Dr. Green

Authors: Ting-Hua Hsu, Vasudha Srinivasan, Aichen Yao
Affiliation: Electrical and Computer Engineering, Carnegie Mellon University

***Abstract*—Dr. Green is a smart recycling device for schools that identifies and self organizes waste to prevent recycling contamination while educating users on the rules of recycling. With a vision-based recycling classifier connected to a microcontroller interface with a mechanical organizer and hardware components for interactive cues, Dr. Green makes learning about recycling a lot easier while reducing contamination and further improving existing waste organization infrastructures.**

***Index Terms*—Arduino, Classification, Computer Vision, Jetson, Recycling, Smart Bin, Waste Sorting**

1 INTRODUCTION

One of the ways people attempt to reduce their waste production is through organization, with infrastructure for trash, recycling, and compost sectors commonly established in public locations such as schools. According to the EPA, while around 75% of overall waste has the potential to be recycled, only 35% of waste in the United States is actually recycled or composted [1]. Of this already low percentage, 25% on average of recyclables are found contaminated with trash [1]. While infrastructure for sorting waste does currently exist and people are generally aware and willing to participate in proper waste organization, complicated recycling rules that differ by region combined with the need to manually separate waste often creates confusion. What makes matters worse is that a single contaminant in a recycling bin can result in the entire bin being deemed unrecyclable, resulting in its disposal in the landfill.

Our goal is to address these very issues with Dr. Green, a smart recycling device that classifies and self sorts attempted recycling waste while providing real time feedback regarding whether the item attempting to be recycled can actually be done so. Its main audience is schools, which have existing attempts at waste and recycling organizations, a large waste producing population, and are a community with a purpose to learn. A self sorting system makes attempts at waste organization easier while preventing error at the root, thus removing the need to further sort at a waste plant. Additionally, with visual and audio feedback for reinforcement regarding recycling attempts, users can learn the given region's recycling rules while reducing the chance that they make the same error later onwards. With this easy to use, self organizing system, we hope to not only educate users on proper recycling rules through reinforcement, but reduce contamination of recycling at its root by identifying and moving recycled non-recyclables to the trash.

2 USE-CASE REQUIREMENTS

The main use case requirements for Dr. Green are as follows:
1. Accurate: Dr. Green needs to be able to accurately separate recyclables from any mistaken recycled trash. Ideally, the level of accuracy needs to be at 100% to prevent any contamination of recycling.
2. Educational: Dr. Green needs to educate users on recycling rules of the region. To do this, the system's setup needs to contain visual and audible feedback alerts that are understandable and educationally reinforcing without an overly negative psychological effect on users who recycled waste incorrectly. For simplicity, we will base this prototype on Pittsburgh's recycling rules.
3. Easy to Use/Maintain: Dr. Green should be straightforward and easy to use for students, as well as easy to set up, empty out, and maintain for staff. Its sizing should be accessible to users of different heights to account for use by younger students.
4. Engaging: The total operation time to throw out a piece of waste should take no more than 5 seconds and alerts must be engaging enough to avoid disinterest of the user.
5. Safe/Hands Free: Self-operation mechanism and material of the system needs to be safe enough for younger users to prevent injury in case of improper use.
6. Sanitary: Since Dr. Green deals with waste, the device needs to avoid sanitary concerns. With a hands free set up, Dr. Green should help users avoid contact with unsanitary surfaces that most existing trash cans consist of.

3 ARCHITECTURE AND/OR PRINCIPLE OF OPERATION

Our design consists of the following sections:

A. Computer Vision System
B. Bin Control
C. Mechanics

Dr. Green's physical structure is a large recycling bin with two smaller inner bins, one for recycling and one for trash. On top of the large bin is a lid frame consisting of the user alerts as well as a swing door platform that the user can place their waste on. The door will rotate towards the respective bin that the waste on the platform will need to fall into. Connected to the lid is a vertical overhead frame to hold up a camera and processor for waste identification.

On a high level, the Computer Vision System will capture, detect, and classify a given piece of waste placed on the platform. This information will then be sent through a wired connection to the hardware controlling unit, which will set off alerts and move the platform according to the CV system output. If time permits past MVP, the device will also be set up to receive notifications when one of the inner bins are full. A block diagram of the system architecture can be found in Figure 7 of the Appendix.

3.1 CV System

In order to capture an image of the waste, we will be using a wide angle camera module, placed directly above and facing the center of the platform door. Using a CSI connector, this camera will be connected to a Jetson NX processor, to which it will forward its captured images. The Jetson will be in charge of looking at the captured images, detecting and identifying the object(s) on the platform, and classifying accordingly. For detection and classifying, we will be using and improving upon the YOLOv5 model.

3.2 CV to Bin Control System

After classifying the given waste, the Jetson will forward its prediction to the main microcontroller in charge of controlling the bin hardware, an Arduino. This will be done by serial communication through a wired USB connection.

3.3 Bin Control System

This system consists of an Arduino which will receive communication of the predicted category from the Jetson. For our MVP, this prediction will be a binary value (recycling vs. trash). However, we have set up the bin components such that its operation can be further expanded (more details explained below). With this information, the Arduino will control three main categories of components: Alerts, Platform Control, and Reminders.

3.3.1 Alerts

For MVP, these components are to notify the user of whether the item they are attempting to recycle is truly recyclable or not through audible and visual cues. A neopixel strip will be placed on the lid frame for the visual cue and flash either green or red based on whether the user is correctly recycling or not. For the audible cue, a piezo speaker will also be placed on the lid frame and either play a jingle or a buzz based on the attempted item. Past MVP, these components could potentially use other colors or sounds to indicate other situations such as fill level and mixed materials.

3.3.2 Platform

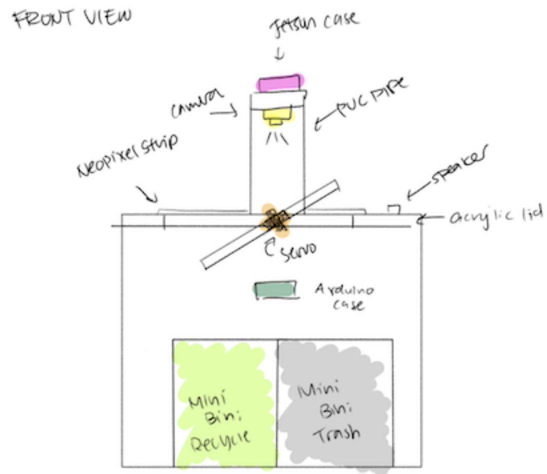
This category is for controlling the swing platform door so that the waste is self-organized into the correct bin. There will be one main servo connected directly to the door in order to control its angle of rotation towards a certain bin based on whether the given object is recyclable or not. On each side perpendicular to the main servo, there will be a servo acting as a lock to the door to provide support and prevent any forceful turning of the door either by the unexpected weight of the object or the user themselves.

