Smart Waste Scanner: An interactive learning tool that identifies waste to help students develop better recycling habits

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Abstract

Individuals are not taught how to properly sort their waste. In fact, according to the US Environmental Protection Agency, 75% of America's waste is recyclable, yet only 30% of it is actually recycled.[1] To tackle this problem, we introduce Smart Waste Scanner, an interactive learning tool that will teach elementary students how to sort waste. This target audience was chosen because children are more receptive to learning new habits in comparison to adults. The user can hold up an item to the camera and it will identify the item, determine its type of waste, and display the correct category on the touchscreen. The touchscreen will also have various interactive features to engage kids in learning about recycling.

Introduction

Problem

Since the start of the 21st century, many environmental changes have been occuring. Climate change and pollution is on the rise, causing wildlife to decrease and our ecosystem to deteriorate. One reason for this is the lack of recycling in today's society. Humans are simply generating a large amount of trash, and it is not dealt with in a sustainable way. Below is a pie chart depicting the total municipal solid waste (MSW) generated in the United States in 2018.[1]

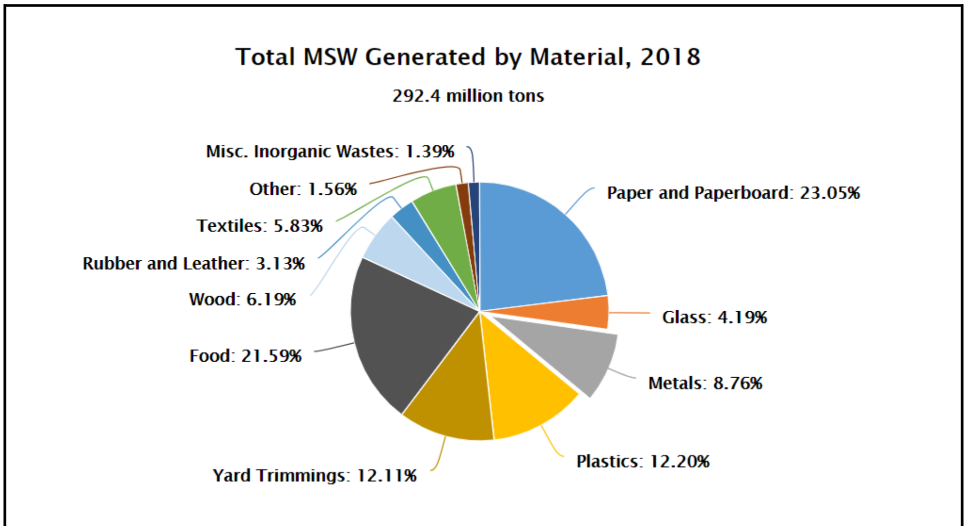

Figure 1: Total MSW Generated in 2018

Within 292.4 million tons of waste generated in 2018, a good portion of that were recyclables. Paper, cardboard, glass, metal and plastic are simple recyclables, estimating to over 50% the chart. We believe this issue stems from the fact that most people are not taught how to properly sort waste. In a study done by Covanta, 22% of respondents report not possessing enough information regarding recycling and 18%

admit they do not understand what can and cannot be recycled.[2] Despite many efforts to emphasize recycling, no major improvements have been made to recycle in the US.

We hypothesize that since habits are frequently developed at a much younger age, it would be beneficial to teach students how to recycle in schools. As students develop proper recycling ediquites, recycling rates would increase in the long run.

Solution

Introducing Smart Waste Scanner, an interactive learning device that will teach elementary students how to recycle, ultimately developing proper recycling habits. This product aims to educate kids on waste and recycling problems by teaching them what can and cannot be recycled. With this, we wish to emphasize the importance of recycling to students in hopes of raising a generation that will always be equipped with the knowledge of sorting waste. As of this project, we will focus on the main recyclables such as plastic, glass, paper, metal, and cardboard.

Technical Aspect

Overall Design

Smart Waste Scanner consists of 4 components:

- Hardware: construction and physical components of product
- Barcode scanning: method of classifying waste material based on QR and barcodes
- Waste Classification: method of classifying waste material based on machine learning algorithm
- UI/UX: web application for intuitive usage and engaging interactions for the users

Each component to the Smart Waste Scanner is crucial to its development, This report will cover the main justifications for our design choices as well as its integration to the product overall.

