DAAAS Trash

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Separating Organic and Inorganic Trash

EID101A

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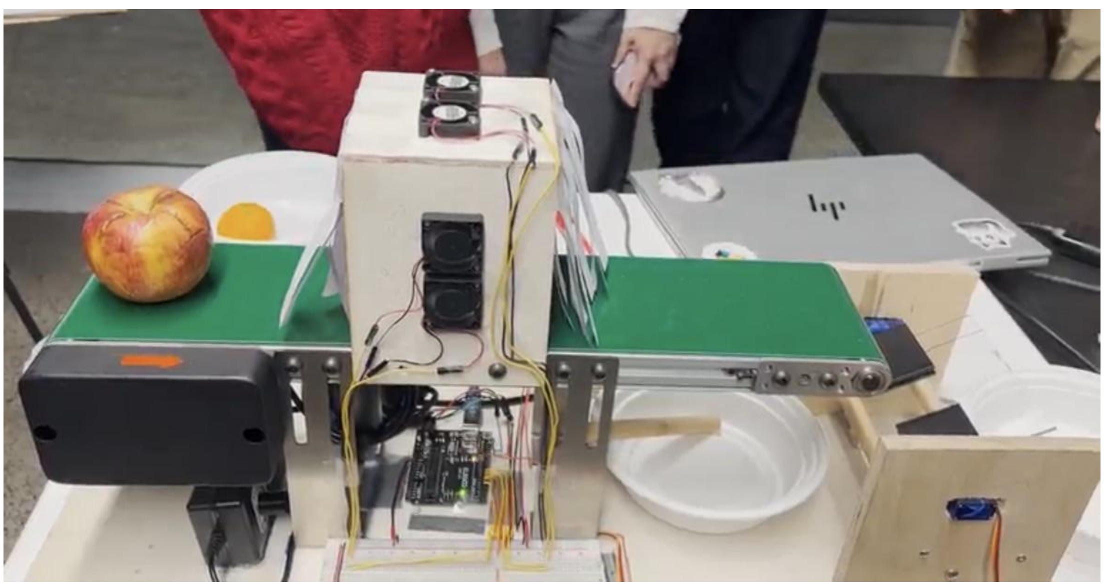

Introduction

Current waste management practices fail to separate organic from inorganic materials before disposal, causing up to 90% of organic waste to end up in landfills, where they decompose anaerobically [1]. This decomposition process produces, methane, a harmful greenhouse gas that contributes significantly to climate change. 14% of all methane emissions in the United States comes from landfills [1]. Additionally, the slow decomposition rate reduces landfill capacity, as this organic material takes up space that should be filled with materials that are not compostable and nonrecyclable.

Organics

Organics is diverted through both curbside and non-curbside programs, as well as third party-vendors. The capture rate for organics is therefore inclusive of material collected curbside as well. Divertible organics collections are inclusive of food scrap drop-off sites, food rescued by partners such as City Harvest, Rikers food waste, landscaper waste, horse manure, and leaves/brush.

Organics FY24	
Tonnage Diverted Non-Curbside (A)	**75,703.18**
Tonnage Diverted Curbside (A)	**49,701.60**
Tonnage Collected Curbside (B)	**1,136,114.81**
All DSNY-Managed Organics (B)	**1,261,519.59**
Organics Capture Rate (B)	**9.9%**

Table 1: NYC Department of Sanitation's definition of organics, as well as data depicting how much organic waste was disposed of and collected by DSNY, in tons. [2]

Organizations like the New York City Department of Sanitation have been making attempts to address this problem by diverting organic waste from landfills and converting it to compost. However, of 1.2 million tons of organic waste collected in 2024, only 9.9% of the diverted waste could be used as compost, as shown in Table 1 [2]. Despite recent mandates on sorting compostable waste, current organic capture rates remain underwhelming at 7.2%, necessitating a new method of separating organic material from general waste [2].

Improving sorting methods has a variety of benefits for both society and the environment. By increasing the amount of organic waste diverted from landfills, the amount of methane emissions from landfills will decrease, slowing down the process of global warming. In addition, the logistical burden placed on sanitation departments to store large quantities of waste would be lessened, as more organics would be diverted to other facilities, such as composting and recycling. This would also free up space for inorganic waste, as organic waste would stop occupying millions of tons of land space [1]. Finally, with correct sorting of organic material from other waste, more useful byproducts like compost can be created to reduce the environmental impact of waste disposal.