3.3.3 Reminders

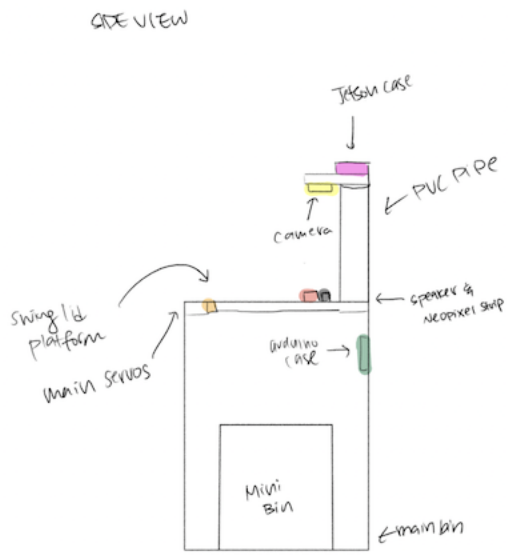
For past MVP, two ultrasonic distance sensors will be placed at the top of the two mini bins within the main bin. These sensors will send fill proximity information to the Arduino, which will then send a notification to the user using the alert category components that the bin needs to be emptied out.

3.4 Mechanics

To put all these parts together, a few mechanical design components are needed. For the CV System to operate as intended, the camera and the Jetson needed to be mounted on an overhead frame. This frame needs to be tall enough that the camera can capture the entirety of the platform. The overhead structure will be connected to the wooden lid frame for support, on which the alert components will be mounted. The swing door platform, made of acrylic for its lightness and strength, will be at the center of the lid frame, connected to the frame by a dowel on one side and a servo on the other to support it. An Arduino will be on the inside of the bin, connected to the alerts, door controllers, sensors, and Jetson.



(a)



(b)

Figure 1: System description. (a) Front view of entire system (b) Side view of entire system

4 DESIGN REQUIREMENTS

Two of the most important requirements for our system are accuracy and speed. These requirements apply to the different subsystems within Dr. Green.

1. Automatic camera capture & detection

The system will not need any manual start. New items should be detected automatically. A camera, connected to Jetson, constantly captures images with a 0.3s interval in between and OpenCV will be used to continuously compare consecutive images using MSE (mean squared errors). If a certain threshold of MSE is exceeded, it should detect a change in the image. The goal of the detection algorithm is to recognize all significant changes on the platform, for example new objects placed or removed. The rate of successful detection is expected to be 100%.

In case of two consecutive changes, which refers to new items placed and users' hands taken away, it should trigger the YOLO classification. The wait time since items are placed and users' hands removed until the start of YOLO classification should be less than 1 second.

2. Accurate YOLO classification

The YOLO algorithm detects and classifies multiple items in an image at once and outputs a single binary classification result. If any item in an image is not recyclable, the correct output is non-recyclable; if all items are recyclable, the correct output is recyclable. This result determines what alerts the users receive.

For each item detected and classified, YOLO would also generate a confidence value of the result. To prevent false positives (trash mistaken as recyclable), the CV system should consider all classified recyclables with confidence value lower than 0.85 as trash. We want to balance between contamination prevention as well as recycling efficiency; 0.85 is chosen as a reasonable threshold. Experiments over large datasets will be conducted later to test if it is indeed a good balance; the exact value will be subject to adjustment.

Overall, the goal of YOLO classification is to reach an accuracy of at least 90%. The runtime of the YOLO algorithm on any image should be less than 2 seconds.

3. Visual & sound alerts

A bar of neopixels and a microspeaker will be installed as a part of Dr. Green to provide feedback. The alerts expected for different classification results are different. If all items are correctly classified as recyclables, the neopixels will light up as green and the microspeaker will make a jingle sound. If any items are not recyclables, the neopixels will light up as red and the microspeaker will make a buzzer sound instead. The accuracy of alerts perceived, depending on the classification result produced (not necessarily the actual classification), should be 100% accurate. The alert should be set off within 1 second of the classification result, and will last for a duration of 3 seconds and be reset afterward.

4. Self-organized recycling

Alerts and swinging will happen simultaneously, both within 1 second since the classification result was computed. Depending on the classification result, items should be placed into the correct bin with 100% precision and the operation time should be less than 1 second. To prevent contamination, if any item is not classified as recyclable or if not reaching the confidence threshold, all items will be thrown into trash. Simultaneously as the alert goes off, the platform holding items should either swing to the trash bin or recycling bin. The servo will naturally adjust the platform back to its neutral state and be ready for the next use.

5. Total operation time

As explained in each section above, the combined operation time since users removed their hands from the platform to the start of alerts and recycling should be limited to under 5 seconds.

6. User safety & education

Using the two-phase detection algorithm, the product makes sure the swinging door will not accidentally hurt users' hands. The self-organized recycling mechanism avoids users' physical contact with the device for the purpose of sanitation. Education is a core goal; all alerts are chosen with the consideration of not raising mental shaming of users, especially as users would mainly be children and teenagers in schools.

5 DESIGN TRADE STUDIES

5.1 Subsystem A: CV System

5.1.1 Resnet

We were considering using Resnet50 instead of YOLO, since it was mentioned that having YOLO would be overkill for just wanting to classify water bottles. Our justification for choosing YOLO regardless is because past our MVP, we would like to be able to handle multiple objects being put on the platform at once, and detection is required for that to be feasible. To maximize our device's potential for expanding abilities and to avoid complications from having to switch the model after achieving MVP, we decided implementing YOLO would be our best option.

5.1.2 YOLOv5

We chose YOLOv5 due to the fact that it is one of the best real time object detection and processing models out there, as well as the fact that it is implemented in PyTorch, which makes it easier to integrate. It helps us to fulfill the accuracy use-case requirement.

5.1.3 Drinking Waste Dataset

We were considering training on other datasets that had images of all types of trash, including plastic bags, metals, and various paper packaging. We decided that having so many different kinds of waste would be too large of a scope for our MVP. We decided that just starting with drinking waste recyclables would be an appropriate scope. Since many people have confusions about which kinds of drinking waste can be recycled, this fulfills the educational use-case requirement.