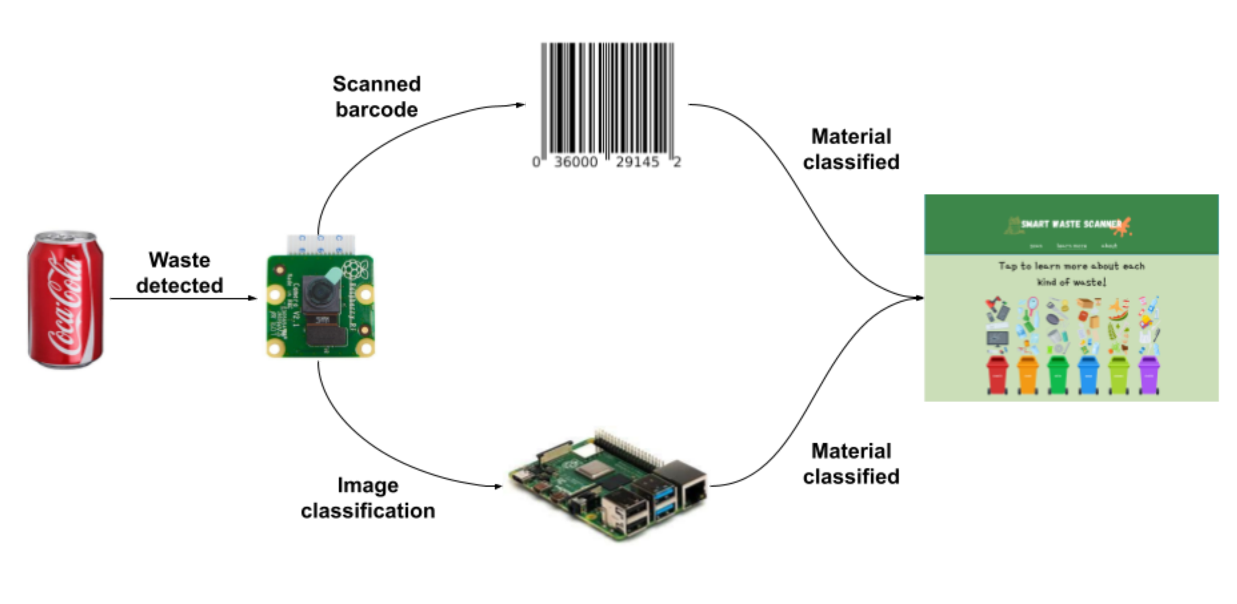

Figure 2: General workflow when identifying the material of object

Figure 2 shows the workflow of the Smart Waste Scanner and how a user can use Smart Waste Scanner to classify the material of an object. The following is a more detailed description of each step in the process:

1. The object is held in front of the camera.
2. The camera detects the object. In this step, there are two steps that occur, depending on the mode selected by the user.
    a. Barcode Scan: The barcode scanner mode was selected and the barcode has been read by the camera. Using an open-source database called Open Food Facts, the system was able to obtain the packaging information.
    b. Image classification: The image classification mode was selected and the object was held in front of the camera. The system takes a frame of the object and passes it through the trained image classification model. The output is the material it associated the waste with.
3. The system was able to classify the object. The possible classifications the system can identify are plastic, glass, paper, metal, cardboard, and trash.
4. The material is displayed on the fronted application, directing the user where to dispose of the newly classified object.

Hardware

The Smart Waste Scanner consists of the following hardware components:

- Raspberry Pi: serves as the main computer of the product
- Raspberry Pi Camera: used as vision for the product to detect objects
- iPad (Generation 4): touch-screen display
- Cardboard box: housing/structure of the product

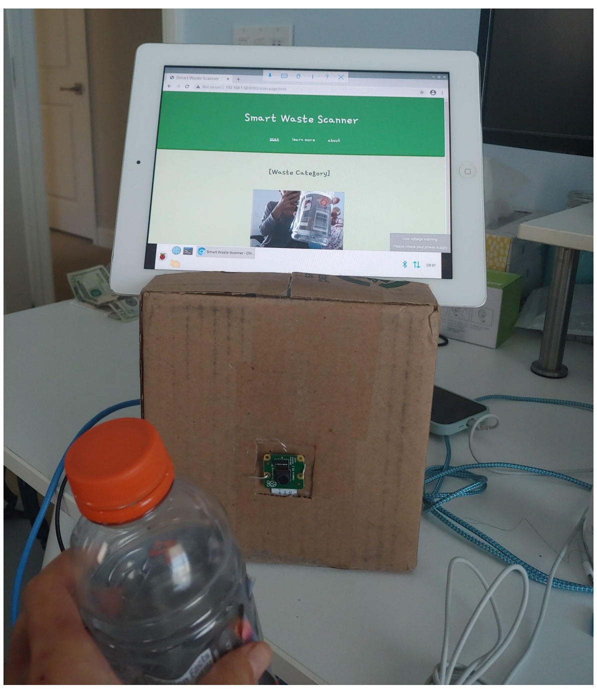

Figure 3: iPad sits on top of the housing box and camera is attached to the front

