

Fall 2026 ECE445 Design Document

Tactile Screen for Visual Aid

Project No. 49

Team Members

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1. Introduction

1.1 Problem & Solution

People who are blind or have vision problems obtain information from tools such as canes, guide dogs, audio, Braille, and other assistive devices. However, each of these tools have their own limitations. For example, a cane can only be used on objects within its physical reach and tactile maps are only available in certain locations. Traditional refreshable Braille displays are effective for communicating text, but they provide constant new feedback on shapes and information in front of them.

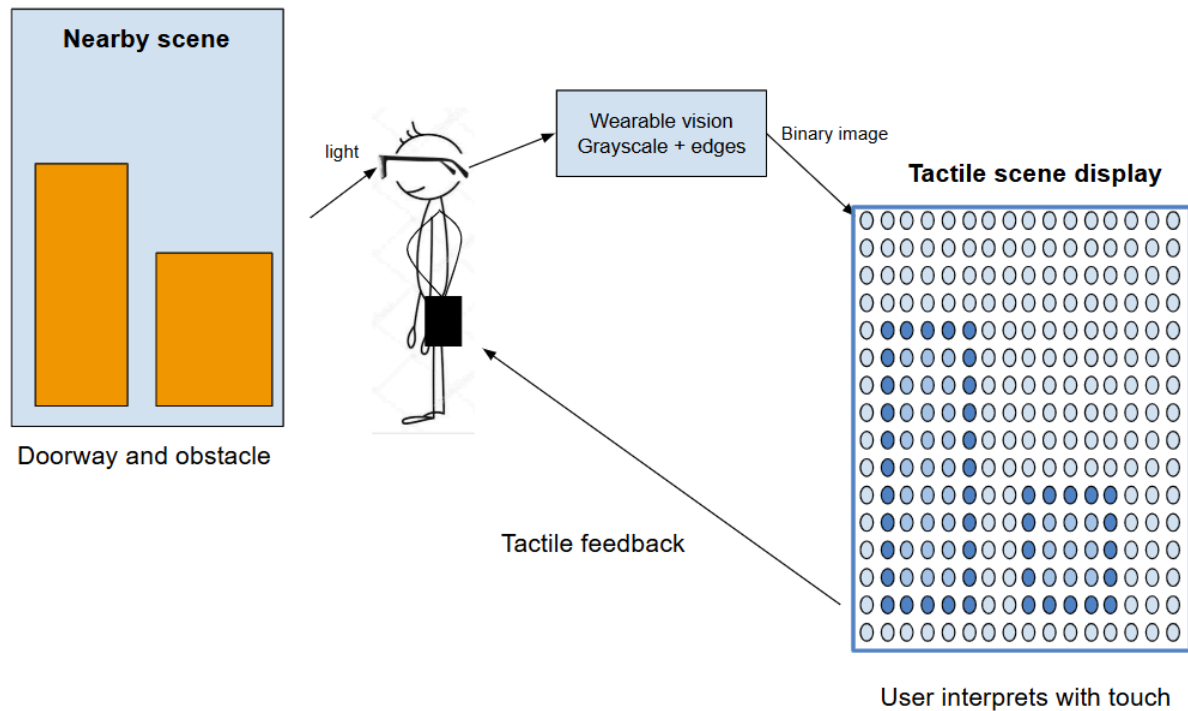
Vision impairment is a problem that affects many people. The World Health Organization reports that about at least 2.2 billion people have near or distance vision impairment (World). Due to this, an estimated 411 billion dollars annually are lost in productivity from vision impairment (World). Vision also affects all areas of life, such as mobility, education, independence, and more. Therefore, our project isn't intended to replace a cane, a dog, or other vision devices. On the other hand, our project gives additional information about one's environment through touch to a person with a vision impairment.

Our solution consists of a wearable camera and processor mounted on a pair of glasses that communicates with a 16 x 16 tactile display. An OV5640 autofocus camera captures what is in view of the user and sends the image to a ESP32 located on the glasses. Using local processing, the ESP32 takes the image from the camera and converts it into a 256 pixel binary image. Navigation mode is used for an object in front of the user, taking the boundaries of the object using Sobel edge detection. On the other hand, reading mode focuses on more closer regions and uses thresholding to capture text.

The processed tactile frame is transmitted over a 3.3V UART connected to a second ESP32 inside of the tactile display. The controller operates a motorized carriage beneath a 16 x 16 surface. By using small push pull solenoids, as well as a sliding sheet to keep the pins in place, we are able to maintain images regardless of the force by the user. This also allows us to maintain still images with low power, while staying dynamic in the case of navigation.