5.1.4 Jetson Xavier NX

For the processing unit, we were considering three main options, the Raspberry Pi, Jetson Nano, and the Jetson Xavier NX. Between the Raspberry Pi and the Jetson series, we chose Jetson because it has a GPU(graphics processing unit) with far more processing power and libraries that makes it more suitable for AI/ML applications compared to just the CPU in the RPI. In our case, since the CV subsystem deals intensively with images, a capable GPU is necessary.

We acknowledge Raspberry Pi is more affordable and did consider using it and running the YOLO algorithm on AWS EC2. However, the combined cost actually may not be lower and the added implementation complexity motivated us to choose Jetson and run YOLO locally on the device. Moreover, if running YOLO on a cloud server like EC2, network latency for Arduino to receive classification results would also be negative for the total operation time. With Jetson, classification results would just be transported using the USB cable from Jetson to Arduino and it leads to almost no delay.

When looking within the Jetson series, while the Nano is cheaper, smaller, and more lightweight, its processing speed and power as well as memory space is far less than the Xavier NX. Due to our project needing to deal with huge amounts of data that requires a good amount of memory and speed as well as the fact that both Jetsons are available in the inventory, we decided the Xavier would be the best choice for this project.

5.2 Subsystem B: Bin Control

5.2.1 Neopixel

We decided to go with a strip of pixels rather than a singular one to make the alert more apparent. By having a whole row of lights glow, it will catch the attention of the user more easily.

5.2.2 Speaker

We decided to include an audible cue rather than just visual to add learning reinforcement and be more inclusive in bin use. We chose a piezo speaker as it would not only be easy to integrate with our Arduino, but give us the ability to control the pitches being emitted. This would allow us to further reinforce the user's actions and provide feedback through "positive" and "negative" tones.

5.2.3 Ultrasonic Distance Sensor

One of the features we wanted to add to our system after MVP was sensing the bin fill level. After some consideration, we decided to go with an ultrasonic distance sensor as opposed to other sensors such as a weight sensor, since it would be difficult to set a threshold as the weight of different trash combinations can result in different total weights. With the ultrasonic proximity sensor, we can place the sensor at the top of the bin and simply measure the distance between the waste inside and the top.

5.2.4 Arduino

In order to control our hardware and mechanical components, we needed some sort of microcontroller. While there are many possible options, we decided to go with an Arduino as it is available in the inventory, is quick to set up, can be easily simulated, and works well with multiple components such as the servo for the trapdoor, the neopixels, and the piezo speaker which don't need any complex libraries or wifi connectivity mechanisms that other microcontrollers such as ESP32 consist of.

5.2.5 Servo

In regards to our trap door control, we decided to go with a servo as opposed to our initial design with an actuator. This change was made alongside our change to the trapdoor itself. Since we changed our door movement from a linear open-close to more of a left-right swing, a servo would have more control due to its angular rotational motion as opposed to the linear movement of an actuator.

5.3 Subsystem C: Mechanics

5.3.1 Trapdoor

The biggest change that we pivoted to during the design revision process is switching from a single-waste stream trapdoor to a multi stream swing door for the bin. The original single door idea would have the user place their waste on the bin, and either open downwards for the waste to fall in if the waste was recyclable, or stay closed and set off alerts until the user removed the waste from the platform. However, this set up would require the user to wait until the device gave its feedback. Since we had an estimated 5 second overall latency after doing some research regarding our device components, we realized it would be difficult to hold a person's attention for that long of a time considering the patience of the average student attempting to throw something away. With a swing door, we can have two compartments instead of one, essentially supporting recycling and trash disposal. This set up essentially gives the system the ability to self organize the waste, leaving the user only having to receive the provided feedback. This makes the time needed for user engagement a lot shorter and therefore more likely that people will use the device. This change also better fulfills the hands-free sorting and cleanliness aspect of the use case requirements. Instead of the user having to pick up their mis-recycled garbage to throw in the trash bin, the device will take care of it by tilting the platform to slide the trash into the correct bin.

5.3.2 Platform and Frame Material

When thinking about the material for the lid frame, door, and overhead frame, we initially thought wood would be our best choice, since some of our members have experience with wood working. However, after switching to our swing door approach, we thought having a wooden door would be too heavy for the servos to hold up and control, causing us to the choose acrylic for the door and frames instead as it is lightweight and strong. However, one design component we forgot to take into account when switching to the swing door was the need of an axle. After adding this to the design, we then realized in order to include some sort of axle/dowel, we would need to drill a hole into the side of the acrylic. Since the acrylic is quite thin, this would compromise the integrity of it. To fix this, we decided to replace the outer frame with wood so that it will be thick and sturdy enough to drill into and support the device, and keep the swinging piece in the middle as acrylic with a axle clamp to support the axle so it can remain lightweight for movement.

5.3.3 Lid Frame Design

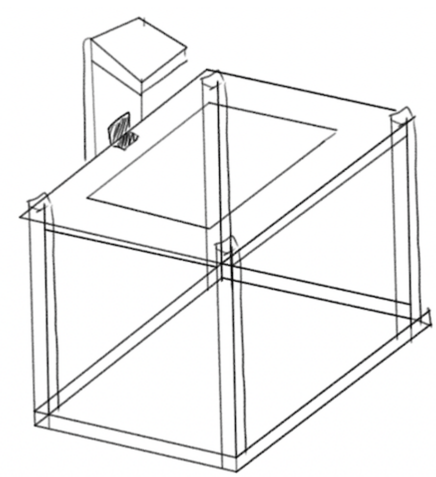


Figure 2: First option of lid attachment

Figure 2 above is our latest lid frame design. It is a cubicle structure that will encase the bin, with a base that the bin sits on. While constructing, we will add diagonals if additional structural support is needed. The benefits of this design is that when cleaning, the bin needs only to be slid out without touching the wooden structure. The downside that it is more complicated to build. This is our optimal choice since it is a more holistic structure.

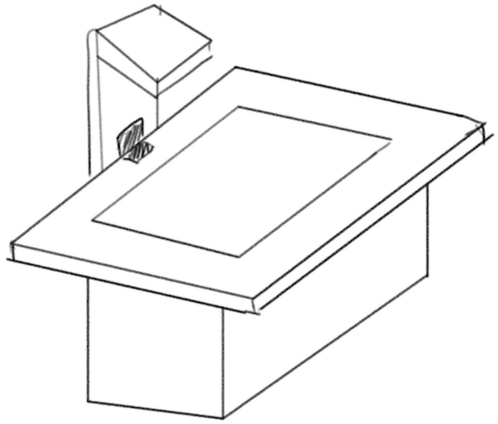


Figure 3: Second option of lid attachment

Figure 3 above is an adaptation of our last lid frame design. This option will sit on the main bin. It will be 2" bigger than the opening of the bin on each side, which will serve as extra space for the backing and platform to sit, as well as serving as a handle to remove the lid structure for bin cleaning. The benefit of this design is that it is more simple to construct. The downside is constantly having to move the lid, which may cause breakage. Additionally, this lid set up may be difficult to balance on the bin without causing accidental warping/breaking of the plastic bin below. We will go with this option as a second choice if our woodworking skills prove subpar to build the first option.