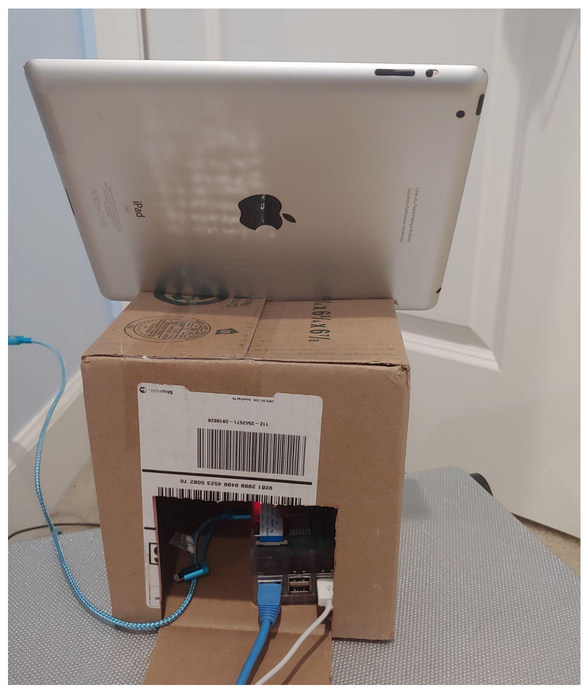

Figure 4: Rear view; Raspberry Pi and the attached wires are hidden inside the housing box

Generally, the reason why these components were utilized is due to accessibility. We have already obtained these components, so purchasing new components for the purpose of this project was not necessary. Therefore, our budget for the hardware component is $0.

Additionally, we saw other benefits when developing our project. The 4th generation iPad is a 9.50” x 7.31” touch-screen display, weighing approximately 1.46 pounds. Its large display and lightweight structure makes it a better choice compared to other displays. Additionally, the iPad is more preferred because of its touch-screen interface, allowing users to zoom in and out when on the frontend application. However, when scanning objects, we have been experiencing lag.

Barcode Scanning

The purpose of the barcode scanning is to allow users to identify the packaging of a specific object by scanning a barcode or QR code. This would serve as an alternative identification method to the waste classification feature.

The barcode scanner uses OpenCV and Pyzbar to identify and decode the information from the barcode. In more technical terms, the program will use the attached camera to consistently take captures of the frame of the video. For each frame, the program checks to see if there is a barcode in the frame that can be successfully decoded. If this holds true, the program attempts to decode the information stored within the barcode.

Below is an example of scanning the barcode from a Diet Coke.

