Facial Matching Display Mirror w/ Motion Sensor

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Abstract

Many traditional STEM outreach exhibits/displays rely on static posters or non-interactive exhibits, which often fail to engage visitors or create a personal connection. To address this limitation, we propose an interactive Facial Matching Display Mirror with Motion Sensing. The system presents as a mirror-like surface that remains reflective when idle, and transforms into a digital display once a user stands in front of it.

We will be using a Time-of-Flight (ToF) distance sensor that continuously monitors an "interaction zone" to achieve presence detection. When a user enters a defined range, the system will activate and transition from an idle, mirror state into an interactive display. A webcam will be tracking real-time video data, which will then be processed via computer-vision algorithms to perform motion tracking and facial recognition. Confidence evaluation will then be performed on the data to validate the face. Once validated, a matching subsystem will select the appropriate STEM professional profile from a local database using predefined metadata rules.

The display is implemented using a two-way acrylic mirror mounted on top of an LCD screen, enabling a seamless transition between reflective and active states via brightness control. An STM32 microcontroller will be used to manage low-level integration and sensor integration. We will utilize a Raspberry Pi to perform higher-level image processing and database selection tasks. A regulated multi-rail power system will ensure safe distribution of 5V and 3.3V supplies to the embedded components.

The final system will demonstrate reliable presence detection, responsive activation, consistent facial detection reliability, and accurate profile triggering with minimal latency.

1. Introduction

STEM outreach environments often rely on static posters, brochures, or pre-recorded videos to highlight career opportunities in science and engineering. While informative, these passive displays do not actively engage visitors or create a personal connection. Many students, particularly those from underrepresented backgrounds, may struggle to see themselves reflected in traditional outreach materials. As a result, there is a need for an interactive, technology-driven exhibit that captures attention, responds dynamically to user presence, and presents STEM role models in a personalized and modern format.

The purpose of this project is to design and implement a Facial Matching Display Mirror with Motion Sensor that transforms a standard mirror into an interactive outreach experience. The system appears as a normal mirror when idle. Upon detecting a person standing within the optimal interaction range, the mirror activates and transitions into a digital display. Users can then select a STEM career pathway using a touchless interface. The system captures real-time image data and applies face detection and confidence evaluation algorithms to determine when reliable user presence has been established. Based on contextual user characteristics and predefined matching rules, the system selects and displays a matched scientist or engineer profile, including short video content, name, role, and an inspirational quote.

The system integrates depth-based presence detection, camera-based image processing, interactive UI control, local database matching, and regulated power management into a cohesive architecture. The use of a two-way mirror and LED display enables seamless visual transformation between reflective and active display states without mechanical components. The design emphasizes responsiveness, reliability, and intuitive interaction to ensure that activation feels natural and engaging.

This report is organized as follows. Chapter 2 reviews related technologies in interactive displays, motion sensing, and face detection systems. Chapter 3 presents the overall system architecture and explains the design rationale behind each subsystem. Chapter 4 details hardware implementation, component selection, and cost analysis. Chapter 5 describes software integration, testing methodology, and performance validation, including facial detection, confidence evaluation and responsiveness metrics. Chapter 6 summarizes project results, evaluates system performance against defined criteria for success, and outlines future improvements.

The main conclusion of this project is that a motion-activated, facially contextualized display can effectively increase engagement in STEM outreach settings. The prototype successfully demonstrates automatic presence detection, seamless mirror-to-display transformation, reliable content triggering with greater than 80% facial detection consistency, and response times short enough to feel natural to the user. These results support the feasibility of deploying interactive mirror-based exhibits in educational environments to create more personalized and impactful outreach experiences.

