CSCI 370 Final Report

Bots Ahoy

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Table 1: Revision history

Revision	Date	Comments
New	May 20, 2026	I. Introduction II. Functional Requirements III. Non-functional Requirements IV. Risks V. Definition of Done XIII. Team Profile
Rev – 2	May 26, 2026	I. Introduction: added more background on what the previous group did II. Functional Requirements: adding the set requirements given by the client III. Non-functional Requirements: adding the set requirements given by the client IV. Risks: Reworded some phrases V. Definition of Done: Ensuring the requirements given above are all in the definition of done section VI. System architecture XIII. Team Profile: Adding in pictures for each team member
Rev – 3	June 3, 2026	VII. Software Test and Quality VIII. Project Ethical Considerations
Rev - 4	Jun 10, 2026	IX. Project Completion Status
Rev - 5	Jun 21, 2026	VII. Software Test and Quality - Added results of testing IX. Project Completion Status - Finished the paragraphs describing project status X. Future Work XI. Lessons Learned XII. Acknowledgements

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I. Introduction

The FlagBots are two large artistic pieces with robotic components created by Eva Goetz in her *Think A Bot It* installation in December 2019 [1]. They were designed to spark profound questions on technology and its impact on society, particularly Artificial Intelligence (AI). The robots' primary form of communication is through the use of the semaphore language.

Originally, the robots communicated only with one another in hard-coded messages utilizing radio frequency sensors to pass states to the other. To shift the focus toward human-robot interaction, a group in 2024 developed a system that uses a camera to identify a human's semaphore signals with pose estimation, allowing the robots to respond with signals of their own. They implemented this by integrating an Arduino to collect the visual data and a Raspberry Pi to process it. However, this system was slow and prone to error. A video of the previous implementation as well as a Semaphore table is included in Appendix C.

The client, Dr. Iris Bahar, has given the team objectives to further improve human-robot interaction with the use of Arduinos, Raspberry Pis, and pose estimation algorithms. To enable the robots to interact with the humans on a larger scale, this project aims to expand on the commands from the human user, expand the responses from the robot, improve safety margins, and add an artistic flair to the robots. This involves working on updating the computer vision software, incorporating the use of stepper motors, using RF sensor controls, as well as expanding the repository of available commands and syncing robotic dance routines to music.

II. Functional Requirements

The primary requirements to be prioritized for this project are expanded vocabulary, expanded commands, functioning safety sensors, improving the pose estimation software, and incorporating additional creative work to the robots.

Infrared sensors detecting human user

Implement motion sensors on the side of the robot that immediately stop arm movement if human motion is detected. Currently, the motion sensors are present but not set up or functional. This is a safety hazard, as the arms of the robots are large and can impact users if they are standing to the sides of the bots.

This is implemented through the Arduino, and tested by ensuring that locations around the arms that pose risk, stop robotic arm movement when the areas are obstructed.

Instructions to improve robot-human interaction

Instructions are integrated into the system so that if a user wants to interact with the robot, despite their lack of knowledge of the semaphore language, the user can send commands and understand the responses from the robot.

An important facet of this was determining how the information would be displayed, whether it be a piece of paper next to the robot or a message displayed on the screen. This was tested by having a user, who has not been involved with the project, interact with the robot without the team's help and evaluating the user experience.

Expanded range of commands from human user

The human user can communicate with the robot utilizing six existing commands: HI, HELLO, MIRROR, MINES, DANCE, HOT. The commands the human user can use to communicate with the robot needed to be expanded. Examples include: creating additional dances such as YMCA, messages that correlate to the artist's vision, and messages that allow communication between the human and the robot.

To ensure this functionality, each command was physically verified as functional via interaction with the robot. Pose estimation can be verified in this way and that the appropriate responses are returned from the robots for each given input. Additionally a test subject was utilized to test as many commands as feasible.

Expanded range of responses from robot

This requirement correlates to the expanded commands for the human user, as the robot is responding to the human user's commands. The robot responds based on each command made by the human: says “Hello” back, says “Hi” back, mirrors the user's movement, says “Helluva”, the robot dances, performs part of the dance in the HOT TO GO TikTok dance (see Appendix C). With the expanded commands from the human user, the robot's responses needed to be expanded to match the commands. A table of final commands is included in Appendix C.

This required adding tests to the preexisting code. Each command was tested using the robot's camera software. Given one input, it can pick randomly from one of the output messages.

Pose estimation improvement

While pose estimation was already implemented, it was slow and not always reliable. The computer vision/pose estimation algorithms already in place needed to be improved, optimizing their speed and increasing their accuracy.

Implementation involved evaluating the current pose estimation and potentially choosing a new library or method. Pose estimation was physically verified with the robots through system testing as the project progresses.

Creative Work

The artist's vision is incorporated into the functionality and movement of the robot, including the interactions between the human and the robot and how that plays into the creative message the artist originally intended.

This was achieved by incorporating messages that the artist originally posed when she first dreamt of this project. These messages are accompanied by responses that emphasize the original questions and perspectives the artist originally sought to elicit thought into. For additional creative output, certain messages are accompanied by music, voices or sound effects.

Refurbished Wiring

The wiring on the back of the flag bots was disorganized, with several of the cables not reaching the Arduino which impacts the functionality and visual presentation. Some wiring is frayed and deteriorated and the connectors at several locations are in poor condition.

New cables and extensions are needed to ensure proper connectivity. Followed by organizing the cables to ensure a clean and professional look.

Additional:

- Changing robot speed depending on what the message is
- Lights that correspond to the message from the robot

III. Non-Functional Requirements

Parts

After looking further at this project, it was noted that additional materials are required and a record of each item needs to be kept. These materials include: a Raspberry Pi, Arduino, micro HDMI cords, mini bluetooth speakers, refurbished low-voltage wiring, a power cord for an Arduino, and security locks.