One important distinction between this device and other computer-vision assistive devices is that the system does not identify and try to tell a user what the object is, instead the device uses a tactile display to represent a simple geometric version of what is in front of the user. This reduces the reliance on complex, and often wrong artificial or machine learning algorithms. Furthermore, all image processing is local to the device, which reduces privacy concerns.

1.2 Visual Aid



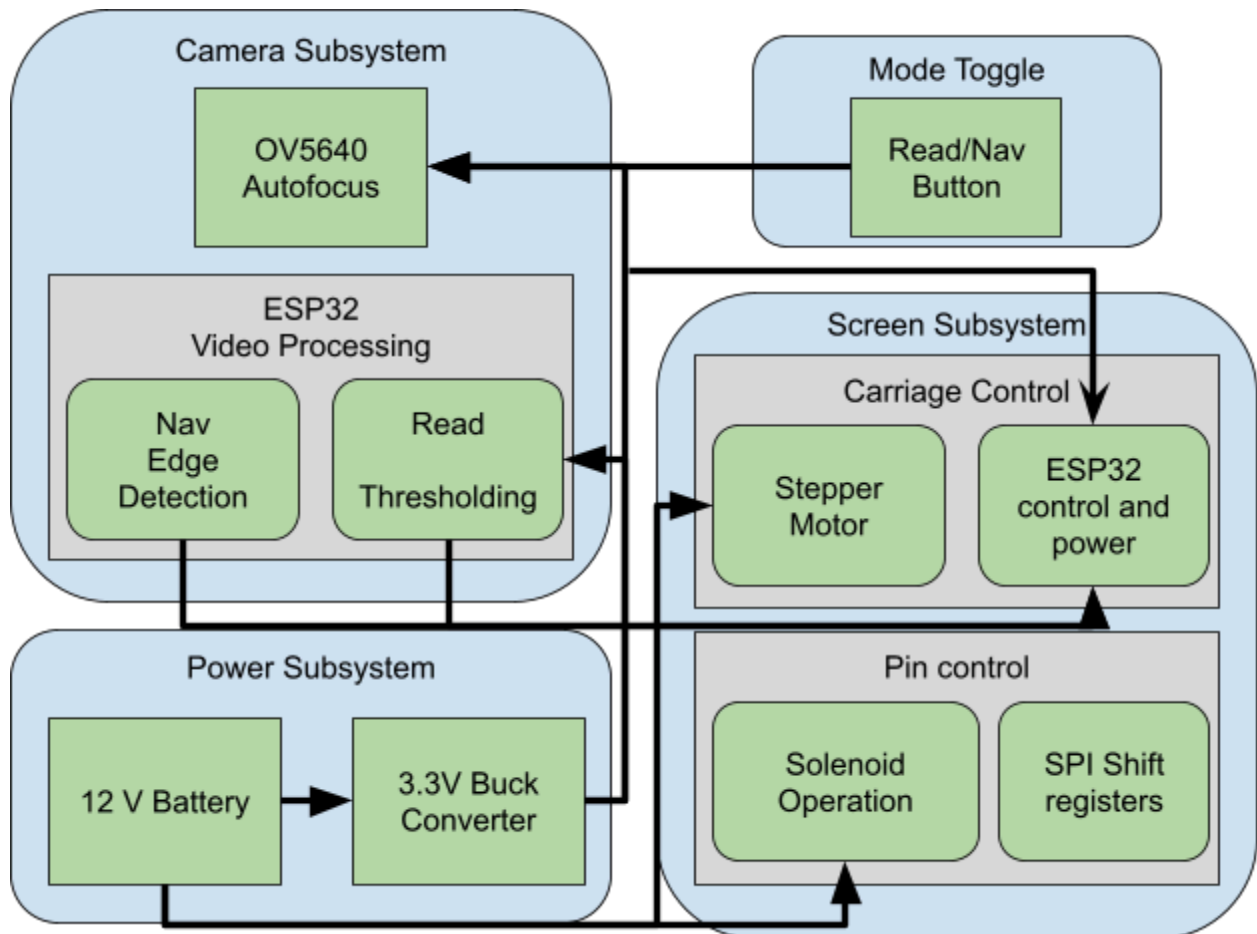
1.3 High-Level Requirements

- The system shall capture and process a visual scene and generate a 16 x 16 tactile frame with a refresh rate of at least 1 Hz
- There should be 95% pin accuracy of the 256 pins, meaning at least 244 of the pins are correctly positioned per completed frame
- Each raised pin should extend on average about 1mm above the nominal tactical surface and shall be able to resist a downward force of at least 0.15 N for 60 seconds without returning to the lowered position