6 SYSTEM IMPLEMENTATION

6.1 Subsystem A: CV System

Our implementation plan for this subsystem involves buying a camera and Jetson, downloading existing datasets, and modifying the YOLOv5 model to fine tune it to our project.

An IMX219 camera, which the Jetson NX is compatible with naturally, will be mounted onto the Jetson with a CSI connector. The camera will be fixed at a certain angle and will capture an image that covers the whole device's platform continuously. As figure 4 explains, the detection algorithm is as follows. At the initial state, the Jetson will run the detection algorithm. If a matching error exceeds the pre-fixed threshold for determining image changes, it will enter the first waiting stage. There, it will again take images and perform detection continuously, waiting for the second change in images which is supposed to be after users remove their hands. In case of the second, consecutive change, Jetson will enter the classification algorithm and use YOLO to identify and classify all items. However, at the waiting state, if no changes are detected within 5 seconds, Jetson will go back to the initial state. After running YOLO classification, the Jetson will review the labels of all identified items. We consider all items identified to be recyclables but with confidence values lower than 0.85 to be false positives. If all items are labeled as recyclables and all with confidence values equal to or higher than 0.85, the Jetson will return positive which signals all items are correctly classified recyclables. Otherwise, it will return negative. The final result of the YOLO classification model will be binary and the type of the return value will be a boolean. Using Python's serial module, the Jetson will serialize the result and send it over a USB cable to the Arduino. The Arduino will then use its Serial module to read incoming data from Jetson and coordinate the bin control system.

Dr. Green is a fully automatic device which does not require users to start it before use. To monitor if new items are placed, the camera, mounted onto Jetson, will capture images continuously with a brief interval in between. Because YOLO has a certainly long runtime, it would be an overkill for just detection purposes. Therefore, we decide to implement a separate detection algorithm and use YOLO only for classification when Dr. Green has to both detect and classify items placed on the platform. For detection, we implement an algorithm using the CV2 module to compare two consecutive images and determine there is a significant change based on the computed matching error. During experiments, the runtime for a single comparison is approximately 0.025s, much faster compared to the estimated 2s of running YOLOv5 on a single image. The separation of detection and classification, in short, saves computational resources (Jetson's GPU utilization rate) and reduces wait time for the users.

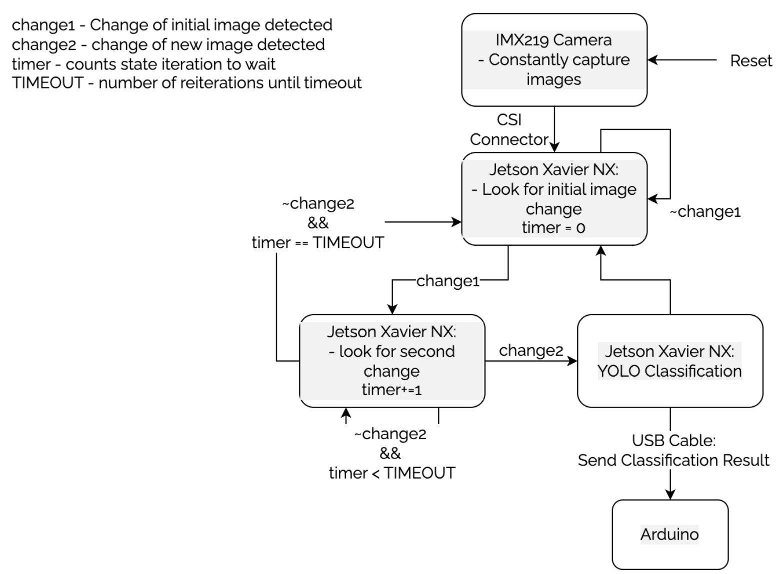


Figure 4: FSM for Detection and Classification

6.2 Subsystem B: Bin Control System

This subsystem consists of an Arduino Uno connected to a Neopixel strip for the visual cue, a Piezo Speaker for the audible cue, a main servo to control the swing door, two side servos to lock the door in place, and two ultrasonic sensors to check the mini bin fill levels. We will by buying the Arduino, piezo, servos, ultrasonic distance sensors, neopixels, and USB cable, and self assembling and programming the circuit. As of now, a circuit schematic has been made, and the circuit has been simulated using Tinkercad.

The specifics regarding connections are described in schematic figures 8 and 9.

The Neopixel will be connected to a power source, ground, and Digital Pin 2 on the Arduino. To control the output of the neopixel strip, we will be using the Adafruit Neopixel library. The specific colors of the neopixels will be specified using RGB values.

The Piezo Speaker will be connected to ground and PWM Digital Output Pin 11 on the Arduino. PWM will be needed for this implementation, as it will allow us to imitate Analog signals with the digital output, giving us control of the pitch.

All of the Servo motors will need a connection to power, ground, and a PWM digital output pin to control the variance of the angles they will need to turn. The main servo will be connected to pin 10, and the side servos will be connected to pins 9 and 6. The main servo's output shaft will be connected directly to the swing door, with each side of the control horn screwed parallel to the sides of the door. The Servo motors will be controlled using the Arduino Servo library. Since servos have a maximum rotation angle of 180°, The center angle will be set to 90°. If the servo needs to turn left, the angle will be increased towards 180°, and towards 0° if it is to turn right. The side servos will be placed under either side of the door, with the control horns perpendicular to the door. If the side needs to be unlocked, the servo will turn 90° to essentially stop blocking the door from turning in the given direction.

Finally, the ultrasonic sensors will be connected to power, ground, and PWM Digital Pins 5 and 3. Since the implementation of these sensors are past MVP, they have not been fully simulated, but will ideally send and receive a signal to calculate the relative distance of objects to it. If the sensed distance of waste to the top of the bin is less than an inch, it will alert the user using the alert components. If further pins are needed based on the type of ultrasonic sensor used, we will need to additionally invest in an Arduino pin extender to account for this addition.