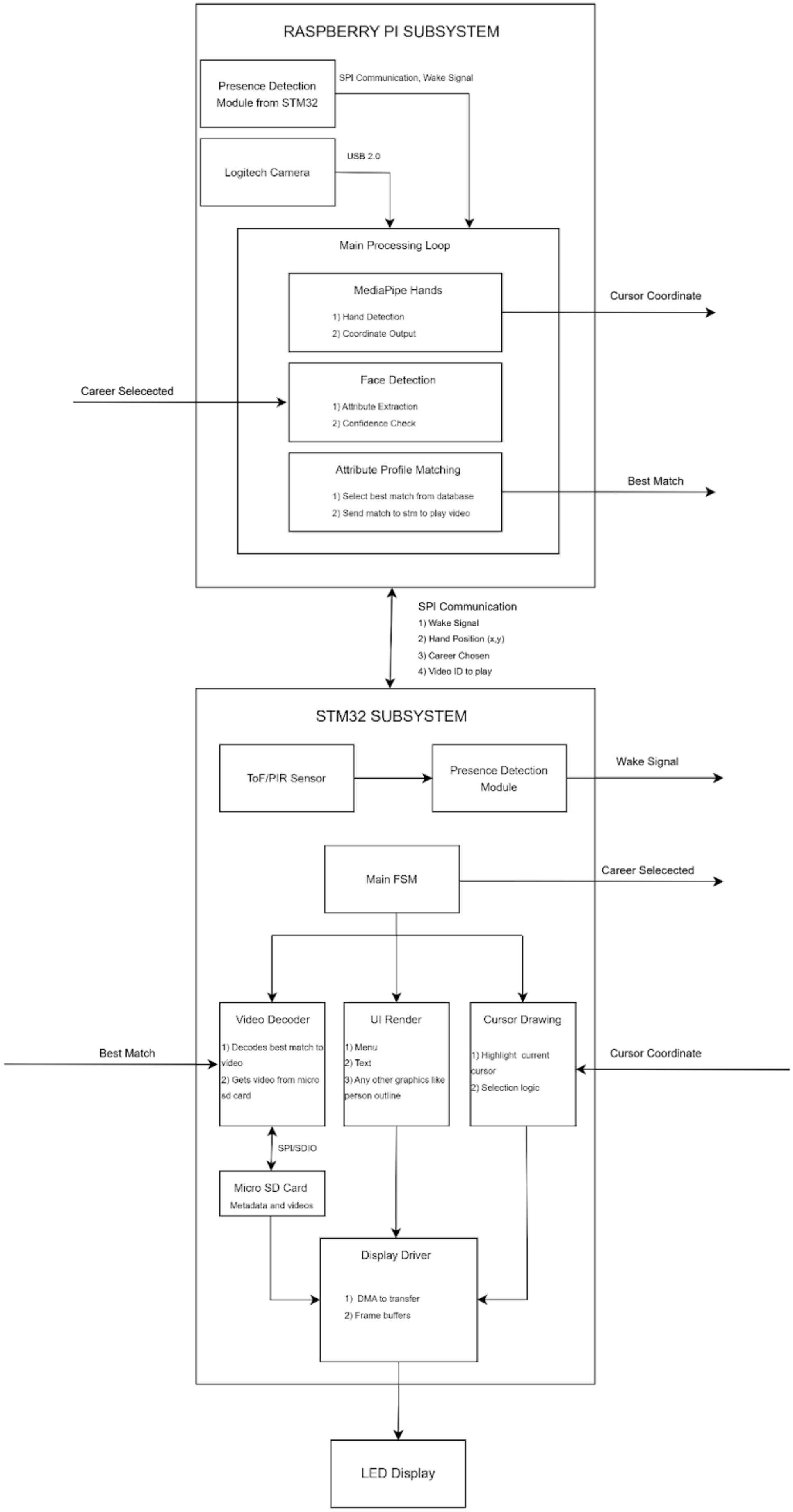
1.1 System Overview

The Facial Matching Display Mirror consists of seven integrated subsystems: presence detection, mirror display, camera and image processing, interactive UI control, face detection confidence determination, data-based profile selection, and power management.