- The camera subsystem shall support a reading mode that should be able to focus on text about 30-40 cm from the user and a navigation mode representing senses about 1-2 m from the user

2. Design

2.1 Block Diagram



2.2 Physical Design

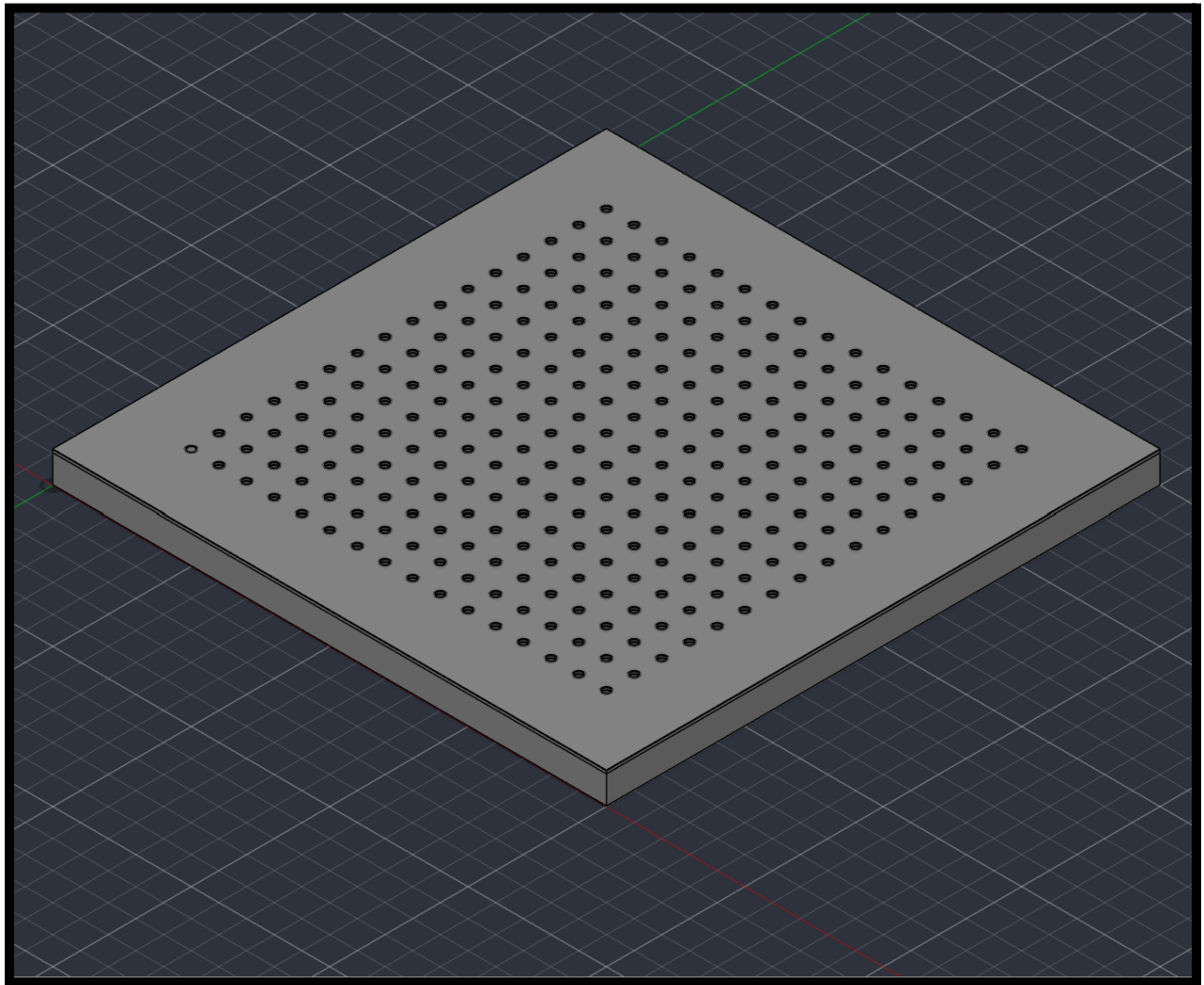
The project has 2 physically separate assemblies. The first assembly is mounted on the glasses and contains the forward facing OV5640 camera and an ESP32 controller. The camera should be mounted on a fixed portion of the glasses, not across the hinge to reduce repeated

flexing of the camera wiring. A physical button will allow the switch between navigation and reading operation.