Existing human solutions that separate organic material from waste have issues that prevent them from being implemented on a large scale. For instance, home composting poses problems because in urban areas, there is no space to place home composters, especially for those who live in apartments. There is also a learning curve associated with using home composters [3]. Another solution is waste-sorting plants, which remove contaminants from large amounts of organic waste using a combination of manual methods. However, as much of this waste is not sorted properly before it reaches these sites, they often contain large amounts of toxic organic chemicals, such as PCBs and dioxins, and heavy metals, such as mercury and lead, which pose health risks for workers [4].

While these solutions tend to provide underwhelming results, the natural world provides a wide array of animals who face this challenge of finding food. Various animals search for food among large amounts of inorganic materials. Scavengers and detritivores, for example, often search for food within soil or sand. These animals' ability to distinguish between what is and is not suitable as food for them provides a useful blueprint for how we may determine what is and is not organic/compostable. Many scavengers rely on their sense of smell to detect chemicals from decomposing carrions, which is processed by their olfactory bulbs, a neural structure that serves as the initial processing center for smell signals [5]. These bulbs play a significant role in finding food and are regarded as a measure of the acuity of scavengers. The larger the olfactory bulb, the more sensitive the sense of smell, which correlates to the accuracy of scavengers when it comes to “sorting” food.

For example, the scavenger turkey vulture has a large olfactory bulb and wide nostrils that allow them to search for food by detecting faint scents, such as ethyl mercaptan, a sulfuric compound that is a more reliable indicator of fresh carrion than CO_2, of carrion from a far distance, even if the carrion is hidden [6]. Similarly, the main parts of the burying beetle’s olfactory bulb are found in their antennas, which then also allows them to detect chemicals from decaying animals, sulfur compounds, from distances as far as 3.2 miles [7], [8].

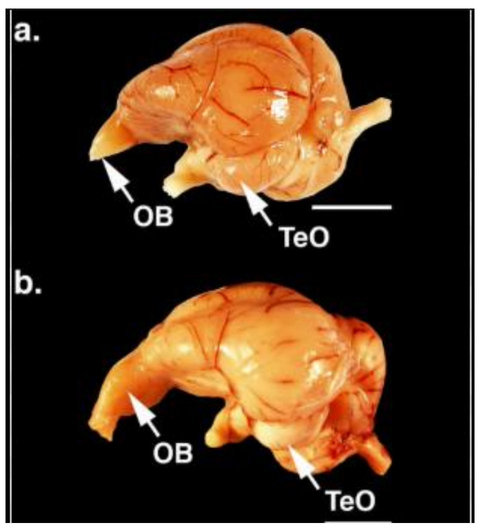

Figure 1: A comparison between a black vulture and turkey vulture’s olfactory bulbs (OB) and optic lobes (TeO). (a) is a photo of the black vulture’s brain, and (b) is a photo of the turkey vulture’s brain. As shown, the olfactory bulb of turkey vulture is visibly larger than the black vulture’s. [6]

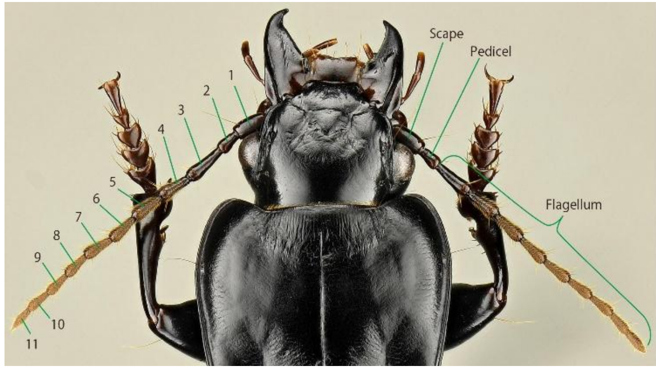

Figure 2: Diagram of beetle antennae. Although this specific picture is of a ground beetle, its antennae work similar to burying beetles. The flagellum contains sensory hairs that allow the antennae to detect chemical signals [8].

