress and negative emotions that the user has. In regards to privacy issues, the mirror will be password protected so that each user can have their own profile and data. The mirror will prompt each user to enter their password into a number keypad in order to access their profile.

1.3 Visual Aid

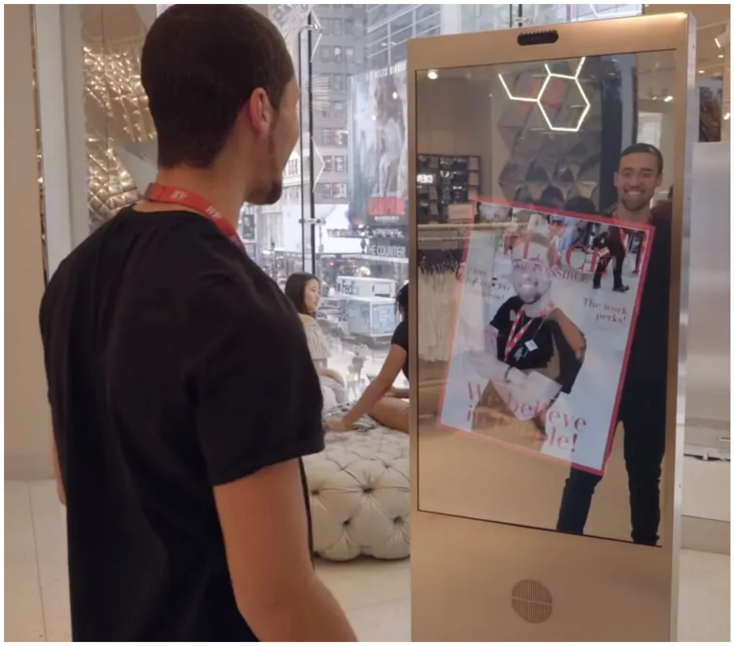


Figure 1: At an H&M store, a person uses a smart mirror to virtually try on clothes.

Currently most interactive mirrors in the market are smart mirrors that have no communicative portion to it. The only commercially available product uses voice activation to suggest relevant fashion trends and outfit ideas. While the ideas involved are somewhat similar to our own concept, our mirror will be used to encourage users to be proactive about their health in a safe and fun way.

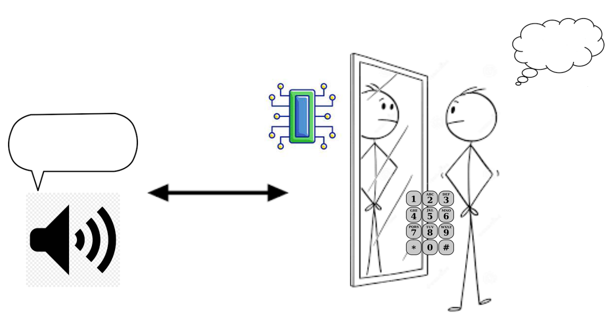


Figure 2: When a person looks into our mirror,

it will be able to capture how the person is feeling and respond verbally.

Our proposed solution, as shown above, will interact with an user to understand how they are feeling and respond accordingly. While the user only sees the mirror and camera attached to it, the rest of the product's components will be hidden. Behind the mirror we will have all the electric components as well as the speaker to communicate with the user. However, we will also have a keypad for the user to login and logout for security reasons.

1.4 High-Level Requirements

To consider our project successful, our project must fulfill the following:

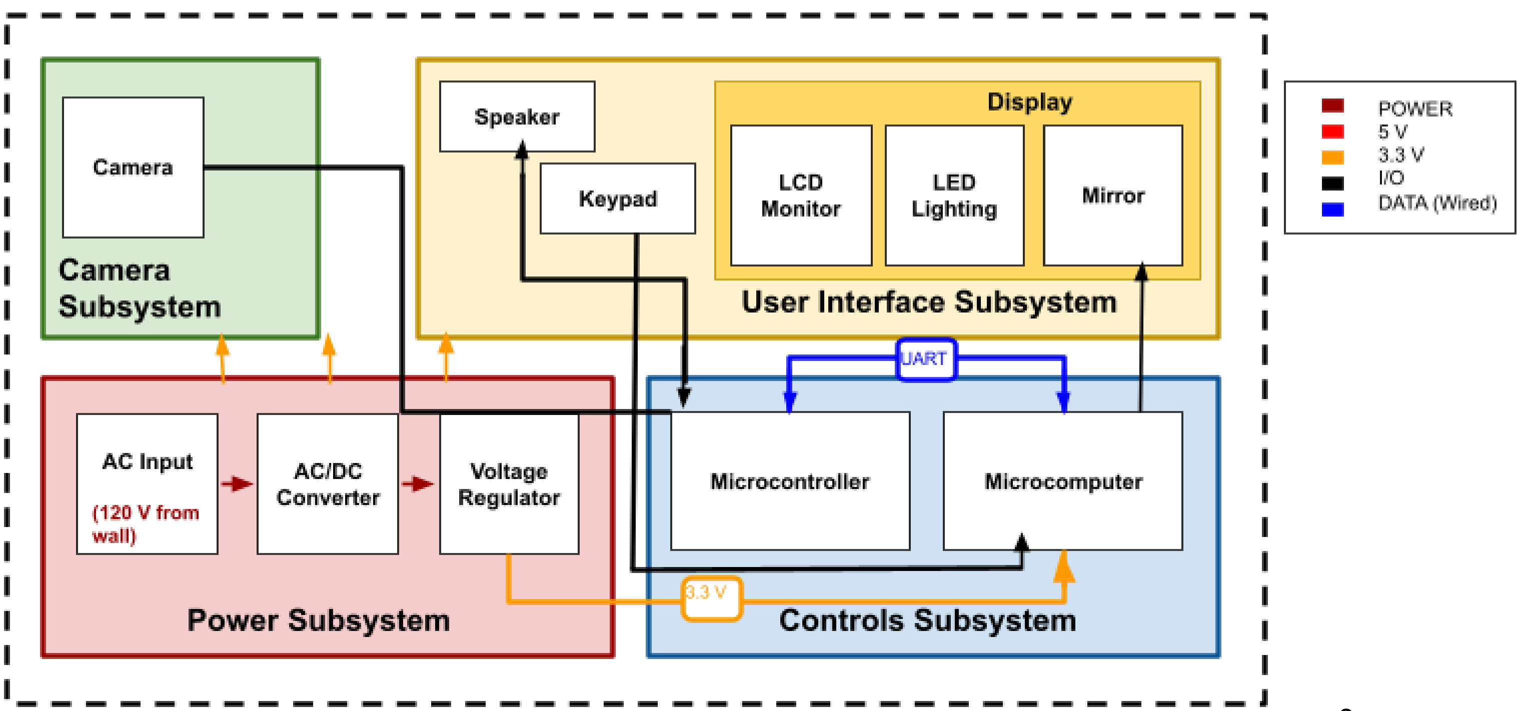
1. The mirror will accurately identify if the user's emotion is negative, positive, or neutral 90% of the time and the specific emotion 80% of the time it is used.
2. After 30 uses of consistently negative emotions recorded on a user's profile, the profile will be flagged, because the user is exhibiting a downward trend in terms of their mental health. It will be flagged and resources like therapists and support groups in the area (within 25 miles) will be provided. For those without nearby resources, online alternatives will be offered.
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.

2. Design

2.1 Physical Diagram

We can separate the overall physical design process into mechanical and hardware parts. In terms of the mechanical design, we are overlaying a two way mirror with a wooden frame around it and LED lighting on the back. The camera will be in an accessible place near the top of the mirror to easily gain input for the system to operate. It will all be attached to the wall with mounts for the demo, but there will be the option for users to create a portable display if wanted. In terms of the hardware, which will be described in future sections, it will be secured in an enclosure between the display and the wall with enough space for connections to the external power supply. We are currently in the process of ordering our parts to assemble everything together.

2.2 Block Diagram



2.3 Functional Overview & Block Diagram Requirements

Camera Subsystem:

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 the most important aspect of our design, since without it we would not be able to analyze 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.

Requirements	Verification
1. When the user stands in front of the mirror, the camera should be able to capture a picture 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 and light requirements are met, the camera will take a photo of the user's face. 3. If the user needs to adjust, they will be notified within three seconds via display monitor through an error message, and an error buzz noise will sound. 4. The photo will be taken within four seconds and the user will be notified through a snapshot sound, and a check mark will be on the monitor. 5. Photos taken will be sent to the microcomputer for analysis.
1. The lighting on the face must be bright enough so that the camera sensor doesn't introduce noise. Otherwise, the user must be notified. Lighting	1. The camera contains light correction properties, but the subject cannot be in the frame with a brightness lower than 100 lux. If that is the case, the user

should be at least 100 lux.	will be told via display monitor. 2. The camera will adjust for lighting and take a photo to send to the microcomputer.

Controls Subsystem:

The microcomputer and the microcontroller 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 processes, work with a camera, and communicate serially. The microcontroller is used to support programming and communicate serially. We will use the UART and SPI communication protocols to connect the two components with the rest of the subsystems. 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 two important components in our PCB.