The second assembly is a handheld tactile display unit. Its upper surface contains a 16 x 16 array of 256 pins. Each hole contains a small pin and spring assembly. The spring will push downwards, while the solenoid pushes up. A stabilizing plate will shift underneath each pin after activation, which allows the pins to stay stable when the solenoid is not below. This spring system allows for a purely one directional linear input to achieve two stable states. This allows the pins to stay raised no matter how much force is applied by the user.

A carriage containing 16 push pull solenoids travels beneath the display. Additionally, one other solenoid will be added along the side to control the stabilizing center plate. A bipolar stepper motor, timing belt and pulley move across the second dimension of the 16 x 16 array. The display ESP32 determines which pins change state. All the moving components will remain enclosed in the physical assembly.

FUSION Drawings for Tactile Display Assembly:



2.3 Substem Design

2.3.1 Camera Subsystem

The camera subsystem is responsible for capturing the environment in front of a user and converting the captured image into a 16 x 16 binary representation for the tactile display. The subsystem consists of a OV5640 autofocus camera and an ESP32 used for video processing. The autofocus capability of the OV5640 allows the system to operate at different viewing distances depending on the selected mode.

There are 2 different modes. Navigation mode mode is for capturing objects about 1-2 meters away from the user. The ESP32 converts the captured image to grayscale and reduces the resolution to 160 x 160 pixels. Sobel edge detection then identifies strong boundaries in the image, which results in a 16 x 16 binary representation. This process removes unnecessary details while trying to preserve the original image.

In reading mode, the camera is interested to focus on text that is about 30-40 cm from the user. The ESP32 processes only a smaller region near the center of the image, which then uses Otsu thresholding to separate text from the background. The result is then displayed on the 16 x 16 display.

After the image processing is complete, the ESP32 sends the binary tactile information to the screen subsystem. The information processing needs to be fast enough to maintain over a 1 Hz refresh rate.

Requirement	Verification
The OV5640 shall obtain usable image information from objects located about 1-2	Place a high-contrast geometric target 1 m, 1.5 m, and 2 m. Process the image and verify

meters away in navigation mode	major boundaries on the 16 x 16 display
The OV5640 shall focus on text about 30-40 cm away in reading mode	Place printed text at 30 cm, 35 cm, and 40 cm and verify recognizable character boundaries remain after thresholding and image reduction
The camera subsystem should support an overall tactile refresh rate greater than 1 Hz	Process at least 30 consecutive frames and record the completion time and calculate the average refresh rate of each frame

2.3.2 Mode Toggle Subsystem

The mode toggle subsystem allows the user to select between the two operating modes of the device, which are the navigation mode and the reading mode. As shown in the block diagram, this subsystem consists of a read/nav button connected to the camera subsystem.

A physical button was selected rather than an electronic interface with visuals, because the user may not be able to use the interface. Therefore, the user can press a physical button to switch between the modes.

Changing between the modes must also prevent information from the previous mode from remaining incorrectly on the tactile display. Therefore, when a mode transition occurs, the screen controller will clear the previous tactile pattern before displaying the first frame of the new mode.

Requirement	Verification
A button press shall switch the device between the reading and navigation modes	Press the read/nav button 20 times during a multitude of different situations while monitoring the ESP32. Verify that every intentional button press changes the mode and only changes once for each button press
Navigation mode shall select navigation image-processing settings and reading mode shall select reading image-processing settings	Monitor the image-processing techniques on the ESP32 in the reading and navigation mode and verify that it is using the correct technique in each mode
Changing modes should prevent data from the previous mode remaining on the screen	Display a pattern in one mode, and then press the button, switching modes, and verify that the previous pattern has been cleared

2.3.3 Power Subsystem

The power subsystem provides electrical power to all the other subsystems in the project. As shown on the block diagram, the primary source of power is a 12V battery. The 12V supply is used for the high power electronics of the tactile screen, while the lower voltage electronics require a regulated supply.

A 3.3V buck converter stage is used to provide the regulated voltage required by the ESP32 controllers and other low voltage electronics. The purpose of separating the high current

actuator supply from the low voltage supply is to ensure that rapid current changes from the electromagnetics or stepper motor do not cause the ESP32 controllers to reset.