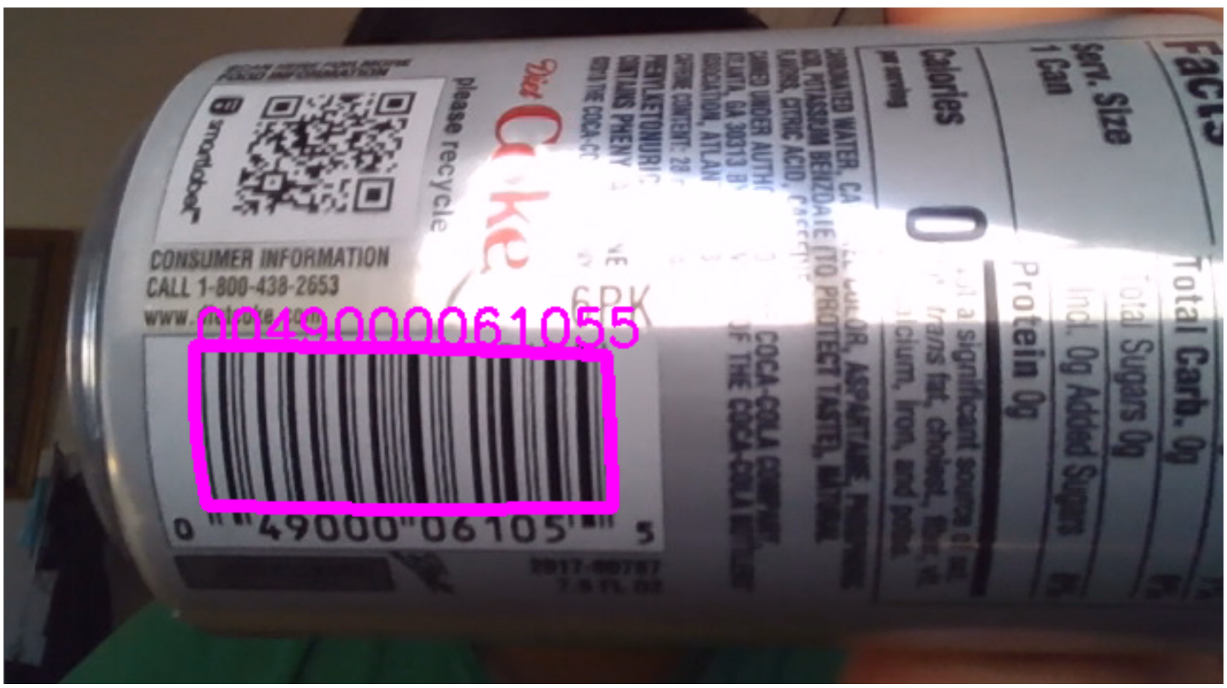

Figure 5: Barcode scanning to identify material of object

When running the barcode scanner, there will be a bounding box that surrounds the QR or barcode. This means the scanner was able to successfully read the information that was encoded in the barcode. The system will obtain the packaging information by making a GET request to [Open Food Facts](), a free open-source database where food products and their data are displayed.

Because Open Food Facts is a free open-source database, it is mostly unreliable, as the public can post information regarding food products. While the packaging information is in French, our categorization is in English. The inconsistent languages caused us to use a Python translation module so that we can classify objects successfully. Additionally, there are some food products that have minimal packaging data on the database. Using Open Food Facts is also a limitation because the database only holds food product information. Because of this, the database we are using causes the barcode scanner to be unreliable and limited.

An alternative to the Open Food Facts database is a paid API service that holds all UPC and EAN barcode information. However, these are expensive and beyond the scope of this project.

Waste Classification

For the Computer Vision aspect of the project, we have experimented with two different models for two classifying tasks: one that classifies less classes and is hosted in the cloud and one which classifies more classes and is hosted locally. Initially, we implemented a model and hosted it on AWS SageMaker and used AWS Greengrass and Lambda to connect our Pi to the model. For this classifying task, we have used 3 main categories: componst, landfill, and recycling. The overall design of the Smart Waste Scanner after deployment is presented in Figure 6.