Considering the approach of scavengers when hunting for food, the final decision was to use scent-based detection to identify organic materials from inorganic materials. Like how a vulture and burying beetle pick out the scent of specific sulfur compounds to locate their food in a dense forest, carbon dioxide sensors were used to detect decomposing organic material, specifically fruits such as apples, bananas, etc. When fruits start decomposing, they emit significantly more carbon dioxide than sulfuric compounds due to the oxidation of carbon-based organic materials by microorganisms [9]. Furthermore, carbon dioxide sensors are more accessible than sulfuric compound sensors.

Ultimately, with this inspiration in mind, we developed a design that uses the CO2 emitting properties of decomposing food products to control a lever meant to redirect individual items into separate containers. This design came about after proof of concepts regarding the ability to control basic electronics with an Arduino microcontroller and testing of the changes in gas concentrations because of decomposing food. The remainder of this paper discusses the design process, and the influences relevant to major design decisions.

Design and Build

One of the most important decisions was to approach the problem at the source. To avoid the challenge of sorting through compressed trash post garbage truck collection, a decision was made to create the device with the intention of using it in apartment complexes before this occurred. With this in mind, three preliminary prototypes were constructed, each inspired by different biological systems in animals: a roller system mimicking the digestive system of owls, a rolling filter based on the digestive system of sea cucumbers, and a piston and sensor system, of which the sensor would work like the olfactory bulbs turkey vultures and chemoreceptive antennae used to find food. The details of these prototypes are outlined in Figure 3.

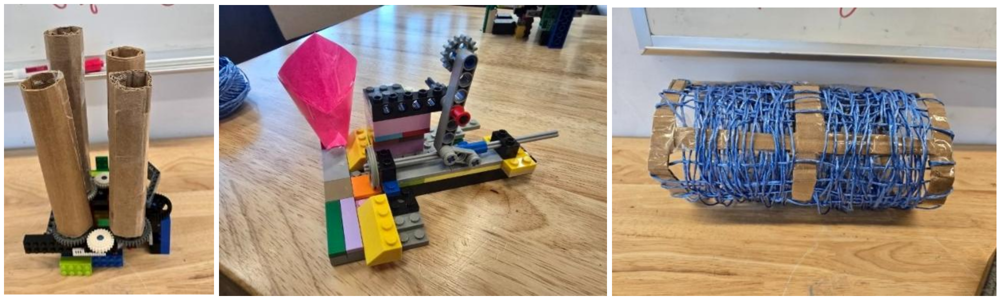

Figure 3: From left to right: A roller system that is bio-inspired by the owl's stomach where textured rollers simulate the pressure cause by the ventricular muscles of owls, which separates soft and hard material; a piston and sensor system that is bio-inspired by burying beetles and turkey vultures where a funnel-like system first separates waste into a single file line and then transports the waste to pass in front of a sensor via conveyor which a sorting mechanism (piston) to redirect one category of waste; a rolling filter that is bio-inspired by sea cucumbers where shredded organic and inorganic materials are spun around in a mesh filter.

To choose which design to continue with, these prototypes were compared in terms of different categories, the most important metrics being separation efficiency, accuracy, which we and minimal environmental impact. A specific goal for the project was to surpass 10% accuracy, which is the NYC Department of Sanitation's current capture rate of compostable waste. Lower maintenance and installation cost, ease of assembly, and durability were also considered, but to a lesser extent, as the prior qualifications are more important to the product's usefulness and purpose of sorting organic and inorganic trash. The piston and sensor design was the prototype that best optimized these.

After obtaining CO_2 and methane sensors, tests were conducted on various fruits to observe the rise in CO2 in parts per million (ppm). From this data, we determined a threshold CO_2 value that would indicate an object as organic or inorganic. It should be noted that the methane sensor was not used as it produced inconsistent results that prevented an accurate threshold value. Additionally, the importance of an enclosed environment became apparent during testing and was considered for the final design, which will be further detailed in Final Prototype Testing.