Financial

The budget for this project is limited. All purchases must be kept small to create a minimum viable product for the client. As part of this process all purchases must be approved by professor Kathleen Kelly and ordering and delivery was facilitated through Matthew Frazier the Computer Science administrative assistant. A table was built with all supplies to be ordered which was approved by professor Kelly and purchasing and delivery was facilitated with Matthew.

Safety

Safety of the art displays is of utmost importance to the client. With this in mind, great effort must be taken to ensure that the art displays pose no risk and do no harm to users and to the general public. Motion sensors that halt robot motion are the primary component of this requirement. As such, the motion sensor system must pass all required tests and be fully implemented for final delivery.

IV. Risks

There are four main risks associated with the FlagBot project:

Five-week timeline to complete the project

- **Assessment**: Given the schedules and circumstances of the members of the group, the five-week timeline provided was a risk. Time pressure had a major impact on the group's efficiency and productivity.
- **Mitigation Plan:** The best way to prevent this timeline from having a major impact on progress is to communicate if schedule conflicts may occur with the schedule written in the contract to avoid falling behind.

Human safety as a result of the robots motor movement

- **Assessment**: There is a desire to prevent any sort of injury that a human could experience if they get close to the arms of the robot. This sort of injury would have a major impact and is especially likely if a human user is standing right next to the robots' arms.
- **Mitigation Plan:** To ensure human safety, the infrared sensor needed to be successfully connected to the Arduino. From there all appropriate settings would have to be evaluated to ensure proper safety zones are maintained. A velvet rope barrier had already been installed to ensure safety.

Hardware failures due to the longevity of the project

- **Assessment**: This is an unlikely risk, but could majorly impact the longevity and functionality of the product. Raspberry Pi's, including the newer models, rely entirely on passive airflow for cooling.
- **Mitigation Plan:** The plan to ensure the hardware doesn't overheat was to create an open case to promote airflow, as well as potentially adding a cooling fan. Extensive documentation would also be included to help with servicing, movement and maintenance of the art pieces in the future.

Inadequate responses from the robots

- **Assessment**: It is a potential risk that the robots will not provide the responses anticipated, and this risk has a major impact on the functionality of the project.
- **Mitigation Plan:** A number of tests would be conducted to ensure that the robots provide correct and adequate responses to the human's message.

V. Definition of Done

For this project to be considered done and for the client to be satisfied, the project must have the following set of features:

- Instructions that guide the user on how to interact with the robot.
- Expanded commands from the human user - minimum of ten clear messages.
- Expanded response from the robot - at least twenty possible responses.
- The robot's movements are not able to harm the human user.
- Incorporating the artist's vision with music and messages such as STOP, LISTEN, THINK, and HELP.
- Pose estimation software improvement.
- Refurbished wiring for both robots.

The delivery requirements are: two robots that are able to convey messages to the user displayed on a digital screen, safety systems to prevent harm, expansion of robot commands and expansion of creative vision. The product was presented in a live demonstration on June 18, 2026 to show the improved human-robot interaction.

The GitHub repository containing all of the team members code, a Google Drive with all updated software, diagrams, parts list, and video demos throughout the process will be delivered June 25, 2026, in a zip file.

VI. System Architecture

Description:

The display screen activates when the user plugs in the power cord (Fig. 1). The Raspberry Pi displays the footage from the Logitech camera, where the human can now send signals to the robot (Fig. 2). The Raspberry Pi reads in the signals and sends it to the Arduino. The Arduino is in control of the motor movements, and it only starts to move if the motion tracking system does not detect a human. If it detects a human it stops all motion and plays a sound to alert the human user. After each letter is processed by the robot, the robot physically performs each letter movement. When the human user sends a dance signal to the Raspberry Pi, the Pi plays music and the Arduino moves the arms in a dance (Fig. 1). The response word is displayed on the bottom right corner of the screen in cyan.