After these connections are made, the Arduino IDE and C++ based library will be used to program the controls for each of the components on the Arduino. The program flow is described in figure 8.

Initially, the Arduino will receive a binary output from the Jetson through a USB connection, 1 if recyclable, and 0 if non-recyclable. Once this output is received, the neopixel will be set either to green for "correct" and red for "incorrectly recycled"." The piezo output will either be set to an ascending jingle tone for "correct" or a low buzz for otherwise. The side of the bin that matches the predicted value, left for recyclable and right for not, will be unlocked. After these series of events, the platform controlling servo will turn towards the bin matching the predicted value so that the waste can fall into the bin. Initially, we will set our turn angle to +/- 80° from center to point the waste to fall towards the center of each of the mini bins, but will fine tune this angle based on how the mechanics end up actually working. After the waste falls, the platform controlling servo re-centers itself. The platform locks then turn back to their original positions, and the neopixel and speakers turn off, resetting the entire system for the next disposal cycle.

6.3 Subsystem C: Mechanics

This subsystem is the implementation of the overall device structure. Our current design, as seen in figures 1 and 2, consists of a large, main recycling bin with dimensions 20.5" x 15" x 21". Inside this main bin will be two mini bins, one for trash and one for recycling with dimensions 8.25" x 11.75" x 11.5". On top of the main bin will be a lid frame of dimensions 24.5" x 19" x 1". This frame will be made out of wood, and have supporting legs on each corner of the lid frame with dimensions 2"x 2" x 21.5". This allows for enough leeway for the main bin to be moved in and out of the lid frame structure for emptying it out. The lid frame will have the neopixel strip and speaker mounted on top, with a small hole in the corner for the wiring of these parts with the Arduino to pass through. In the middle of this wooden lid frame will be a cutout for the acrylic platform door of dimensions 9" x 14" with 0.25" space in between the door and lid frame for free movement.

We need the platform to tilt at an 80 degree angle in both directions in order for the waste to fall into the smaller bins. This means that the platform cannot be too long and the main bin needs to be tall enough that the platform clears the opening of the smaller bins while turning. This is reflected in the fact that half the platform size, 7", is less than the the difference between the height of the main and mini bins, 9.5".

The platform will be acrylic, and use a c clamp to attach a dowel in the middle of one of the long sides. The other three sides will have cutouts for the servos. There will be a hole in the wooden outside frame of the lid, which the dowel will fit into to rotate.

We will be buying the main and mini bins, acrylic and wood for the door and frames, axle/dowel, and clamps. We then will be self cutting and assembling the mechanical parts and connecting them to the hardware for operation.

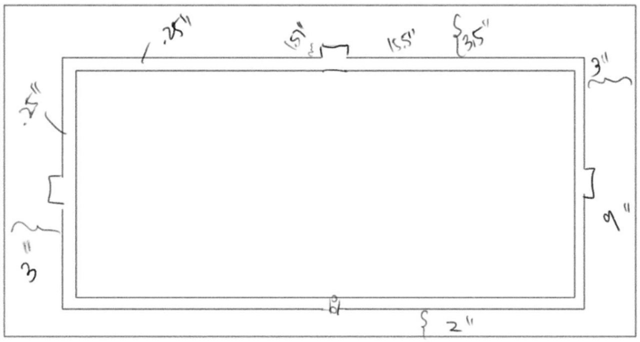


Figure 5: Bottom inside view of lid with dimensions

7 TEST & VALIDATION

Our testing plan is to initially test each component of our device, then test their integration step by step. Since our main quantitative requirements are speed and accuracy, we will make sure to test these at each step.

7.1 Capture and Detection

We will be testing our image capture set up to make sure the camera is placed at a height such that the door platform is captured entirely and accurately, and the performed detection is done with complete accuracy. Additionally, we will be timing this process to match our time of less than 0.3 second for capture, and less than 1 second for overall capture and detection time.

7.2 Model

Since our requirement is a model accuracy greater than 90%, we will individually test our model on known objects and images to see if we achieve this metric. We want our MVP to be able to correctly classify the four types of drinkable waste that the dataset that we trained our ML model on consists of, as well as 3 types of commonly mis-recycled trash. Our input therefore will be these types of waste, with an expected output of 0 for trash and 1 for recyclables. Additionally, we will time the operation of the model to ensure it meets our requirement of less than 2 seconds.

7.3 Visual/Sound Cues

As per the requirement, we want 100% accuracy for the operation of the alert components. Given the correct input of 0 for trash and 1 for recyclables, the output color of the neopixel and and sound of the speaker should always be correct, with red and buzz for trash and green and jingle for recycling. The outputs should also reset after each round. This overall operation will be timed to match the requirement of being overall less than 3 seconds.

7.4 Bin Operation

We need to test if differently shaped and weighted objects will successfully fall into the smaller bins. To do this, first we will test the servos controlling the door before attaching the platform. Given a correct input of 1 for recyclable and 0 for trash, the main servo should turn towards the recycling bin (left) when the input is 1 and towards the trash bin (right) if the input is 0. The lock servos will also be individually tested, with the left one unlocking and right staying locked if the input is 1, and the right unlocking and left staying locked if the input is 0. All three servos should return to their center positions after operating. After testing the servo operation, the mechanics will be attached, and similar tests will be made: the door should turn the correct amount (about 80°) in the correct direction, and the locks should block and unblock the correct side accordingly, all actions in the correct order, and then resetting at the end. The overall operation will also be timed, with the goal of it being less than 3 seconds.

7.5 Integration

Once all the individual components are tested, we will move onto integration testing, once again looking for accuracy and time.

Once the camera capture and detection as well as the model work, we will test their connected operation, with an overall goal time of 3 seconds.

Once the operation of the classification model and alerts are correct, we will connect the Jetson output and the Arduino input to make sure these parts first work together and can send and receive the intended serial information with 100% accuracy. Then, we will check that the outputs from the Jetson produce the correct outputs from the components connected to the Arduino (neopixels, speaker, and servos). We will look for this system to produce an accuracy rate matching the classification model (since the cues will already have 100% accuracy). We will also time this to make sure operation time is less than 3 seconds (not counting the time for the alert reset).

Lastly, we will check the operation accuracy and time of the overall device, testing different waste objects as inputs similar to the model testing, this time with real physical objects to be captured by the camera (similar to the camera and model integration test setup). We will then look for the bin door turning the correct direction and the alerts producing the correct output and then resetting for the next disposal cycle. We will also time this operation to make sure it meets our target of 5 seconds.