The final system consisted of two main components built around a conveyor belt: wooden housing for the sensor and motorized sorting flaps. The wooden housing was made of thin wood, with a sensor attached to one wall and fans attached to the others. The sensor was placed relatively close to the conveyor belt in terms of height to optimize readings, as CO_2 typically sinks in air. The fans were installed to circulate any lingering CO_2 between readings, coded to run whenever the sensor was not taking in readings. Finally, paper flaps were installed on the remaining two openings to create a more closed system that would increase sensor accuracy.

After an object passes through the wooden housing with the sensor, it reaches the motorized sorting system at the edge of the conveyor. This system was a rotating flap connected to servo motors, which was more accurate than the original piston component considered and more efficient in terms of resource use. This flap was made of acrylic and was attached to the servo motors via a custom 3D-printed part. However, this connection was not very solid and would break when trash fell on it, so two servos were used to increase strength. The motors were then mounted on two wood boards, which would be screwed into a base board that connects it to the conveyor. In addition, wooden support beams were also added underneath the flap to bear the weight of the items that would be dropped on it. These support beams needed to be placed in very specific locations to allow the flap to rotate ninety degrees, which was the measurement necessary to direct trash in two directions. During sorting, the trash would be directed by the flap into one of two plastic Tupperware collection bins: organic and inorganic.

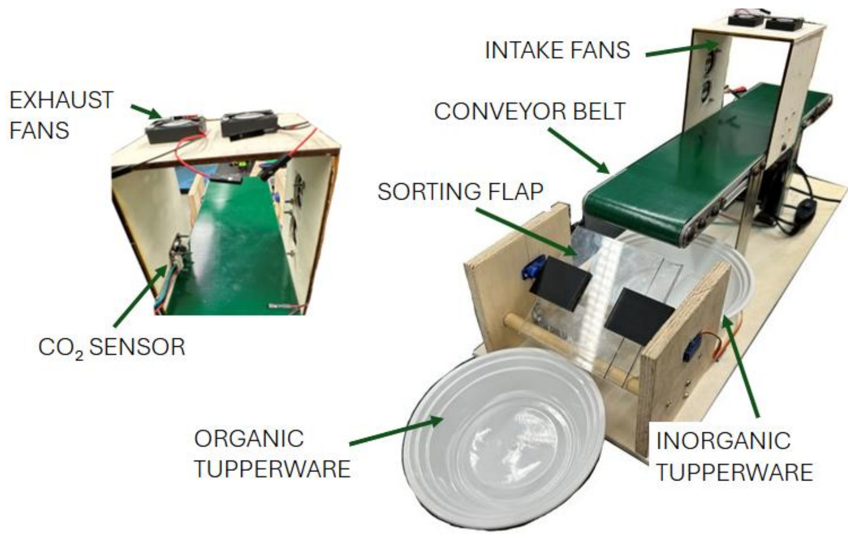

Figure 4: Left: diagram of inside of chamber where reading was taken. Right: diagram of entire final prototype. All parts are shown and labeled, with the exception of the paper flaps, which were added after (see cover page)

The final product is a scaled-down version of what is envisioned to be implemented in an apartment complex. This system assumes that there is another component, consisting of either conveyors or hoopers, that would output one item at a time onto the conveyor. Additionally, this model uses Tupperware, but the full-scale model would use the same bins that the NYC Department of Sanitation uses to collect compost and landfill waste. Our design intends to demonstrate how CO_2 concentration can be used to control physical sorting systems, the exact nature of which may change as the scale of these designs increases.

Testing and Results

Testing was conducted in various stages, beginning with individual components and then progressing to the larger system. This allowed performance limitations to be identified early and addressed before the final assembly. During the component testing phase, the CO_2 and methane sensors and servo motors were prioritized, as they were high-risk components that were necessary for sorting between organic and inorganic materials. After identifying various points of potential issues, the final prototype was constructed, tested, and modified with speed and accuracy in mind.