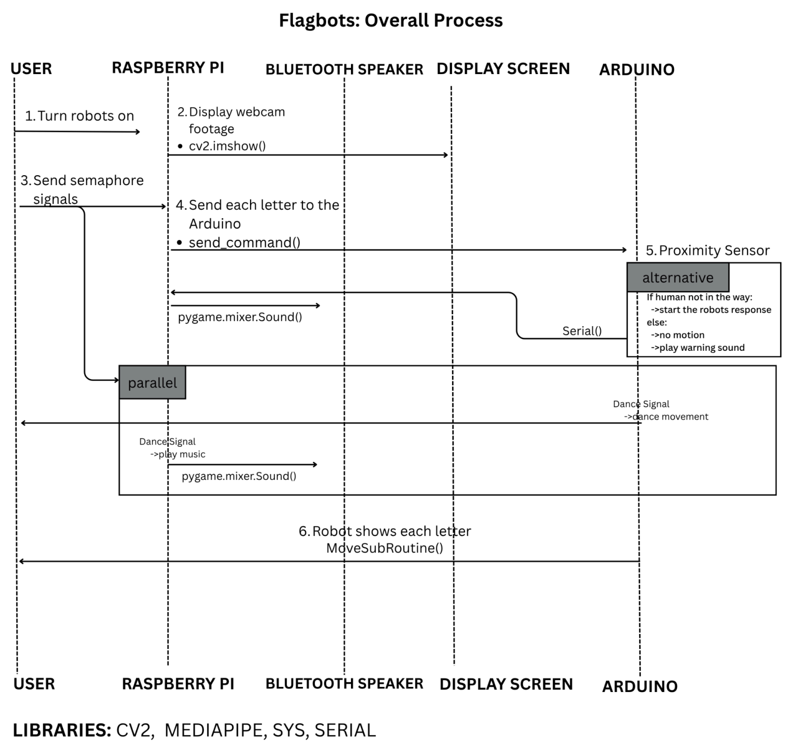


Figure 1: Sequence Diagram

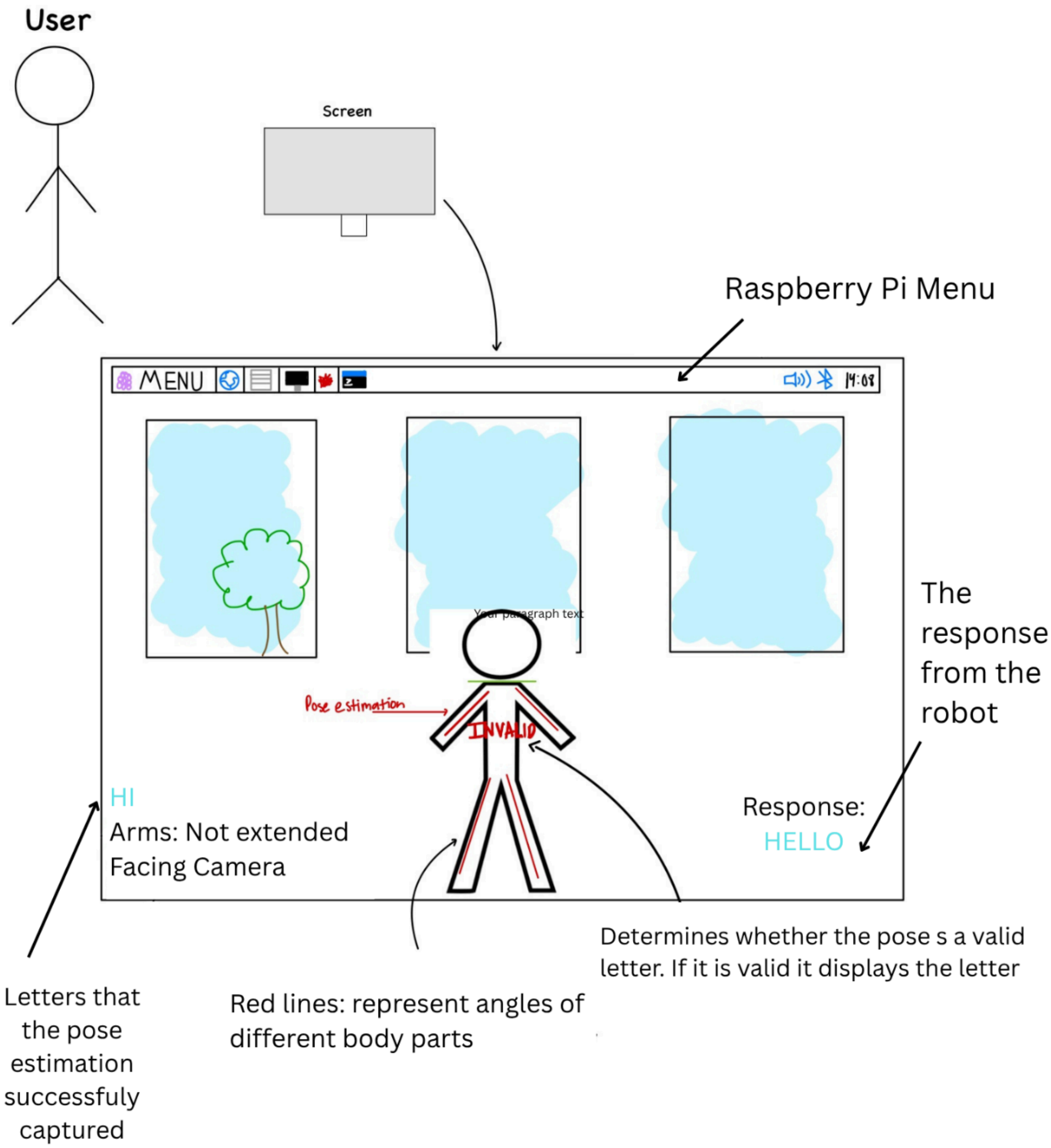


Figure 2: The display screen that pops up on the digital screen so that the human user can interact with the FlagBots and send semaphore signals

Risk Treatment Plan:

The main risks that need to be mitigated for human safety and maintenance of hardware are: hardware failure, software errors, human unfamiliarity, and environmental influence.

Risk ID	Risk Description	Category	Likelihood (1-5)	Severity (1-5)	Risk Score	Mitigation	Responsible Person
R-01	A human user is impacted by the moving robot arms	Human	2	5	10	Sensor that detects when a human is in range of the robots arms	Leo
R-02	Raspberry Pi overheating	Hardware	2	4	8	Creating an armor case to act as a heatsink. Also installation of a fan system for security enclosure for good airflow.	Aisha
R-03	Code halts	Software	2	4	8	Creating a startup script that reboots the system	Gryphon
R-04	Hardware being stolen from the robot	Hardware	3	4	12	Adding a hole on the armor case to allow the use of a physical lock to secure the hardware	Travis
R-05	Pinch points on robots during operation injure users	Human	1	3	3	Safety barriers already exist	N/A
R-06	System does not initialize on startup/reboot/interrupt	System	4	4	16	Instructions that walk the user through troubleshooting steps	Leo
R-07	Damage to installation via nefarious factors	System	2	4	8	Existing barriers and security cameras serve as deterrents and leave instructions for the next group who's responsible for it	Aisha
R-08	Wiring loom failures/shorts	Hardware	3	3	9	Keeping extra wiring looms and replacing them when/if needed	Travis
R-09	User does not know Semaphore	Human	5	1	5	Virtual/Hard display	Aisha
R-10	Group members graduate - no maintenance team	System	5	2	10	Extensive documentation on how to setup, initialize, maintain and service robot	Travis
R-11	Human safety emergency occurs	Human	1	5	5	Emergency stop/shutdown	Gryphon
R-12	Power Loss or arm failure/fall	Hardware	2	3	6	Lock arms in place	Leo