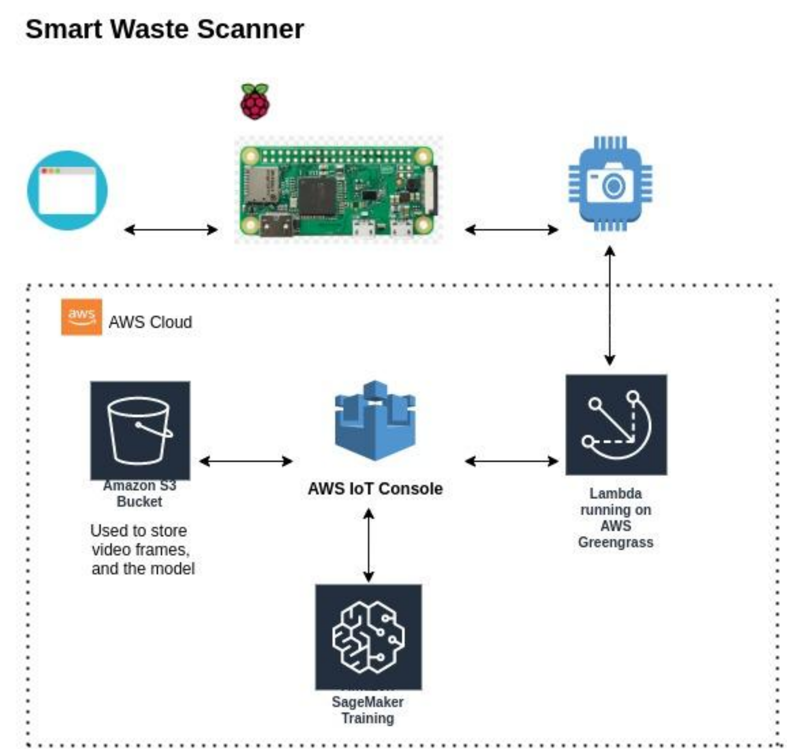

Figure 6: Waste classification workflow

When analyzing the performance of our models, we observe that, on a test set of 10 images, the model had 80% accuracy. These results are presented in the confusion matrix in Figure 7. Moreover, this model does have increased costs due to requiring cloud hosting. The overall costs of hosting and training the model are approximately $12 per day, but this depends on the number of requests sent to the model. The implementation of our model is present here presenting the detailed architecture of it.

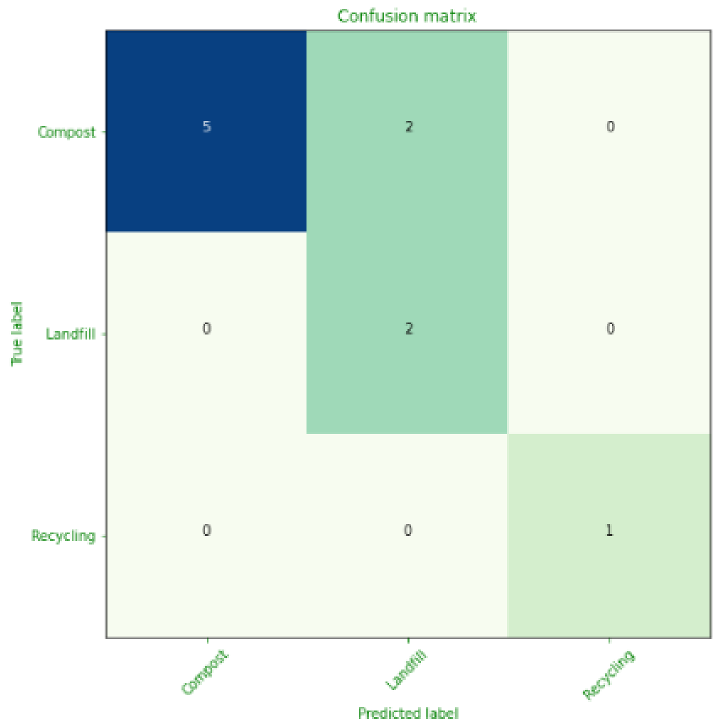

Figure 7: Confusion Matrix for 3 classes

To increase the accuracy of our model and include more prediction classes, we developed a second model which can predict cardboard, glass, metal, paper, plastic, and trash using the Garbage Classification Dataset. On this task, our model has more accurate predictions, correctly classifying 97% of our test set. One recurring issue is the model confuses metals and plastic bottles. For example, the bottom of metal cans is the main indicator that an object is a metal. However, when this is not present in frame, the model is more likely to misclassify the object as a plastic.

On a further note, to reduce the costs of deployment, we hosted our model locally using TensorFlow Serving and Lobe.ai for the training process. The Raspberry Pi sends HTTP Requests that include the current frame to the model to obtain a prediction from the trained model. The model responds with the predicted class and confidence.

The reported accuracies for each class are presented in the table below.

Class	Accuracy
Cardboard	0.98
Glass	0.98
Metal	0.98
Paper	0.98
Plastic	0.96

Trash	0.95

UI/UX

Our UI/UX is tailored for our specific audience, elementary school students, and thus has several colorful and youthful elements to it. Upon identification of waste, a color-coded border appears around the camera feed, indicating which bin the waste should go in (recycling-blue, trash-black). Additionally, the l*earn more* page (Figure 8) provides an interactive platform for students to quickly learn more about different kinds of waste. Here, they can learn how to prepare the waste for disposal from a description of each recyclable and fun facts (Figure 9).

Figure 8: Learn More Page

Figure 9: Interactive Information Modals for Different Types of Waste

We chose green for the main color background because it is the general color for the environment and healthy ecosystem. When implementing the UI, we wished to emphasize healthy recycling habits for the benefit of the environment, thus leading to our usage of green. Additionally, the solid green represents a simple and minimalistic view to the application.

We used different colors for each type of waste so that the colors can appeal to young students while also highlighting the separation of the wastes. The interactive information popup was added so that users can conveniently learn about a type of waste with a simple tap. We plan on adding more interactive videos in the future to increase learning.