Requirements	Verification
1. Ensure power and functionality of the microcontroller	1. Ensure all connections are secured correctly, especially the grounds. Connect AC to DC convertor to PCB. 2. Connect the external clock circuit in an oscillator configuration with any necessary parts. 3. If there's any data on the microcontroller, erase it. Power up and verify the oscillator is producing a good waveform. 4. Measure voltage at the 12V pin of LED strips. Measure 3.3 V linear regulator using a multimeter 5. 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 keypad and confirm behavior

User Interface Subsystem:

The user interface subsystem contains the mirror, the LED lights, a display monitor, the speaker and the keypad. In order to display all the information and interface with the user, there will be a mirror attached on a wall. The mirror is the main component of our project and will hold the user interface that the user interacts with. The mirror will prompt the user to enter their password into the number keypad. The display monitor and speaker will be used to communicate with the user. To reduce overall power consumption from the external wall source, we will include LED lighting to better see and receive visual input from the user. The display subsystem will receive input from the controls subsystem and will provide input to the controls subsystem. It will interact with the power system to stay running.

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 user will start the camera on the mirror; a blue blinking light indicates that the mirror is ready to be used. 2. The speaker will ask the user to press 1 to ‘Create an Account’ (indicating an new user) or 2 to ‘Log In’ for existing users. 3. The user will choose either 1 or 2 using the keypad. At this point, we will start a stopwatch and measure the time it takes for the mirror to log into the user’s profile. 4. If this user chooses 1 on the keypad, they will be prompted to enter a four-digit password and confirm it. The prompts will be received through the display monitor. 5. If this user chooses 2 on the keypad, they will enter their password and log in. Their confirmation of login will be an ‘unlock’ noise and a check mark on the display.

	6. At this point, stop the timer and ensure the mirror was able to log in the user under five seconds.
1. The speaker should be able to speak to the user after ten seconds of the user standing in front of the mirror.	1. Post-log in, the camera subsystem* will send the image to the microcomputer within the controls subsystem. 2. We will use a stopwatch to time how long the microcomputer running the CNN algorithm takes to identify the emotion the user is feeling. 3. Stop timer once the emotion is detected. Ensure that less than ten seconds have passed.
1. The speaker should say something to the user or play music that is relevant to the way the user is feeling.	1. 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. The display monitor will show a smiley face for encouragement. 2. If the emotion detected has a positive connotation (joy), the speaker will deliver a message that recognizes the user's positive state of mind, and the display monitor will show a star to keep the momentum going for the user. 3. 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. The display monitor will show a 'thumbs up' for the user.
1. Mirror should display resources to the user if his mental health starts to deteriorate over time.	2. Disconnect display subsystem from the microcomputer housing the software in the product and connect to the external computer where the software was developed. 3. If resources do not display successfully on the computer, debug

	software 4. If resources display successfully on the computer, debug hardware connections

*Refer to Requirement 1 from the Camera subsystem for more information on how the image is obtained.

Power Subsystem:

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 an USB port to connect to the controls system to power all the components.

Requirements	Verification
1. Must be able to regulate voltage to power components throughout the operation of the system 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

Software Design

For the software portion of our design, we are going to be using Convolution Neural Networks (CNN) to detect the human face in the mirror, extract the points of interest in the face and then analyze the emotion the user is feeling. CNN is a deep learning algorithm that differentiates between images by assigning weights to various objects within the image. This algorithm was chosen because it is able to notice the subject's features without supervision, eliminating the need for depth sensors or any other hardware components that detect the subject (in our case, human user) from the background. It is also computationally efficient, making them a great choice for our lightweight microcontroller. Before we can use the CNN algorithm, we will have to convert the image of the user into an array of pixel intensities which we will be doing using NumPy. Once we have converted the image into an array, we will use the Dlib library to extract the important points we need to analyze the emotion. Dlib uses a Maximum-Margin Object Detector with CNN based features. First, it will draw a rectangle around the user's face to separate him from the background. The rectangle will be defined by two coordinates: the upper left corner and the bottom right corner. Using these two coordinates as input to the Dlib shape predictor, we will be able to extract the key facial features that we need from the image. The CNN algorithm consists of convolution, pooling, and a fully connected layer. The convolution operation consists of 3 convolutional layers. The first layer learns features such as edges, color and gradient orientation. The second layer learns more complex textures and patterns and the last layer learns features such as objects or parts of objects. The element that carries out the convolution operation is called the kernel. The kernel shifts over the entire image performing matrix multiplication operations on the part of the image over which the kernel is hovering. The kernel moves right with a certain stride value until it reaches the width of the image then moves down with the same stride value, repeating the process until the entire image has been traversed. The pooling operation is responsible for reducing the spatial size of the convolved feature. It is useful for extracting dominant features which are rotational and positional invariant. In our project we will be using Max Pooling which returns the maximum value from the portion of the image covered by the kernel. Max Pooling acts as a noise suppressant so it performs better than the other technique which is Average Pooling. Then we can add a fully connected layer where the neurons have connections to all the neurons in the previous layer. In this layer, the input from the previous layer is flattened into a one dimensional vector and an activation function is applied to obtain the output. Softmax and Exponential Linear Unit (ELU) are activation functions commonly used in CNNs. The model is now able to classify the images and detect the emotion in the picture.