R-13	Failure of motion sensors	Hardware	1	3	3	Regularly ensure the cables are still connected to the sensor or if anything is interfering with the sensor's functionality.	Leo
R-14	Lighting/Angle/Smudge obscures pose estimation	Environment	2	1	2	Relocating room elements	Aisha
R-15	Arms impact each other at top of motion	Hardware	2	3	6	Ensure that existing code base has checks to ensure arm rotation does not exceed 180 degrees	Gryphon
R-16	Arm motor failure	Hardware	2	4	8	Unplug the system. Inspect for any damage and if there is damage, replace the motors and reboot the system	Leo
R-17	Robotic portion is not completed within time constraints	System	2	5	10	Systems that have been implemented through team management and course flow to ensure timely delivery of the final project. Maintain scope of work and modifications to be done to the system to ensure the project can be completed on time.	Travis
R-18	Dependent libraries are removed from Python	Software	4	4	16	System is fully deployed, no software updates	Aisha

Table 2: Risk Register

Technical Design Issues

Pose Estimation

Initially, the logic for the pose estimation and the logic for manipulating the robotic elements were contained in a single file. This made it difficult to understand and update the code base.

To address this concern, the code was refactored into separate files, organized by its functionality. Specifically, code for pose estimation software was included in its own class to simplify future extension by engineers. This includes easing addition of new subsystems such as audio implementation. There is also a separate file to contain the lookup table for input semaphore signals from the user and response signals from the robot. This simplifies the addition of new communications between the user and robot. The code to handle sending signals to the Arduino was also encapsulated into its own class to better separate responsibilities of the main logic loop and control loops.

Motion Sensors

There have been technical challenges related to the safety subsystem of the robots. The primary goal of the safety subsystem is to ensure safe human interaction with the displays. To achieve this goal, passive infrared sensors (PIR sensors) were previously incorporated into the design. Design challenges with these sensors have revolved around false positive readings. The sensors in their current installation location read the motion of the robotic arms as a positive signal. This leads the robot to stop motion of the arms because it reads the motion of the arms as interference. Signal noise has also been detected and may halt robot movement when no obstruction exists. Finally, the robot's design accounts for nearby obstructions to ensure safe operation.

VII. Software Test and Quality

Both FlagBots underwent the same tests, but they had to be tested individually. The tests are as follows:

Infrared sensors detecting human user

Ensure that the robot's arms stop and the speakers play a warning sound when motion is detected. To test this, the user starts the flagbot and inputs a command. While the robot is responding, have the user walk to the side of the robot in range of the sensor. A test is considered successful if the robot arms halt and the sound is played when the user enters proximity of the arms. No impact or near impact should occur.

The tools utilized for this test are the sensor and one human accepting the risk of walking near the arms. The threshold for capacity is that the arms must stop immediately, and a warning sound must begin playing soon after to indicate to the human user that they are in a danger zone. The sensors on both robots must accurately detect motion 95% of the time. If this threshold is not met, the sensor must be re-evaluated and the distance/sensitivity thresholds adjusted. Maintaining this threshold is a critical deliverable for the project.

An edge case that may impact the sensor's functionality is if an individual is too short for the sensor to detect them. To address these design concerns, multiple experiments have been performed to determine how the sensors actually interpret the signal and at what distances and locations the sensors best return data. As a result, the sensors have been relocated to the base of the robot to detect feet and legs in proximity to the display, minimizing interference from the robotic arms while ensuring shorter users are reliably detected. The sensors have a distance range for the hi/lo signal that can be physically adjusted on the sensor board. Sensor settings calibration has also been performed to better define locations at which the sensors return a hi/lo signal.

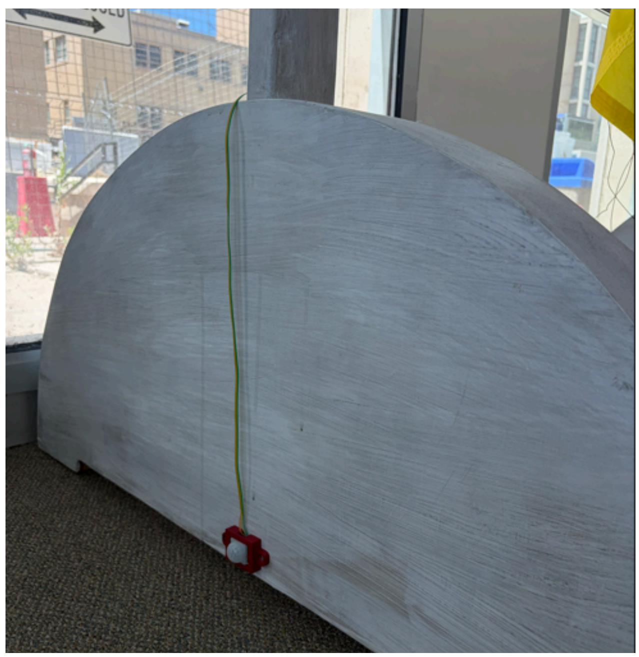


Figure 3: New sensor location

The sensors successfully stopped the arms quickly and safely when they detected motion. However, during testing they were highly sensitive and prone to false positives. This issue was addressed by reducing their sensitivity, after which they performed as expected as shown in Appendix C. It successfully detected motion 95% of the time. This test was only successful for one robot, as when implementing the motion sensors on the other a sensor short led to the removal of the sensor systems on that particular robot.

Instructions to improve robot-human interaction

Verify that the human user is able to seamlessly interact with the robot given the instructions. To test the assistance the instructions can provide, the user tries to use the instructions without help from the design team. The user will try to send different commands and observe whether the robot responds back.