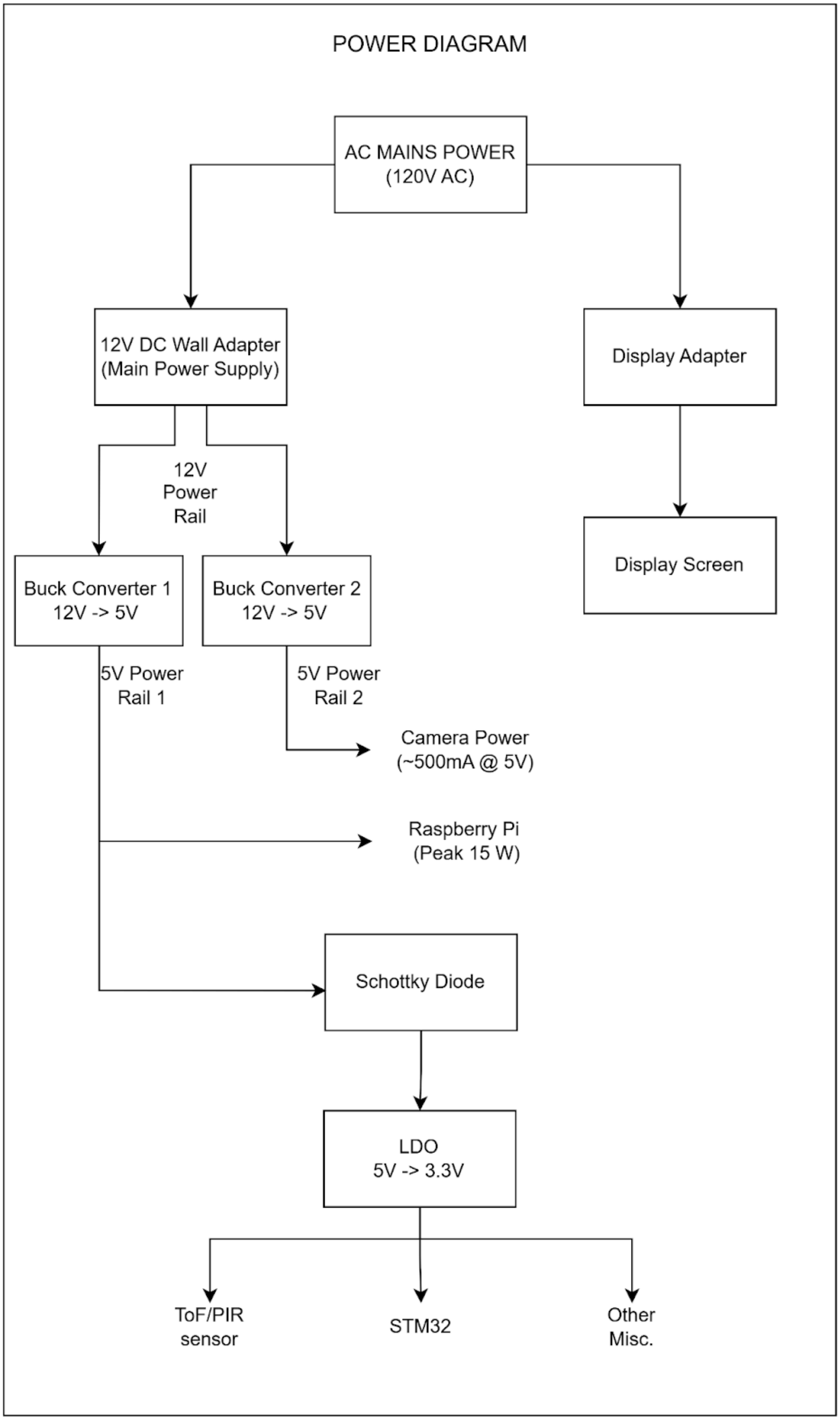
The presence detection subsystem uses the Kinect's infrared depth stream to determine when a user enters the 1.5–3.5 meter interaction zone. The mirror display subsystem utilizes a two-way mirror and LED television to transition between reflective and active display states. The camera and image processing subsystem captures visual data and prepares image regions for analysis. The face detection confidence subsystem evaluates detection quality to prevent false activations. The data-based search subsystem selects appropriate STEM role model profiles from a local database. The interactive UI enables touchless selection of career paths using skeletal tracking. Finally, the power management subsystem safely distributes regulated voltage to all low-voltage components.