The actuator system creates short duration current transients when the solenoids are energized. Therefore, bulk capacitance is included near the higher current loads to reduce supply voltage droop and smaller decoupling capacitors are near the ICs to reduce high frequency noise. Electromagnet activations will also be staggered so that a large number of actuators are not energized at the same time.

The proper operation of all the subsystems rely on the power subsystem. Therefore, the power subsystem must have stable power, in order to ensure that all other subsystems meet their requirements.

Requirement	Verification
The power subsystem shall provide a regulated 3.3V supply within 5% during normal operation	Measure the 3.3V rail with an oscilloscope during operation of the device. Verify that the voltage remains between 3.135V and 3.465V
Electromagnet activation should not cause either ESP32 to reset	Repeated command alternating tactile patterns while monitoring the ESP32 reset messages and the 3.3V rail. Verify that no unintended reset occurs
All power components, traces, connectors, and wiring should remain within their voltage	Measure the maximum current during a worst case scenario and compare the measured

and current limitations	value with the ratings on the datasheets of the battery, regulator, PCB traces and other components
The subsystem should have enough supply to operate the camera, ESP32s, controllers, electronics, motors and all the magnets at the same time	Operate the device with all the subsystems working simultaneously and verify that no subsystem has a loss of power or has a shutdown

2.3.4 Screen Subsystem

The screen subsystem converts the binary image produced by the camera subsystem into a physical tactile representation for the user. This subsystem controls the carriage control and the pin control. The tactile surface has a 16 x 16 array of 256 bistable pins. Each pin can be in a raised or lowered state. Each state represents either a 0 or 1 bit, received from the camera subsystem. Because the pins are bistable, they remain in their position without the need for continuous electrical current.

The carriage control portion contains one of the ESP32s and the stepper motor system. The ESP32 receives the processed image from the camera subsystem and stores the states of all the 256 pins. The ESP32 then controls the stepper motor to move the electromagnet carriage beneath the tactile display. Using an endstop or reference point, the controller can correctly align the solenoids beneath each line of the pins. At each location, the ESP32 determines if the pin needs to be changed or not, and then controls the pin control circuitry. After each pin at that

location has been updated, the ESP32 tells the carriage to go to the next location. This goes on until every pin has been updated.

The pin control is used for physically raising and lowering the tactile pins. It uses electromagnet actuation circuitry and SPI-controlled driver electronics, as well as a mechanical spring latch. The display uses 16 push pull solenoids mounted on the moving carriage. The ESP32 communicates with the driver circuitry through SPI and selects the electromagnets that must be energized at each location. The solenoids use short pulses to change the pin positions, and due to the sliding stabilizing plate, the pins do not need continuous power. The electromagnetic activation will be staggered rather than all possible 16 actuators simultaneously. The current design targets short pulses of 5-10 ms, which lowers the instantaneous current demand.

The screen subsystem is also in charge of making sure that there is a 95% pin accuracy. Meaning 244 of the 256 pins must display correctly. The pins must extend on average about 1 mm above the surface and endure a downward force of 0.15 N for 60 seconds.

Requirement	Verification
The completed tactile display must have 95% accuracy on the 16 x 16 pattern	Command test patterns to the display, such as stripes or all-up. Count the pins and verify that at least 95% are properly displaying
Raised tactile displays should extend on average about 1 mm from the lowered surface	Raise a certain amount of pins multiple times, measuring each pin, and comparing it against

	the lowered pins. Verify that the raised pins extend on average about 1 mm above the lowered pins
A raised pin should endure 0.15 N of downward force for at least 60 seconds without returning to the lowered state	Apply a calibrated 0.15 N of force to selected pins and verify that they do not return to the lowered state
The carriage should move through the entire display without losing alignment	Home the carriage, and perform at least 10 test of displaying an image to the tactile screen, and verify that the carriage moves back to the home location each time and retains alignment
The electromagnets shall remain in the current state without continuous current	Pulse an electromagnet to change a pin's position and remove the power from the coil. Verify that the pin stays in the correct position for at least 60 seconds

One of the most critical mechanical interfaces is the mechanical latching mechanism used to hold the tactile pin in the raised location. After an the solenoid pushes the pin up, we will use a sliding sheet that will hold it in place.