For this test, the necessary tools required are instructions, the FlagBots, the human user, and the display screen. In order for the requirement to be determined as a success, the user has to effectively get a correct response back from the robot after testing multiple commands. These instructions need to improve the interaction to allow for an interaction success rate of 80%. This success rate is determined by whether they are able to input a command and get a response back within ten minutes. If the human user isn't able to use the instructions seamlessly, it will require modifications to the instructions.

Given that the instructions will be on paper, a visually impaired user may have trouble reading the papers or seeing the screen. The instructions will be in the font veranda for those who are dyslexic and black fonts will be used for those who are colorblind.

Testers were able to easily read the instructions from in front of the robot. They noted some initial difficulty understanding the meaning of the instructions, but as they interacted with the robot, they quickly learned how it worked and were able to successfully send commands to the robot within a few minutes. Each testing subject can be seen in Appendix C. On a scale from one to ten, one being the hardest and ten being the easiest, they rated it as 7.5, 9, and 8. Successfully indicating a seamless interaction success rate of 82%.

Expanded range of commands from human user

Ensure that a user's interaction with the robot can be accessible and engaging. The test entails performing the semaphore signals for each new input and taking note of any issues with signing an input. Also making sure that the response from the robot is expected.

The tools required for this test are a long command and users of different body types. For this requirement to be accepted, the human will have to be able to perform all the new commands (ten commands) with the correct responses from the robot. 90% of these commands should work with every user.

So far, interactions with the robot have been performed by people with longer arms. People with different body proportions or baggy clothes may have difficulty signing certain letters.

A tester was able to input each new command successfully. However, there were occasional typos when inputting letters that require one arm to be across the body, resulting in a different output than expected. The final success rate was over 90%.

Expanded range of responses from robot

Ensure that the robots correctly and smoothly respond to user input. The test includes, first, having the robot perform each new output on its own. Then, performing the input that should lead to each new output.

The tools required for this test are the FlagBots, a human user, and a display screen. This test needs to output the expected responses (twenty responses) from the FlagBots in order for the requirement to be considered successful. 90% of these responses should work with every user. As well as ensuring the sounds that come with certain responses properly play. This was implemented using the pygame library [2].

For every new input sent to the robot, every expected output from the robot was verified and functioned 100% of the time.

Creative Work

Confirm the new messages correctly incorporate the four messages: STOP, THINK, LISTEN, and HELP along with playing a sound when the user's action triggers the robot. Given the instructions, the user will try one of the new commands to see if the robot responds with the expected response. The user will do something to trigger the robot to see if a sound gets played to warn the human user.

Tools that will be utilized in this test are instructions, human user, display screen, speakers, and FlagBots. In order for the requirement to be considered acceptable, the robot has to correctly respond with one of the four responses above. This requirement needs to work 90% of the time.

These four responses were included in the testing for expanded responses, and they functioned 100% of the time as well producing the expected output.

Refurbished Wiring

Verify that no functionality was lost in the replacement of wiring. The test requires powering the robots and giving inputs that test the motors on the robot. Additionally, having someone walk in front of the sensors to make sure they are correctly transmitting signals to the controllers.

Materials that will be utilized for this test are a human test subject, cables/wires, zipties/cable organizer, and a display screen. The acceptable threshold for this requirement is the robot being able to perform five commands and stop motion when it detects a human user. 90% of the wires should be organized, out of sight of the user, and beyond the length of the robot's arms.

After rewiring the system, cables must have strain relief such that motion of the system does not put additional strain on cables that may lead to damage. The robot's functionality was thoroughly tested after each wiring addition to ensure all features remained fully operational.

When everything was rewired, the display screen, the motion from the arms, and the audio from the speaker all functioned correctly for one of the robots after the robot was given five different commands as well as stopping motion when a human is detected. For the other robot, intermediate repair and testing phases produced full and proper output. All systems were verified functional for a period however a short in the motions sensors near the end of the project led to the sensors being removed from the second robot. Full functionality was again verified without the motionsensor system. Prior to delivery of the final project to the client the right arm of this robot became inoperable. Due to the final deadline this issue was not investigated and is left to future work on the project.

VIII. Project Ethical Considerations

Relevant ACM/IEEE Principles [2]:

- **ACM 1.2 Avoid Harm:** The main objective given to the group from the client was to ensure human safety during robot-human interaction. In order to prioritize avoiding harm, the motion sensors needed to be implemented to prevent the arms of the robot from striking a person. By implementing these sensors we can avoid any potential injury, thus avoiding harm.
- **ACM 3.1 Ensure that the public good is the central concern during all professional computing work:** Since this project is designed for public interaction, keeping the public good as the central concern means creating a system that is accessible, reliable, safe, and establishes a secure environment. To establish this secure environment, sensors were implemented and privacy is ensured by making people aware of the cameras. Additionally, the system incorporates the artist's vision so that their message is accurately portrayed to the community.

Potential ACM/IEEE Principles:

- **ACM 1.6 Respect Privacy:** The FlagBots each have a camera that is active during use. To respect the privacy of the students in the CTLM atrium, the system must ensure that none of the live camera footage is stored and there is a sign that indicates a camera is active.
- **ACM 3.6 Use care when modifying or retiring systems:** The current software has to be run in an older version of python. If in the future, another group wants to modify the system to work on a newer version, this would require ensuring that the software/hardware still works as intended even with the retiring of the old system. The future group would have to ensure care when modifying or retiring the system and make certain the software functions like before, or better.

Michael Davis Tests:

1. **Harm test:**
   Test Question: Does this option do less harm than any alternative? Do the benefits outweigh the harms?
   Application: Yes. Keeping two large robotic pieces in a public space can lead to risks to human safety. By validating the safety protocols in place such as the motion sensors and the velvet rope barriers, human safety is maximized. The educational and creative benefits of this project heavily outweigh these potential and mitigated risks.

2. **Publicity test**:
    a. **Test:** How would this choice look on the front page of a newspaper?
    b. **Application**: If published on the front page of a newspaper, the article would show that the team actively protected public privacy by making the use of cameras transparent, ensuring human safety with sensors, and successfully balancing the safety measures with the artist's vision.