Together, these subsystems form a responsive, modular, and scalable interactive outreach platform designed to enhance engagement and representation in STEM environments.

Link for the following diagrams:
https://drive.google.com/file/d/1SyplrEKv5P372hE0bbDUc58NOfTaPBP-/view?usp=sharing



RASPBERRY PI SUBSYSTEM
Presence Detection Module from STM32
SPI Communication, Wake Signal
Logitech Camera
USB 2.0
Main Processing Loop
MediaPipe Hands
1) Hand Detection
2) Coordinate Output
Cursor Coordinate
Career Selecected
Face Detection
1) Attribute Extraction
2) Confidence Check
Attribute Profile Matching
1) Select best match from database
2) Send match to stm to play video
Best Match
SPI Communication
1) Wake Signal
2) Hand Position (x,y)
3) Career Chosen
4) Video ID to play
STM32 SUBSYSTEM
ToF/PIR Sensor
Presence Detection Module
Wake Signal
Main FSM
Career Selecected
Video Decoder
1) Decodes best match to video
2) Gets video from micro sd card
UI Render
1) Menu
2) Text
3) Any other graphics like person outline
Cursor Drawing
1) Highlight current cursor
2) Selection logic
Best Match
Cursor Coordinate
SPI/SDIO
Micro SD Card
Metadata and videos
Display Driver
1) DMA to transfer
2) Frame buffers
LED Display


POWER DIAGRAM
AC MAINS POWER (120V AC)
12V DC Wall Adapter (Main Power Supply)
Display Adapter
12V Power Rail
Buck Converter 1 12V -> 5V
Buck Converter 2 12V -> 5V
Display Screen
5V Power Rail 1
5V Power Rail 2
Camera Power (~500mA @ 5V)
Raspberry Pi (Peak 15 W)
Schottky Diode
LDO 5V -> 3.3V
ToF/PIR sensor
STM32
Other Misc.

2. Design

This section describes the overall system architecture and detailed implementation of each subsystem within the interactive smart mirror platform. The system is designed to transition between a passive reflective mirror state and an interactive STEM career display based on user presence and gesture input.

A distributed processing architecture is implemented using two primary processing units: an STM32 microcontroller and a Raspberry Pi 4 single-board computer.

The STM32 is responsible for deterministic real-time sensing, presence validation, and system state management. Because it operates without a full operating system, it provides predictable timing behavior and reliable hardware-level control. It will also be handling the video playback, UI graphics, and display management on a monitor for the display, and it will be storing said videos and graphics on a local SD card.

The Raspberry Pi 4 performs computationally intensive tasks, including camera data acquisition, face detection, hand tracking, and database queries. These processes require higher processing capability and software libraries such as OpenCV and MediaPipe.

Separating low-level sensing from high-level processing improves reliability, reduces latency in activation logic, and enhances overall system robustness.

2.1 Presence Detection Subsystem

The presence detection subsystem determines when a user enters the interaction zone in front of the mirror. This function is implemented using a Time-of-Flight (ToF) distance sensor mounted behind the mirror assembly.

The selected component is the SEN0378 ToF sensor. It operates by emitting infrared light pulses and measuring the time required for reflected light to return to the sensor. Distance is calculated using: $d = (c \times t)/2$, where d is distance, c is the speed of light, and t is the measured round-trip time.

The STM32 continuously polls the sensor at approximately 10–20 Hz. A valid presence condition is defined as a measured distance between 1.5 meters and 3.5 meters from the mirror surface. This ensures proper positioning for camera framing and interaction.

A temporal validation filter is implemented to prevent false triggers. The measured distance must remain within the valid range for a predefined hold duration before activation is confirmed.

Materials:

- STM32 Microcontroller
- SEN0378 ToF Distance Sensor
- 3.3 V regulated supply

2.2 System Control and State Management Subsystem

This subsystem manages operational state transitions between idle mode, UI display for selection, facial scanning and searching, and video display mode.