7.6 Overall Experience

We will also be testing the overall experience of our device. We will ask staff and other students to test out our device and ask for their feedback regarding user experience, whether the device was easy to use, safe, educational, engaging, and did its job properly. We will also ask some friends who are less informed about recycling to go through the whole process of the device and give us their feedback.

8 PROJECT MANAGEMENT

8.1 Schedule

Before our design presentation, our schedule had to be revised due to the mechanical parts not yet arriving so that we could not start construction. We were also having some problems with the training of the ML system, so that portion was also pushed back by a few days. But we have now fixed the code and are on schedule again. In terms of the revised schedule, we are currently on track. The schedule is shown in Fig. 11 in Appendix.

8.2 Team Member Responsibilities

At the design stage, Aichen is in charge of writing scripts for organizing the dataset file structure and for image comparison and helping with debugging the ML code. Vasudha is in charge of simulating hardware components, programming the Arduino, researching and designing the mechanics, dimensions, and parts for the physical device. Ting is in charge of setting up and training the model to detect drinkable waste, finding the datasets to train the model on, and helping with designing the physical bin.

After design is finalized, Aichen and Vasudha will set up the Jetson and its connection to the Arduino. Aichen will set up camera capture and deploy the detection algorithm. Vasudha will implement the hardware circuit, including controlling the alert system and servos using the Arduino. Ting will keep fine tuning and optimizing the ML model and deploy it to the Jetson. The whole team will work on the mechanics of the device.

8.3 Bill of Materials and Budget

Item	Quantity	Manufacturer	Source	Price (Total)	Arrived?
Jetson NX	1	Nvidia	18-500 Inventory	$0.00	No
Arduino Uno	1	Arduino	Amazon	$27.00	Yes
Large Recycling Bin	1	Enviro World	Home Depot	$45.00	Yes
Small Waste Bins	2	Acrimet	Amazon	$33.00	No
Acrylic Sheet (for Swing Door, 18”x24”x0.375’ ’)	1	Sourceone	Amazon	$49.99	No
Neopixel Strip (0.5 m)	1	Adafruit	Amazon	$29.85	No
Ultrasonic Sensors	2	Exelity	Amazon	$7.99	No
Piezo Speaker	1	Uxcell	Amazon	$10.55	No
Servo Motors	3	Aideepen	Amazon	$28.99	No
USB Cable (10 ft)	1	Cable Matters	Amazon	$8.99	No
Wood (for Lid and Bin Frame)	Various	–	McMaster Carr	-	*Not Ordered
Dowel	1	WN	Amazon	$9	*Not Ordered
Wires, Screws, and Mounts	Various	-	Techspark	$0.00	*Not Ordered
Axle Clamp	1	Amazon	Amazon	$0.77	*Not Ordered

Total: $_____222.15______

* Not Ordered but needed due to new design changes made this past week while writing the report.

Figure 6: List of parts

8.4 Risk Mitigation Plans

No one on the team has had much experience with mechanical construction, which is a critical risk for us since the construction of the lid structure needs to be able to physically sound while able to swing and also hold up a weight. This requires both woodworking and laser cutting of the acrylic. To mitigate this risk, we plan to ask the techspark staff for help with the machines, and one member does have wood working experience. On the design side, we plan to mitigate this risk by adding support through diagonal support pieces for the lid and overhead frames, and a stronger axle setup in case the door is not strong enough. If the door continues to cause issues, we have also planned to switch to a thicker material to allow us to directly drill into the material for better support.

On the software side, we have the risk of the ML algorithm not being accurate enough in classifying. We can mitigate this by using the GPU in the ECE machines to train for many more epochs. Additionally, another risk is the ML algorithm operating too slowly, or there not being enough memory space in the Jetson for fast operation. To mitigate this risk, we will work on optimizing our algorithm and removing unnecessary/unused data from memory to free up space.

9 RELATED WORK

One project that is closely related to ours is Oscar, the world's first AI trash can. It has the same idea as our project, sorting waste that the user places into the device recyclable and non-recyclable trash, and having a big bin that contains two little bins. Instead of using a swinging platform, they use a conveyer belt to transport the waste to the left or right bin. Oscar also uses a camera that captures images to feed through a neural network in order to classify the object. They use Inception Network instead of YOLO. One special feature that Oscar has is buttons to teach him about what is recyclable or not when the system is confused. We do not have this feature, since we want Dr. Green to be educating the students and not the other way around. The ML classification should be accurate enough that there should be no confusions, and the students are able to learn about recycling rules instead of propagating their misconceptions. This is also why our system has an alert system, with lights and sounds.

10 SUMMARY

We are creating an educational waste bin that will sort the user's waste while teaching them recycling rules. Stakeholders are students in schools who are willing to learn the correct way to recycle, and they will help their community by learning correct recycling rules from Dr. Green and carrying this on to other places that do not yet have Dr. Green. The recycling at their school will also be uncontaminated.

Glossary of Acronyms

- CV - Computer Vision
- FPS - frames per second, measurement for GPU capability
- ML - Machine Learning
- PWM - Pulse Width Modulation
- YOLO - You Only Look Once

References

[1] Arie, L. G. The practical guide for Object Detection with YOLOv5 algorithm. towardsdatascience (2022). Available:https://towardsdatascience.com/the-practical-guide-for-object-detection-with-yolov5-algorithm-74c04aac4843.

[2] Solawetz, J. Deploy YOLOv5 to Jetson Xavier NX at 30FPS. roboflow (2020). Available: https://blog.roboflow.com/deploy-yolov5-to-jetson-nx/.

[3] Cho, R. Recycling in the U.S. Is Broken. How Do We Fix It? new.climate.columbia.edu (2020). Available at: https://news.climate.columbia.edu/2020/03/13/fix-recycling-america/.

[4] Jetson Benchmarks. developers.nvidia Available at: https://developer.nvidia.com/embedded/jetson-benchmarks.

[5] Jetson Xavier NX Series. developers.nvidia Available at: https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/jetson-xavier-nx/.