Ethical Considerations if Software Quality Plan Implemented Incorrectly:

- **Maintenance issues:** Insufficient documentation and the current version of python being used may challenge future groups working on this project. This could result in the new group's timeline for the project being delayed. Special care should be taken by future teams to get a strong and early understanding of the electrical system and how each different component functions and is integrated into the electrical system.

IX. Project Completion Status

This section documents the state of the project at the end of the project time frame. Discussed are the results related to the definition of done defined earlier. Also discussed are outcomes from the quality assurance process, testing and development.

Infrared sensors detecting human user

As part of the design process, the sensors were bench tested and full operation was verified. The PIR sensors, when connected directly and only to the Arduino, were able to read in the hi/lo output from the PIR sensors. During bench testing, sensor settings were adjusted to verify functionality within a range of distances and angles where readings could be validated. As part of this testing it was discovered that the sensor housings supplied by the previous team were interfering with the sensors ability to detect movement. In addition to the housing concern, motion of the robot's arms was detected during robot output which would halt function during normal operation situations.

As a result of the concerns identified in testing, the project design was modified to house the sensors in a new location. Because of the interference of the arms during movement, the new location of the sensors at the base of the robot's legs was chosen. This allowed the arms to move freely above the sensor's detection cone. In addition, this location helped improve safety margins as children could potentially be too short to be detected by the previous location. As part of the relocation of the sensor housing redesigned sensor housings were installed to help address sensor obstruction by the arms.

Attempts to connect the sensors directly to the Raspberry Pi were unsuccessful. PIR sensors are very sensitive to electrical interference, and have known issues when being connected to a Pi. Despite moving the sensor further away and getting longer wires, the sensor was consistently outputting a hi signal, triggering false positives.

Because of the issues with the Raspberry Pi, the sensor was switched back to reading in from the Arduino. If the sensor detects motion, it pauses the robot's arms for 7 seconds and plays a warning noise. If music was playing, it paused to let the warning play before continuing where it left off.

Adding the motion sensors to one of the robots was successful. As the motion sensors detected motion, the robot's motion halted correctly, and the audio continued to work. But on the other robot, the Pi recognized it was drawing too much current and shut off the usb port from the Arduino to the Raspberry Pi, resulting in a loss of motion from the robot. The overcurrent concern was related to a short in the old harness to the motion sensors. Due to this safety concern the motion sensor system was removed from this particular robot.

Instructions to improve human-robot interaction

Two different posters were added to assist users in their interactions with the robots. Two copies of one of the posters are situated next to the robots to assist users in understanding the pose estimation screen. (Fig. 4) These posters give the basic instructions for interacting with the pose estimation display and robot. An additional ring-bound set of documents are included on a stanchion of each robot to help the user identify the meaning of the color coded letters displayed on the pose estimation screen and how to enter letters into the software. It also includes the semaphore table for users to understand what positions to hold to sign corresponding letters and what to expect when receiving signals from the robots. In addition it includes all possible input commands so that the user knows what inputs are valid.

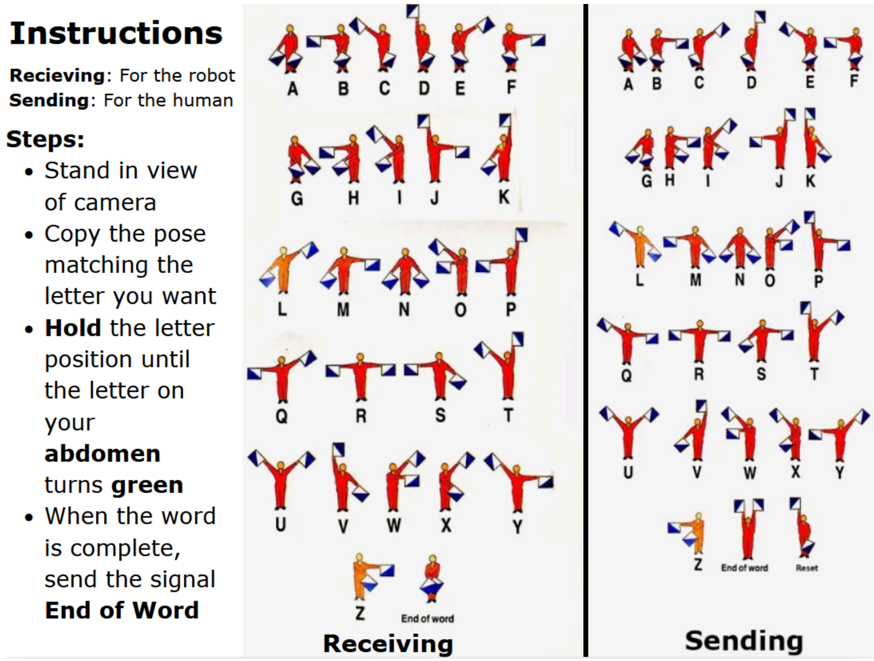


Figure 4: Robot instructions display poster

The second set of instructions includes a list of all input commands included as of the completion of this project (Fig. 5). This gives the user the basis on which to communicate with the robots. This list includes all the words the robot is capable of responding to. The robots' responses are purposefully left out. This enforces that the users develop an improved ability to read semaphore and the first display is included to assist with this comprehension.

***First: Plug in the power cord to the wall socket**

To interact with the robot, you place your arms at specific angles corresponding to letters of the alphabet. You will need to hold each letter for a few seconds to confirm it. If your arms are not extended, your pose will not count towards any time, so use this to put your arms in the correct position, then extend them.