3. Cost & Schedule

3.1.1 Labor Cost

For the labor cost estimate, the group assumes a starting salary of \$85,000 a year, which comes out to about \$40.83 an hour. Each team member is expected to dedicate about 12 hours a week to the project on average. With a 16 week semester, this comes out to a total of 192 hours. Therefore, using the formula: $(\$40.87/\text{hr})(192 \text{ hours})(2.5)$, gives about \$19,615 per team member, which when multiplied by 3 is \$58,846. The group also talked to the machine shop. The machine shop estimates 37 hours of work at a rate of \$56.5 an hour, which comes out to \$2090.50. Therefore, the total cost of labor is \$60,936.50.

3.1.2 Electrical Component Cost

The table below shows the current PCB BOM for our 2 PCBs.

Component / Part Number	Manufacturer	Description	Unit Cost (\$)	Quantity	Extended Cost (\$)
ESP32-S3-WROOM-1-N8R8	Espressif Systems	ESP32-S3 Wi-Fi/Bluetooth microcontroller module	6.32	2	12.64
XL1509-5.0	XLSEMI	5 V step-down switching regulator	0.62	1	0.62

TMC2209-LA	Analog Devices / Trinamic	Bipolar stepper-motor driver with STEP/DIR and UART control	6.25	1	6.25
XL1509-3.3	XLSEMI	3.3 V step-down switching regulator	0.62	1	0.62
IHLP4040DZER470M8 A	Vishay Dale	47 μ H shielded power inductor	1.44	1	1.44
IHLP4040DZER680M5 A	Vishay Dale	68 μ H shielded power inductor	1.20	1	1.20
SBR3U40P1-7	Diodes Incorporated	40 V, 3 A Super Barrier rectifier diode	1.00	2	2.00
EEU-FM1V471	Panasonic	470 μ F electrolytic capacitor	1.04	2	2.08

CC0805JKX7R9BB105	Yageo	1 μ F 0805 ceramic capacitor	0.223	5	1.12
EEU-FM1V331	Panasonic	330 μ F electrolytic capacitor	0.87	1	0.87
EEU-FR1V181	Panasonic	180 μ F electrolytic capacitor	1.00	1	1.00
CC0805JPX7R9BB104	Yageo	100 nF 0805 ceramic decoupling capacitor	0.18	10	1.80
1206YC225K4T2A	KYOCERA AVX	2.2 μ F ceramic capacitor	0.62	1	0.62
CL21B223KBANNC	Samsung Electro-Mechanics	22 nF ceramic capacitor	0.16	1	0.16

ECE-A1EKS100	Panasonic	10 μ F electrolytic capacitor	0.30	3	0.90
EEU-FR1V101	Panasonic	100 μ F electrolytic bulk capacitor for TMC2209	0.70	1	0.70
B4P-VH(LF)(SN)	JST	4-position VH-series power connector	0.25	1	0.25
B2P-VH(LF)(SN)	JST	2-position VH-series power connector	0.16	1	0.16
USB4105-GF-A	GCT	USB Type-C receptacle	0.93	1	0.93
TSW-101-07-G-S	Samtec	Single-position male header	0.12	1	0.12
B3B-XH-A(LF)(SN)	JST	3-position XH-series connector	0.13	1	0.13

TSW-116-07-G-D	Samtec	32-position dual-row male header	3.91	1	3.91
KDV12FR270ET	Ohmite	27 Ω power resistor	0.31	2	0.62
RC0805FR-072K7L	Yageo	2.7 k Ω 0805 resistor	0.10	1	0.10
RC0805FR-078K2L	Yageo	8.2 k Ω 0805 resistor	0.10	1	0.10
ECE-A1EKS100	Panasonic	10 μ F capacitor	0.30	5	1.50
CC0805JKX7R9BB105	Yageo	1 μ F 0805 ceramic capacitor	0.18	12	2.16
CL21B104KBCNNNC	Samsung Electro-Mecha nics	0.1 μ F ceramic decoupling capacitor	0.10	4	0.40
CL21B223KBANNNC	Samsung Electro-Mecha nics	22 nF ceramic capacitor	0.20	2	0.40

EEU-FM1V471	Panasonic	470 μ F electrolytic bulk capacitor	1.05	2	2.10
BLM21PG221SN1D Ferrite Bead	Murata Electronics	220 Ω @ 100 MHz, 0805 EMI suppression ferrite bead	0.11	1	0.11
				Cost:	64.47

3.1.3 Total Cost

The current grand total as of now with labor and parts is \$61,1001.11.