Milestones

Our Gantt chart lists our original milestones and deliverables that we established in the beginning of development.

Below are our milestones established throughout the quarter. The milestone ID uniquely classifies each milestone by the team responsible for completing the milestone under a specific deliverable. For example, ML-201 means that the milestone is the first milestone that belongs to the ML/CV team during the second. The cells highlighted in green indicate that the milestone is complete.

ID	Milestone Title	Milestone Description	Priority
ML-101	Setup QR/barcode reader	The system shall be able to read the data that is encoded from any QR or barcode.	HIGH
UI-101	Set up GitHub Pages	The system shall display the web application, which is hosted on GitHub Pages. This is currently a mockup.	HIGH
H-101	Camera and tablet setup to Pi	The camera and tablet shall be connected to the Raspberry Pi. The tablet will be used as a monitor.	HIGH
ML-201	Object/material classifier through barcode	The system shall be able to classify an object's packaging after scanning the barcode. The packaging information is used from Open Food Facts, which is limited to only food products.	HIGH
UI-201	Set up navigation links on website	The web application shall contain working navigation links to navigate the user to different sections of the website.	HIGH
H-201	Set up video stream	The Raspberry Pi shall be able to video stream from the camera directly to the web application. In the future, this will implement ML-201 and ML-202.	HIGH
H-202	Combine video stream with barcode scanning	Video from the camera module is streamed to the website but needs to be combined with the barcode scanning script so that the script is scanning items that the camera module on the Raspberry Pi is viewing.	HIGH
ML-301	Increase accuracy in object detection	We will improve the program so that it can detect objects and barcodes at a higher accuracy.	MEDIUM
ML-302	Perform user testing to ensure most objects can be classified.	We will test the program with a variety of real items to make sure that most objects that we want to be able to classify can be classified.	MEDIUM
ML-303	Add more classifications	If we have time, we will add items beyond paper, plastic, metal, glass, and trash such as writing utensils and other school supplies. However, this is a low priority as it is not needed for the MVP.	LOW
UI-301	Add animations	We will add animations to the website so that once an item is scanned it will give more instruction on how to prep the item for disposal such as emptying or rinsing the item.	MEDIUM
UI-302	Add info to learn more page	We will add info about each of the waste categories beyond what our product's MVP can categorize so that kids can still learn how to dispose of waste that they may encounter outside of school.	HIGH

UI-303	Add color depending on which waste category	Each of the waste categories will have a different color that corresponds to the colored waste baskets that would ideally be in the classroom. The border of the video will change color with the waste category. This is of medium priority as it is not necessary for the MVP.	MEDIUM
H-301	Combine video stream and waste classification	Website needs to be combined with the waste classification script so that it can classify objects and display the correct category on the screen.	HIGH
H-302	Kiosk mode	This will allow the device to automatically boot into the website and run the script for the waste classification. It will also keep kids from exiting out of the app. Though this would be useful, it is not necessary for our MVP so it is of medium priority.	MEDIUM

Integration and testing took a lot longer than we had expected, which is why we were not able to get to many of the other milestones in Deliverable 3.

Conclusion

This project aims to tackle the waste problem in America by teaching elementary schoolers how to properly sort waste. Waste is an inevitable part of our lives, and the way that we are currently dealing with it is ineffective. This is a large and diverse problem caused partially by bad waste management on a country-wide level, but also it is also due to a lack of education around the subject. The waste categories and features that we were able to tackle in this class are just the beginning. Moving forward, here are some changes that we would make to the project and features that we would add:

- The Raspberry Pi is not powerful enough to run the software that we developed and the iPad is very old which is why the video was laggy. In the next iteration of this project, we may consider turning the software into an application.
- As seen in the Milestone portion of this report, there were some features that we didn't have time to implement but would like to later on such as integrating the barcode scanning program, adding animations and videos to the frontend, and adding other classifications (compost, specialty recycling, etc).
- Another feature that we could add if we turned this project into an application is a map that shows users the nearest recycling drop off location.

References

[1] *National Overview: Facts and Figures on Materials, Wastes and Recycling*. (2021, May 4). US EPA. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#main-content

[2] Ruiz, A. (2019, April 22). *Why Americans aren't recycling.* Waste Advantage Magazine. https://wasteadvantagemag.com/why-americans-arent-recycling/