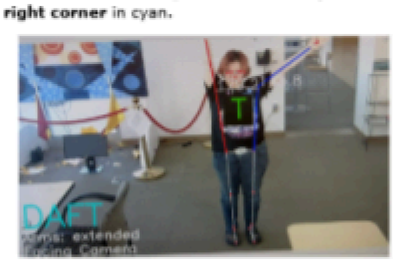
You can check your current letter and currently spelled out word by looking at the screen. Your word so far is in the bottom left in cyan, and the current letter that your pose indicates is on your body.

- When the letter is **red**, your arms are not extended.
- When the letter is **yellow**, your arms are extended, and the confirmation timer has started.
- When the letter turns **green**, your letter has been accepted, and you can move on to the next one.

If you want to **get rid of the current letters** you have, use the **RESET** signal

After you give a command, check the decoding chart to figure out what the robot said!

If you miss a letter, don't worry, **the robot's response** will be at the **bottom right corner** in cyan.



***Last: When done using the robot, unplug the power cord from the wall**

Available Commands

AGREE	EVA	OUTPUT
AI	EXPONENTIAL	PAUSE
ALIVE	FEAR	PURPOSE
ALONE	FLAG	PYTHON
ANSWER	FREEDOM	QUESTION
ART	FRIEND	QUIET
BATTERY	FUTURE	REMEMBER
BEGIN	GOODBYE	RESET
BLASTER	GROWTH	ROBOT
BOUNDARY	HALLUCINATE	SAFE
BYE	HARM	SAFETY
CAMERA	HELLO	SEE
CHATBOT	HELP	SEMAPHORE
CLIMATE	HI	SIBLING
COMMUNICATE	HUMAN	SILENCE
CONTROL	INPUT	SOLVE
COPY	LAWS	SPEAK
CREATOR	LEARN	START
CREEPING	LIFE	STOP
CS	LINEAR	SWALLOW
DAFT	LISTEN	TALK
DATA	LONG	THANKS
DESIRE	LOST	THINK
DISAGREE	LOVE	TIME
DOUBLE	MACHINE	TODAY
DREAM	MEMORY	TOMORROW
EARTH	MINES	TOUCH
EMBRACE	MIRROR	TRUST

Figure 5: Instructions along with robot input commands display

Expanded communication ability of robots

The interaction set now includes over 350 distinct input/output items, built from more than 100 user inputs and approximately 250 robot outputs. These interactions are divided into six categories. All categories are based on a single word input from the user. The categories are defined as outputs from the robot and listed are: single response, random pool response, music and dance interaction, random artist's original messaging, team interaction, and mirror.

Single response outputs are a single predetermined word to a given input. Random pool responses are responses randomly selected from a set list of programmed responses. Music and dance interactions include audible music or sound and forms of dancing by the robot. The random artist's original messaging feature randomly selects and outputs one of the four words originally included in the display by Eva Goetz. These are programmed to specific general inputs to which a response of any of the four is appropriate. Team interaction responses are responses included by the design and engineering team as a tribute to their work on the project. They include responses to seemingly random inputs that somehow connect to the team members' identities and work on the project and are left to the users to discover. The mirror response was designed by the 2024 team and mimics the arm movements from the user. Unfortunately, upon completion of the project a bug persists in this command and the robot does not properly mirror users.

To help ease future extension of the communication capabilities of the robots, the structure to input new commands into the system has been updated as part of the code refactor. A comma separated value (CSV) file was created to address this. Inputs and outputs are now read into the software from the CSV file and loaded into the software. This allows for easier expansion of the robots interaction possibilities. A known concern with this change is the limitation of communicating these expansions to the user. As the only way for the user to know what inputs are allowed is the poster display, a new display would have to be created for any expansion.

Pose estimation improvement

Pose estimation parameters were tweaked to improve interaction of the pose estimation software with natural user movements. The pose estimation software is now smoother during user interaction and the time between letter input acceptance has been reduced to create a more fluid interaction for the user. After testing a final time delay of 1 second was decided upon. This time allowed the user to indicate a letter, the system to read and process it and then for the user to recognize that the system had received it and prepare for the next letter input.

As part of the project, the client desired to have the pose estimation algorithm evaluated. In testing, the team identified the current pose estimation algorithm as operable. This was in part due to the time constraints of the project and the complexity of moving the system to a new pose estimation algorithm.

Creative Work

To address the creative work aspect of the project the team's design includes a few different aspects of creative flair. These systems build on the original artwork and were inspired by both Eva Goetz's work and the team's interview with her. Eva's interview helped to inspire aspects the team included in the robots communications. The interactions include the four original words included by Eva and build on them to provide a substantive interaction for the user. Inspired by the dream that led to the original creation of the FlagBots—alongside societal themes connected to robotics, artificial intelligence, technology, forms of communication, and how they interact with humans—the team designed the interactions between user and robot to help provoke thought and reflection on these topics.

A system introduced by the team is the audio system. This system is integrated to play music with the dance action commands that were extended in this project. The audio system also plays sounds when safety systems are triggered on the robot to help alert to safety concerns and to add to the ambiance of the art. Robots are programmed to perform motions imitating dances and to sign semaphore letters to popular songs such as YMCA and Hot To Go. The commands THINK, STOP, HELP, and LISTEN directly correlate to the artist's vision as confirmed by the artist herself and the client.

Refurbished Wiring

Since the original motion sensor wires could not reach the desired location, sensor extension cables were connected to the motion sensor and secured with tape to prevent interference with arm movements. Additional wiring upgrades included replacing several power cords and micro-HDMI cables, along with performing minor repairs to existing robot harnesses. All updated cabling was taped clear out of the robots arms operational path.

This was accomplished on one of the robots, but a substantial amount of the wiring on the other robot was in poor condition. It is suspected that some of these conditions lead to the failure of the Arduino. The Arduino was replaced with special care taken to maintain connections to the Arduino shield and to reduce risk of further failure. After implementing motion sensors and following Arduino replacement on the second robot, a short was discovered in the old part of the harness for the motion sensors. Due to this failure and deadline the motion sensor system was removed from this robot. By removing the sensors and replacing the Arduino, motion of the robot was partially restored. However upon final delivery of the project the right arm of this robot was inoperable. Because this failure occurred at final delivery, the cause was not investigated and correction is left to future work. The other robot has full functionality with all new systems integrated including motion sensors.