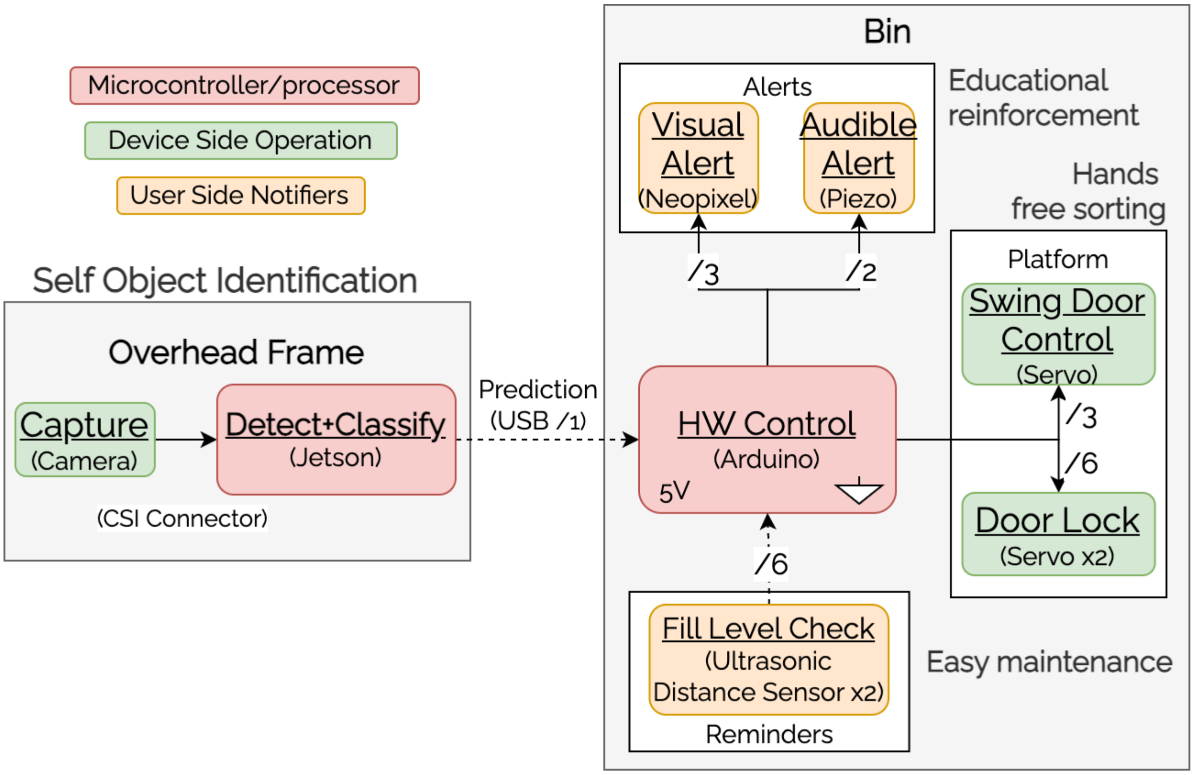


Figure 7: Components of system relating to use-case requirements

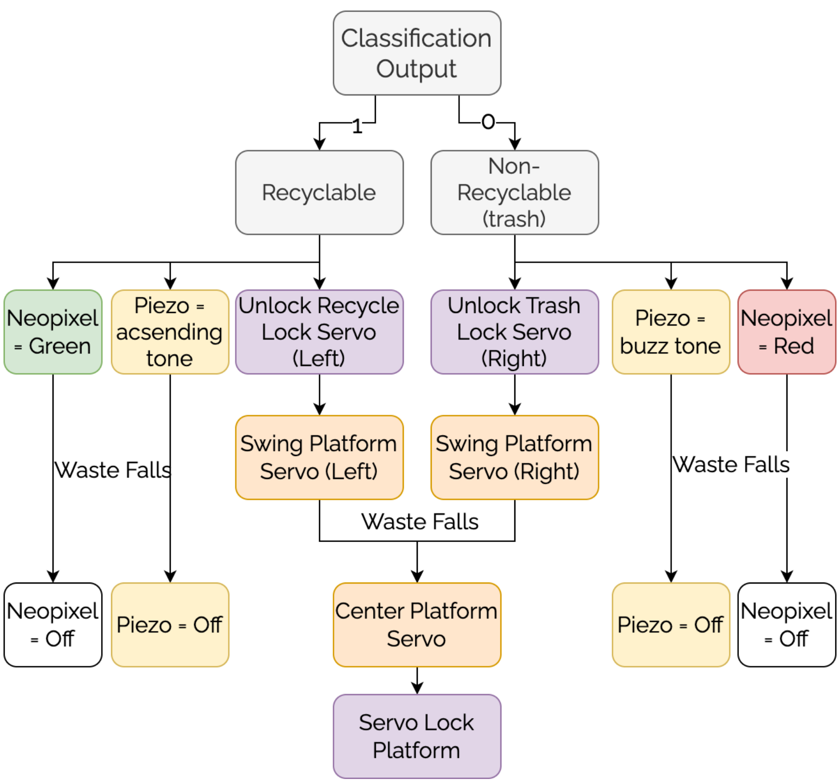


Figure 8: General flow of the system

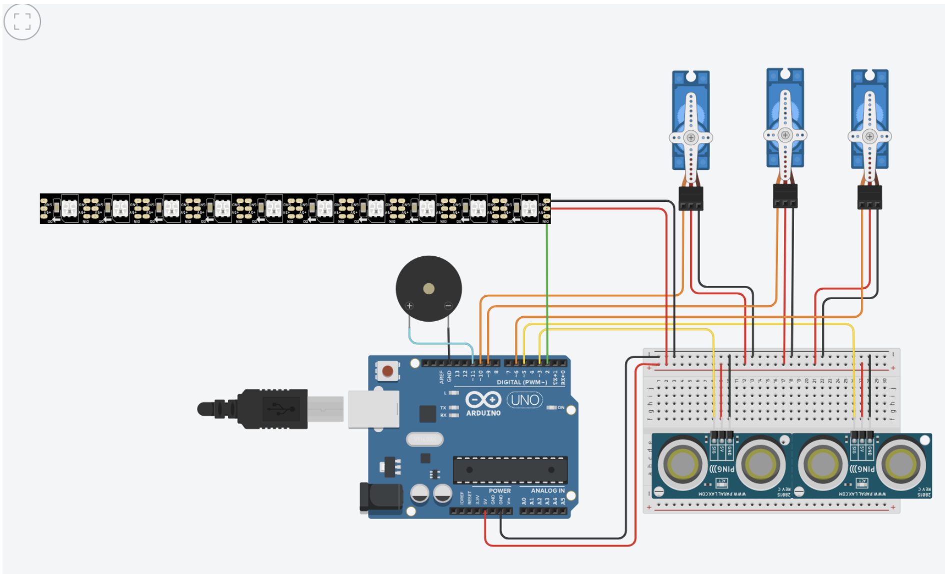