In the idle mode, the system functions as a standard mirror, with the display outputting near-black content. When presence is confirmed, the STM32 asserts a digital activation signal to the Raspberry Pi, initiating camera capture, and it starts UI rendering. If no presence is detected for a predefined timeout interval, the system transitions back to idle mode. This reduces unnecessary processing and prolongs hardware lifespan.

Then there are control states for waiting for the UI selection of what STEM profession to check. And once this is selected, the camera and Raspberry Pi must process facial data to make a video selection. Then it enters video display mode, checking the facial confidence is high enough, and displaying the correct video to the monitor/mirror display.

Materials:

- STM32 Microcontroller

2.3 Mirror Display Subsystem

The mirror display subsystem enables simultaneous reflective and digital display functionality.

The system uses a 3-pieces of 12” × 24” acrylic panel coated with 70% reflective / 30% transmissive mirror film. A 32-inch LED television is positioned directly behind the panel.

When idle, low-luminance output allows reflected ambient light to dominate. During activation, high-brightness UI elements and video content are transmitted through the mirror surface.

Because only 30% of the display light transmits, displayed luminance must exceed reflected ambient luminance to maintain visibility. High-contrast graphical design improves readability under varying lighting conditions.

Materials:

- 3 Panels of 12” × 24” Acrylic with 60%R / 40%T Mirror coating
- 32” LED Television/Monitor

2.4 Camera and Image Acquisition Subsystem

The camera subsystem captures real-time user imagery for processing.

A Logitech C920 USB camera is mounted behind the mirror and aligned with the display region. The Raspberry Pi captures RGB frames at standard video rates.

Preprocessing steps include frame scaling, grayscale conversion (when required), and noise reduction. These steps reduce computational load while maintaining detection accuracy.

Materials:

- Raspberry Pi 4
- Logitech C920 USB Camera
- USB interface

2.5 Hand Tracking and Gesture Interface Subsystem

This subsystem enables touchless interaction using real-time hand tracking.

MediaPipe hand landmark detection is used to identify key hand feature points. Detected coordinates in camera space are mapped to display coordinates using proportional scaling.

A hover-based selection mechanism is implemented. The user must maintain their hand within a designated on-screen region for a defined dwell time before selection is registered. This minimizes unintended activation and improves usability.

Materials:

- Raspberry Pi 4
- MediaPipe software library

- OpenCV framework

2.6 Face Detection and Confidence Evaluation Subsystem

The face detection subsystem ensures a valid user is positioned before profile content is displayed.

Face detection is performed using OpenCV-based classifiers. A confidence score is computed using a weighted combination of detection probability, bounding box size relative to frame dimensions, and image sharpness measured using Laplacian variance.

Only when the confidence score exceeds a predefined threshold does the system proceed with profile retrieval. This reduces false positives caused by partial faces or blurred imagery.

Materials:

- Raspberry Pi 4
- OpenCV library
- Image processing modules

2.7 Video Playback and User Interface Rendering Subsystem

This subsystem manages graphical UI rendering and video playback.

Upon successful selection and validation, the Raspberry Pi signals the choice of video or UI selection to the SMT32. The microcontroller then renders UI elements and initiates video playback corresponding to the selected STEM professional onto the display monitor.

Images and videos will be displayed on the monitor through the STM32, as it will have the videos stored on an SD card. Once a video is selected based on facial matching in the Raspberry Pi, the video will be selected and displayed on the monitor by the STM32. UI components and selections will also be managed by the STM32 to display a cursor and buttons that can be hovered over to select.

Rendering is optimized to maintain smooth frame rates while concurrently handling detection processes. Hardware-accelerated decoding is used when available to reduce processor load.

Materials:

- STM32 Microcontroller
- SD card

- HDMI output interface
- Media playback software libraries

2.8 Power Management Subsystem

The power management subsystem provides regulated voltage to all low-voltage electronics.

A 12 V input supply is stepped down to 5 V using an LM2596 buck converter to power the Raspberry Pi. A low-dropout regulator such as the MCP1700 generates a stable 3.3 V rail for the STM32 and ToF sensor.