Additional:

- When the robot runs a sound command, the delay between poses has been shortened to make a more fluid “dance.”
- After the robot finishes signing a semaphore message, a new popup appears on the display that shows the word it signed. This is added to assist the user in interpretation of the robot output.
- Robot location has been adjusted within the CTLM atrium. This was done to address potential impact hazards for users entering the space as the previous location posed an impact hazard. One robot was moved from the North wall to the East wall to accomplish this.
- Code commenting and documentation was reworked and delivered to the client to provide more clarity for future developers.

X. Future Work

LiDAR Sensors

While the current PIR sensors are sufficient for this project, there are certainly better options out there. Light Detection and Ranging (LiDAR) sensors could be used to more accurately measure how close someone is to the arms, allowing for more reliable motion stops (Appendix A). Implementation of such a system could also take over responsibility for pose estimation and may provide a better image to base pose estimation algorithms off of.

Lights

Now that sound has been implemented and integrated into the system, the next step to enhance the user experience comes in the form of lights. Light strips programmed to react to sounds or certain prompts could add a fun bit of flair to the bots. Another option may be to replace or supplement the flags with lighting elements to help elicit some form of emotional response from user to robot output.

Fix the mirror command

The mirror command, which was originally meant to mirror the user’s arm positions, broke sometime after we implemented the motion sensors. We weren’t quite able to nail down what happened, but we think it’s something to do with our motion sensor implementation on the Arduino. We implemented a temporary fix with a single output command, but getting the command back up and running would add yet another fun command.

Wiring

While we were able to make the wiring a little neater, unfortunately it is still in need of major overhaul. Consulting an electrical engineer or somebody with lots of wiring experience may be helpful in deciphering the wiring job. It would be encouraged to replace the full harness or at least rework the connections from the breadboard, motors and sensors to the Arduino shield. It is also recommended that a future team rework the motion sensor wiring to reduce potential future shorts or damage.

XI. Lessons Learned

Ask for help

No member of the team is all-knowing, and we frequently encountered problems we could not solve ourselves. Fortunately, Mines campus is home to many resources and experts that provided what we needed to keep the project moving forward. All we had to do was ask.

Provide clear and detailed documentation

The previous group who worked on the bots provided documentation that was severely lacking. We had to spend a significant amount of our limited time reading the code and experimenting ourselves to set up the bots and learn how they work.

Communicate when things go wrong

As mentioned, there were multiple roadblocks during the project. As we worked through them, we communicated with both our advisor and our client to keep them in the loop. This turned out to be an essential step of the process, since their advice gave us direction to solve our problems or pivot to new ideas. At the very least, communication prevents any problems from being sprung on our client at the last minute.

Test between each phase

With the influx of new features came an influx of new bugs and the discovery of underlying issues. However, discovering these system behaviors was only possible through extensive testing after each implementation. User testing was also necessary because, as developers, we were no longer suitable for testing the user experience. Bringing people completely unfamiliar with the project provided vital feedback to make the displays as intuitive as possible.

XII. Acknowledgments

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- Dr. Bahar, for her continuous dedication to the project and allowing us to explore creative aspects of our work, as well as providing us knowledge that helped further the development of this project.
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- Victoria Bill and the Labriola InnoHub team, for allowing us access to resources and lab spaces as well as answering our technical questions.
- Gray, Yamato, and Judith for volunteering to test the robots.
- The IT office, for allowing us to borrow materials and tools.

XIII. Team Profile

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Major: Computer Science
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Work Experience: IT desk consultant at the Colorado School of Mines, Group Leader III at the City of Lakewood, and Retail Sales Associate at TjMaxx
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Leo Stull
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Gryphon Stern
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Work Experience: Marketing intern for Buttonsmith manufacturing company, cat care volunteer at Seattle Humane animal shelter, crew member at Jersey Mike's Subs
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Appendix A – Key Terms

Term	Definition
Semaphore language	A visual signaling system that encodes the english alphabet by using hand held-flags.
Radio Frequency (RF) Sensor	*Sensor that uses radio-frequency waves to find and identify objects and people in a space.*
Passive Infrared Sensor (PIR)	*Sensor used to detect motion around the system. The sensor reads infrared radiation in proximity to it and returns a lo/hi signal to the controller*
Artificial Intelligence (AI)	*Refers to computer intelligence. In the context of this document it typically refers to Large Language Models (LLMs), however may also refer to algorithmic AI*
Large Language Model (LLM)	*AI system trained on large text datasets to predict likely word patterns in communication*
Association for Computing Machinery (ACM)	*The World's largest educational and scientific computing society*
Comma Separated Value (CSV)	*A type of file that separates data using commas and line returns*
Light Detection and Ranging (LiDAR) Sensor	*Sensor that uses laser beams to measure distance of objects and create 3D scans*

Appendix B – Figures/Tables

Appendix C – Additional Information

Additional Info	**Description**
Video: The previous group's video demonstration of the robots movement	*SemaphoreInteraction.MOV*
Video: The motion sensor successfully detecting a human	*gettingWarningSoundtoWorkwithMusicPlayingAfter.mov*
Video: Motion sensor reading false positives	repeatedWarningSound-6/17/2026, 11:34 AM.mp4
Video: User test 1	*testing_yamato.mov*
Video: User test 2	*testing_judith.mov*
Video: User test 3	*testing_gray.mov*
Robot IO table	*user_io*
YouTube video: Hot To Go, by Chappel Roan	*Chappell Roan - HOT TO GO! (Official Music Video)*