3.2 Schedule

The first PCB order was submitted during the week of September 28th. The team expects to use at least another 2 PCB fabrication rounds for revisions of the PCBs. The 4th round will be kept in mind in case of another revision only if necessary. Josh will focus on mechanical design of the tactile display, Tyler will focus on the tactile display PCB and electronics, and Walter will focus on the camera PCB and camera subsystem. All three team members will participate in subsystem integration and testing.

Week	Design and Construction Work	Task Distribution
Sept. 28 – Oct. 2	Finalize the overall system architecture, component selection, PCB designs, and initial mechanical design. Submit the first PCB fabrication order. Prepare preliminary enclosure and tactile-display drawings for the machine shop.	Josh: mechanical design and machine shop preparation, and submit Design Document Tyler: tactile-display PCB. Walter: camera PCB
Oct. 5 – Oct. 9	Continue breadboard prototypes of the camera, power, stepper, and actuator circuits. Identify possible PCB changes for the second fabrication round. Begin evaluating solenoids if they arrive.	Josh: continue talks with machine shop Tyler: tactile electronics and PCB revisions. Walter: camera electronics and image processing. Submit round 2 PCBs
Oct. 12 – Oct. 16	Complete Breadboard Demo and verify that the major subsystem concepts operate independently. Continue electrical prototyping while waiting for Round 1 PCBs. If solenoids have arrived, measure them, finalize enclosure dimensions, and submit final mechanical drawings to the machine shop. Submit PCB revisions if required.	Josh: solenoid measurements and final mechanical drawings Tyler: PCB revision. Walter: camera testing and PCB revision

Oct. 19 – Oct. 23	Receive and assemble the first-round PCBs. Perform initial PCB bring-up and verify power rails, ESP32 operation, stepper control, actuator-driver outputs, and camera operation. Begin machine-shop fabrication if the magnets have arrived and dimensions have been verified.	Josh: mechanical testing and machine shop coordination. Tyler: tactile-display PCB assembly and testing. Walter: camera PCB assembly and testing
Oct. 26 – Oct. 30	Continue PCB debugging and assemble available mechanical components. Complete magnet measurements when the remaining magnets arrive. Begin or continue machine shop fabrication of the enclosure and tactile display structure. Prepare an additional PCB revision if hardware problems remain.	Josh: enclosure, carriage, pin, and magnet integration. Tyler: tactile PCB debugging. Walter: camera PCB debugging
Nov. 2 – Nov. 6	Assemble major subsystem prototypes and demonstrate progress. Establish communication between the camera-side and tactile-display ESP32s. Demonstrate camera image processing, carriage movement, and tactile-pin actuation.	Josh: mechanical assembly. Tyler: tactile-display electronics. Walter: camera electronics and image processing. Progress Demo

Nov. 9 – Nov. 13	Integrate the camera, mode toggle, power, carriage control, and pin control subsystems into the first complete prototype. Send processed camera information to the tactile display and begin generating complete 16×16 tactile patterns	Josh: mechanical integration and alignment. Tyler: tactile electronics and actuator integration. Walter: camera electronics, processing, and communication. All members assist with system integration
Nov. 16 – Nov. 20	Refine the integrated prototype. Adjust carriage alignment, stepper timing, pulse duration, image-processing thresholds, and communication timing. Correct failures identified during integrated testing and prepare for the Mock Demo	Josh: mechanical refinement. Tyler: tactile-control refinement. Walter: camera and processing refinement. Mock Demo & Presentation
Nov. 23 – Nov. 27	Review Mock Demo results and make corrections. Perform debugging, documentation, or minor assembly work as needed.	Work separated as needed
Nov. 30 – Dec. 4	Test the completed integrated system against the project requirements. Verify tactile accuracy, refresh rate, pin displacement, holding force, camera	All members: final verification, integrated system testing, documentation, and presentation.

	operating distances, mode switching, power stability, and overall operation. Make final minor refinements and complete the Final Demo and Presentation.	
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4. Discussion of Societal Impact, Engineering Standards, Ethics, & Safety Considerations

4.1 Societal Impact

The intended societal benefit of this project is to provide those that have a severe vision impairment with another method of gaining spatial information. As previously stated, the design is not meant to replace canes or guide dogs. Instead, it converts part of the visual environment into a tactile representation that can provide the user with boundaries, shapes, obstacles and nearby text.

The system may also provide benefits in education or workplace environments where knowing the dimensions of a two dimensional object may be useful. Due to the onboard processors, the user does not have to have access to the internet. This allows the user to bring the device anywhere, without worrying about connectivity.