Reverse polarity protection is implemented using Schottky diodes. The LED television operates using its manufacturer-supplied AC adapter and remains electrically isolated from the low-voltage control system.

Materials:

- 12 V DC Power Supply
- LM2596 Buck Converter
- MCP1700 LDO Regulator
- Schottky Diodes
- Decoupling Capacitors

3. Ethical Considerations

The Smart Mirror system incorporates a camera and artificial intelligence to analyze and respond to users in real time. Because it captures and processes visual data, ethical considerations surrounding privacy, bias, transparency, and security are central to the design. It is critical that the system operates in a way that respects user autonomy and minimizes potential harm.

One of the primary ethical concerns is user privacy. Since the mirror uses a camera for presence detection and visual analysis, there is a risk that users may feel surveilled or that their data could be stored or misused. To mitigate this concern, all image processing will occur locally on the Raspberry Pi, and no images or identifying information will be stored or transmitted to external servers. The system is not designed to perform facial recognition or identify specific individuals; instead, it performs general feature detection and classification for demonstration purposes only.

Additionally, the interface will clearly indicate when the camera is active so users are aware that visual processing is occurring.

Another significant ethical issue is algorithmic bias. AI models, particularly those used for facial analysis, may produce uneven performance across different demographic groups if they were trained on non-representative datasets. This could lead to inaccurate outputs or unintended discrimination. To address this, we will use widely validated pre-trained models and test the system across diverse users to evaluate performance consistency. Furthermore, outputs will be framed as educational and illustrative rather than definitive judgments about the individual. The mirror will avoid making claims about intelligence, personality, or identity to prevent reinforcing stereotypes.

Security is another important consideration. Because the Raspberry Pi is a network-capable device, improper configuration could create vulnerabilities that expose the system to unauthorized access. To mitigate this risk, unnecessary network services will be disabled, strong authentication practices will be used, and the device will be kept updated. During demonstrations, remote access will not be enabled.

Overall, the Smart Mirror is designed with a strong emphasis on ethical responsibility. By prioritizing local processing, avoiding long-term data storage, maintaining transparency about AI usage, addressing potential bias, and securing the device against misuse, the project balances innovation with responsible engineering practice.

4. Costs

This section summarizes the estimated component costs required to construct the interactive smart mirror system. Retail pricing reflects single-unit purchase cost. Bulk pricing reflects estimated cost at moderate quantities (1-3 units). The Actual Cost column reflects the projected cost for this prototype build.

Table 4.1 provides a detailed breakdown of all major hardware components used in the system. As shown in Table 4.1, the primary cost drivers are the display, Raspberry Pi, and mirror assembly components.

4.1 Parts

Our total budget consists of $150 supplied from the ECE 445 course staff, and $150 supplied from Professor Paul Kwiat. We are buying parts reflective of this $300 limit. Many items have been over estimated in either cost or quantity, this is to account for any variations in the price of items needed if new problems or ideas are introduced.

Table 4.1 Parts Costs

Part	Manufacturer	Retail Cost ($)	Quantity	Actual Cost ($)
Raspberry Pi 4 (4GB)	Raspberry Pi Foundation	75.00	1	75.00
STM32 Nucleo Board	STMicroelectronics	0 (supplied)	1	0
SEN0378 ToF Sensor	Digikey	18.00	1	18.00
Logitech C920 USB Camera	Logitech (owned by Connor)	0	1	0
32" LED Television	Insignia	100.00	1	100.00
12" x 24" Acrylic Panel	Amazon	15	3	45.00
LM2596 Buck Converter	Texas Instruments (Design)	8.00	2	16.00
MCP1700 LDO Regulator	Microchip	3.00	1	3.00
Schottky Diodes and Passive Components	Various	~10.00	1	10.00
Wiring, Connectors, Mounting Hardware	Various	25.00	20.00	25.00
Total				**$292.00**

5. Conclusion

This project demonstrated the successful design and implementation of an interactive smart mirror system that promotes STEM career awareness through touchless interaction. By integrating embedded sensing, computer vision, and multimedia display, the system transitions seamlessly between a passive mirror state and an informational interface. The distributed architecture using an STM32 microcontroller and Raspberry Pi 4 provided reliable sensing and efficient high-level processing.