Tolerance Analysis –

An aspect of this project that is critical to its success is the lighting in the room at the time that the picture of the user is taken. Different levels of lighting will affect the quality of the image taken therefore the accuracy of the emotion that is analyzed will also be affected. We specified in our RV table that the brightness should be at least 100 lux so that we can get a clear picture. However, we will not have a device that measures the exact brightness in the room so there is no way of knowing for sure if the brightness is over 100 lux. Our camera is supposed to have light correction which will help if the brightness in the room is too low but that is definitely a risk in the success of our project since it directly affects the accuracy of the emotion analyzed. To track the accuracy of emotions detected, we are going to test the mirror with different lighting intensities and see the accuracy of the emotion at that level. By tracking the accuracy of the mirror across different lighting intensities, we will be able to inform the user of the appropriate level of brightness he needs to have a fully functional mirror. To track this data, we will be using a receiver operating characteristic curve. An ROC is a plot of test sensitivity as the y-coordinate versus its false positive rate as the x-coordinate.

Cost Analysis –

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

Parts Costs –

Description	Quantity	Manufacturer	Vendor	Cost/Unit	Total Cost
One way mirror	1	Better Homes & Gardens	Walmart	19.99	19.99
Raspberry Pi Microcomputer Model 3B	1	Raspberry Pi	Digikey	35	35
ATmega32PU Microcontroller	2	Atmel	Digikey	4.77	9.54
Waterproof IP65 LED Flex Strip	1	LED Supply	LED Supply	9.99	9.99
Display Monitor - 104990244 7 Inch HDMI 1280x800 IPS Display	1	Seeed Development Limited	Verical	50	50

Camera	C615 1080 Webcam with HD Light Correction	Logitech	Best Buy	29.99	29.99
Wooden frame + parts to assemble	1	ECEB Machine Shop	ECEB Machine Shop	0	0
SanDisk 16GB Micro SD	1	SanDisk	Amazon	6.90	6.90
Keypad	1	Foloda	Amazon	18.79	18.79
Used Portable Speaker JBL GO	1	JBL	Amazon	14.99	14.99
6 feet 2.1mm Coaxial AC to DC Converter	1	Roofull	Amazon	17.99	17.99
Micro USB	1	Raspberry Pi	Amazon	7.5	7.5
LP2953 Voltage Regulator	1	Texas Instruments	Mouser	3.12	3.12
Total					$

Total –

Category	Total
Labor	$67,500
Parts	$223.80
Total	$67,723.80

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	
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

3 Discussion of Ethics and Safety

Our project aims to provide mental health resources to individuals efficiently within the comfort of their own homes. With this principle guiding the project development, we are focusing on maintaining the highest of safety standards correlating to Electrical Engineering, Computer Science, and industry standards. 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 have also researched HIPAA laws but we believe that those laws won't be applicable to our project since we will not be collecting patient information through a healthcare plan. Security and privacy on each user's profile will be of utmost importance with the sensitive information we are using. Every time the mirror is used, the user will complete an authentication process before the mirror stores their health information, to ensure that no other user can see their history. As an additional security measure, we will give them the option to delete their photos after a 30 day period, after which we provide resources. This way, users have the option to store their data for a longer period of time or delete it entirely. Because we are storing and analyzing mental health patterns over time, we have a moral duty to provide resources and any help we can if we notice someone struggling. We will keep these concerns in mind as we design our final product. In terms of safety, we do not anticipate any significant safety issues for ourselves as the lab team or end users. While we are using common power rated materials, our circuitry could be harmful if external fluids like water comes into contact with it. We are not using significant voltage or battery power in our project nor are our end users putting themselves at risk by using the product. Even with this being the case, the PCB will be encased in housing to prevent any potential damage. The end users will be looking into the camera on our mirror and hearing its response; the hands-off approach to our product lends itself to minimal safety issues.

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