Figure 9: Simulation of Arduino pin connections

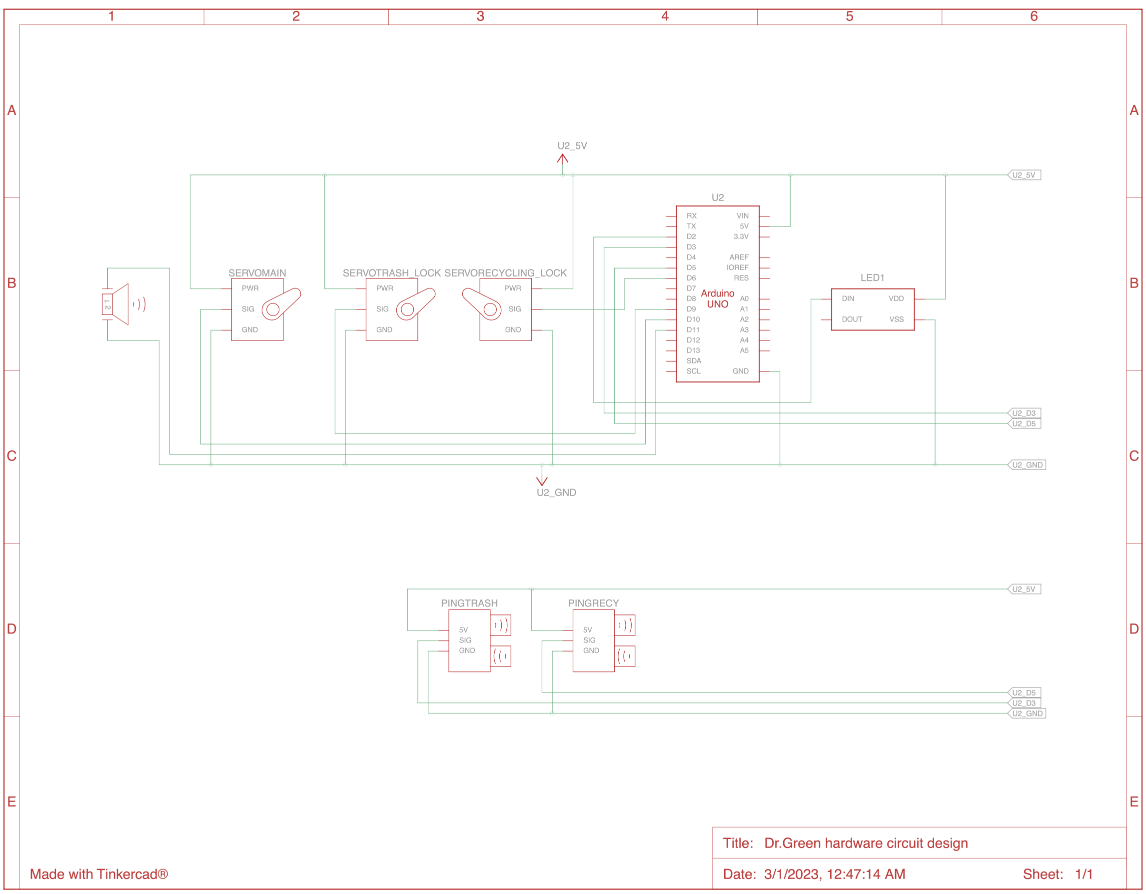


Figure 10: Hardware circuit design

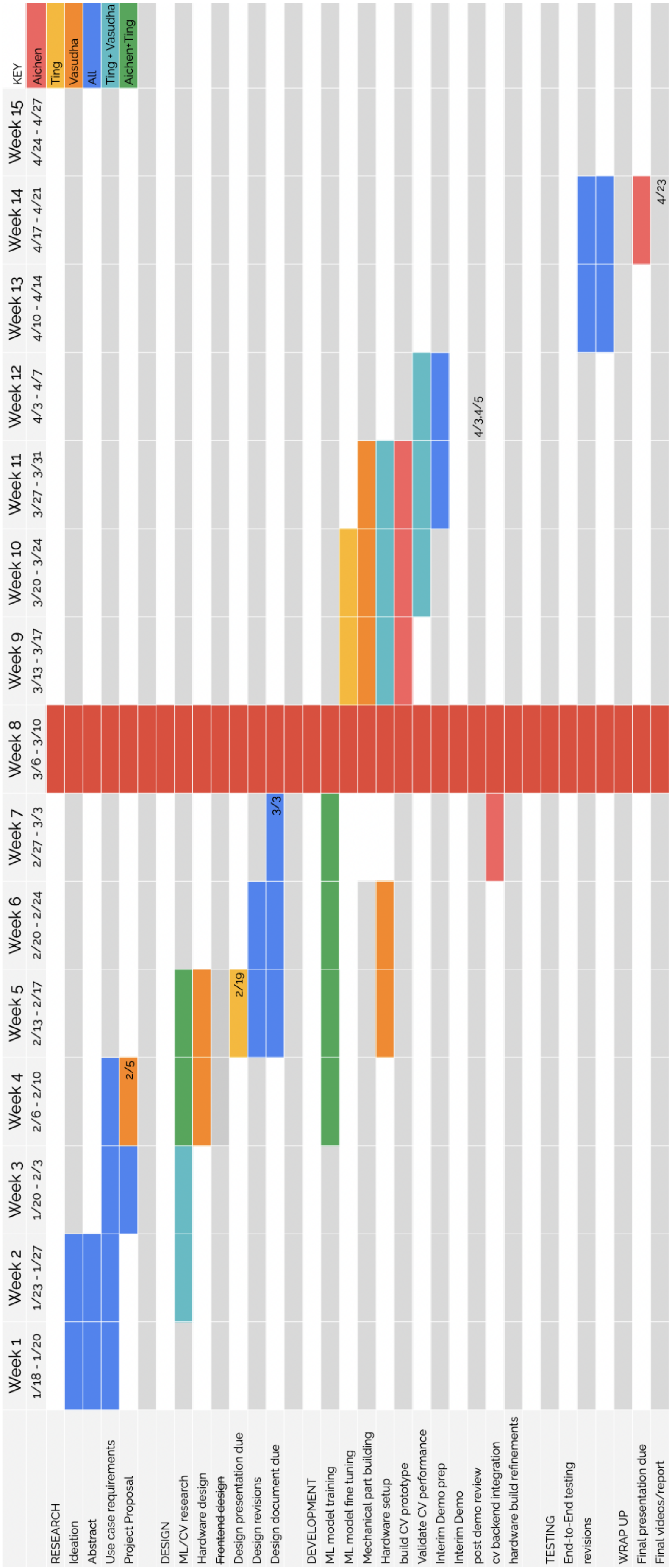


Figure 11: Gantt Chart