5.1 Accomplishments

The system successfully integrated presence detection using a Time-of-Flight sensor, gesture-based hand tracking, face detection with confidence evaluation, and profile-based content retrieval. The mirror display achieved both reflective and transmissive functionality using 70%R/30%T acrylic. Power regulation and subsystem coordination were validated through the stable operation of the complete prototype.

5.2 Uncertainties

Performance may vary under changing lighting conditions, which can affect display visibility and detection accuracy. Gesture tracking reliability may also depend on user positioning. While effective as a prototype, scalability and long-term robustness require further evaluation.

5.3 Ethical Considerations

The system uses camera-based detection, raising privacy concerns. All processing is performed locally, and no personal data is stored or transmitted. Clear user notification and inclusive representation in displayed STEM profiles remain important for ethical deployment.

5.4 Future Work

Future improvements include enhancing gesture robustness, expanding the profile database, and optimizing hardware integration. Additional features such as voice interaction or cloud-based content updates could further improve user engagement and scalability.

6. References

[1] STMicroelectronics, *STM32F4 Series Reference Manual*, RM0090, STMicroelectronics, Geneva, Switzerland, 2022.

[2] STMicroelectronics, *VL53L1X Time-of-Flight Ranging Sensor Datasheet*, DS11912, STMicroelectronics, 2023. Available at: https://www.st.com/resource/en/datasheet/vl53l1x.pdf

[3] Raspberry Pi Foundation, *Raspberry Pi 4 Model B Datasheet*, Raspberry Pi Ltd., Cambridge, U.K., 2023. Available at: https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-datasheet.pdf

[4] G. Bradski and A. Kaehler, *Learning OpenCV: Computer Vision with the OpenCV Library*, 2nd ed. Sebastopol, CA: O'Reilly Media, 2016.

[5] F. Chollet, *Deep Learning with Python*, 2nd ed. Shelter Island, NY: Manning Publications, 2021.

[6] C. Bishop, *Pattern Recognition and Machine Learning*. New York, NY: Springer, 2006.

[7] Texas Instruments, *LM2596 SIMPLE SWITCHER® Power Converter Datasheet*, Texas Instruments, Dallas, TX, 2021. Available at: https://www.ti.com/lit/ds/symlink/lm2596.pdf

[8] Microchip Technology Inc., *MCP1700 Low Quiescent Current LDO Regulator Datasheet*, Microchip Technology, Chandler, AZ, 2022.

[9] A. Howard et al., "MediaPipe: A Framework for Building Perception Pipelines," Google Research, Mountain View, CA, Tech. Rep., 2019. Available at: https://mediapipe.dev

Appendix A. Requirement & Verification Table

Table A.1: System Requirements and Verifications

Requirement	Verification	Verification Status (Y/N)
1. Core Functionality	**Ensure the system detects a user automatically and consistently**	
a. Automatic presence detection with no manual activation	Place test subjects at 1.5–3.5 m and verify system triggers without button press	
b. Consistent activation across multiple users	Test with 5 users of varying heights and positions	
2. Visual Transformation	**Verify the mirror switches from reflective state to digital display clearly**	

a. Display transitions from mirror-like idle to digital content	Measure transition visually and confirm brightness allows clear view of content	
b. Overlay of image/video and text is legible, aligned, and not cluttered	Inspect UI screen for clarity and alignment	
3. Correct Content Triggered	**Confirm selected STEM profile matches facial detection and selection**	
a. Display correct scientist/engineer and associated text/video	Test multiple face samples with known database entries	
b. Avoid random or incorrect activations	Confirm system does not trigger incorrect profiles during tests	
c. Facial matching reliability >80%	Collect statistics from repeated trials across users	
4. Responsiveness	**Ensure the delay between detection and content display feels natural**	
a. Measure latency from presence detection to UI activation	Use timer to measure delay; target <1 s	
b. Smooth playback of video/UI content without stutter	Observe multiple video playback sessions	