Environmental impacts can include the use of copper, magnetic steel, permanent magnets, PCB materials, semiconductors, batteries, and the materials to enclose the device.

Therefore, the device is designed in such a way that a failure of electronics, the carriage, or another part does not require a replacement or disposal of all the parts.

The project should not make any unsupported claims about affordability, navigation safety, or effectiveness for the users. Performance claims will be accurate measurements from the prototyped device, using a multitude of lighting conditions, distances, and test patterns.

4.2 Engineering Standards

Multiple standards are relevant to our project. IEC 62368-1 is relevant to the electrical and electronic portions of the project, due to the fact that it is about safety for information and the communication equipment (“What Is IEC 62368-1?”). The code is meant to reduce the probability of electrical and thermal injury. Although our project will not have a formal product certification, these standards should still be used to increase safety and ensure that correct design principles are in use when creating our project.

Since the project is using a battery, IEC 62133-2 is relevant to battery safety. It ensures that batteries are being used safely and without normal operation (“What’s the IEC62133”). Furthermore, since the electronics have a USB-C type interface, the USB Type-C Cable and Connector Specification defines electrical and mechanical requirements that should be met when designing the power connector and the corresponding circuitry. The design will also follow the principles of the IEEE Code of Ethics, where our project will prioritize safety, privacy and be honest to the users.

4.3 Ethical Considerations

The primary ethical concern is that a person with impaired vision could put a lot of trust into the wrong tactile image. If a problem were to arise with the device, such as a missed obstacle, mechanical pin failure, or poor camera image, then the tactile image could create

incomplete information. The demonstration and reports will state missed cases and accuracy instead of stating perfect reliability.

Privacy is also important as the project contains a camera that will scan lots of information in front of the user. The system will process images locally, and not require any connection to the internet. The camera will not retain information either and delete photos shortly after use.

The device provides processed spatial information through tactile geometry, leaving the final interpretation up to the user, which reduces the risk of an incorrect classification being presented to the user. Furthermore, any testing on humans will be done after extensive testing has been done on the electrical and mechanical systems of the project.

4.4 Electrical & Mechanical Safety

The main electrical hazards are associated with high currents required by the electromagnets and stepper motor. Although this system operates at 12V, there can still be enough current to overheat wires, connectors, PCB traces, and other electrical equipment. Furthermore, a fault in the electrical system could create a fire or battery hazard.

The electromechanical design introduces additional hazards from the moving carriage, stepper motor, belt and magnetic components. If the carriage and belt are not completely covered from the user, they can create pinch points. These components need to be securely enclosed in order so they do not detach or become accessible to the user.

Furthermore, thermal safety is important. Electromagnets are pulsed rather than continuously energized, and firmware will restrict coil activation time. The actuator drivers provide electrical and thermal protection features, but the physical design will still need to be

tested in the lab. The camera and ESP32 near the head of the user must remain at an acceptable temperature.

4.5 Safety Mitigation Procedures

Before testing the complete system, each subsystem will be tested independently. The 3.3V power rail and control electronics will be first tested using a current limited power supply without the stepper motor or electromagnets connected. After verifying the correct voltages, the stepper motor will be tested individually, followed by a single electromagnet channel before the remaining actuator channels are connected.

During electromagnet testing, solenoid time will be limited in software to prevent continuous energization and excessive heating. Not all electromagnets will be activated at the same time to reduce maximum current. Testing will be stopped if excessive heating or current draw occurs, if the ESP32 resets, or if there is damage to any components.

The moving carriage, belt and stepper motor will be tested without any user contact. The carriage and endstop operation will be tested, before a user touches it, and all components and wires will be enclosed. Furthermore, all PCB traces will be monitored to make sure they are not going over their maximum current, and the entire device will be powered off before any changes are made to it. Once the device passes through testing, only then will a user be able to wear the device.

5. Citations

“What Is IEC 62368-1? The Importance of Safety Standards for Industrial Computers.” Premio, Inc., July 28, 2023.

<https://premioinc.com/blogs/blog/what-is-iec-62368-1-the-importance-of-safety-standards-for-industrial-computers>.

“What’s the IEC62133 Certification of Li Polymer Battery?” LiPol Battery Co. Ltd. Accessed October 2, 2026.

<https://li-polymer-battery.com/whats-the-iec-62133-22017-certification-of-li-polymer-battery/>.

World. “Blindness and Vision Impairment.” Who.Int, World Health Organization: WHO, 10 Aug. 2023,

<https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment?>.

Accessed 29 Sept. 2026.