Sensor Testing and Characterization

Initial testing for the CO_2 and methane sensors focused on characterizing the behaviors of the gas sensors independently of any potential prototype in various environments. This consisted of a series of experiments done by placing various fruits in a closed cardboard box and open air while continuously recording the sensor outputs. The experiment started with overripe bananas, as they emit higher concentrations of CO_2 and methane compared to other fruits [10], which made it easier to test the function and sensitivity of the sensors. While the CO_2 sensor displayed a difference in CO_2 concentrations before and after it was near the banana, the methane sensor did not perform as expected and was unable to pick up a reading. This was later confirmed to be caused by the lack of measurable anaerobic respiration, which is the primary contributor to methane production in organic material [11]. Due to this, the methane sensor was excluded from future testing and prototypes.

Afterwards, other fruits such as apples, oranges, and avocados were introduced to the experiment to determine their CO_2 behavior over time. Using the peak CO_2 readings for each fruit, the minimum time required to sense if the material had enough CO_2 emissions to be classified as organic was determined. These values were relatively consistent for the tests conducted within the closed cardboard box, but extremely variant in open air. This was theorized to have been caused by the number of people in the room, and more impactfully the number of people closer to the sensor. This theory was confirmed by testing the sensor near different amounts of people and monitoring proximity to the sensor during group discussions, with the sensor averaging higher CO_2 readings when more people were around the sensor. This meant that the sensor would be more accurate in a closed environment. This caused the final prototype to employ a tunnel with flaps to house the sensor on the conveyor, like those found at car washes, to close off the system enough while still letting the object pass through.

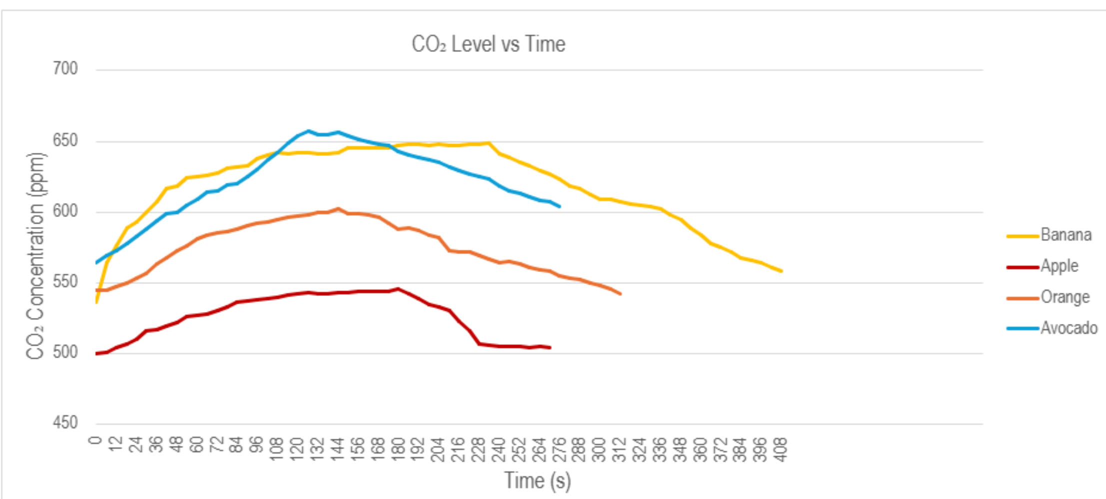

Figure 5: Average results for CO_2 levels measured after three types of fruit were introduced into the environment (0 sec). At 240 seconds, 186 seconds, 132 seconds, and 144 seconds, the banana, apple, avocado, and orange reached their peak values and were taken out of the system, respectively.

In addition, for the tests conducted within the cardboard box, varying the placement of the sensor within the box confirmed the fact that CO_2 was more easily identified closer to the bottom of the box, as CO_2 is denser than air [12]. Thus, for our final prototype, the sensor was positioned closer to the conveyor belt for maximum CO_2 detection.

Through these series of experiments, it was also discovered that the sensor is extremely slow to adapt to environmental changes, taking 2-3 minutes to rise and stabilize at an elevated CO_2 level and 4-5 minutes to fall back to environmental levels after the fruit was removed from the box. This was problematic, as any future prototype design was reliant on a fast-reacting sensor to sort material quickly. To circumvent this issue, the final prototype used a combination of fans and software control, which will be discussed in the Final Prototype Testing section.

Final Prototype Testing

After completing the physical build of the final design, a series of tests was conducted to determine the best way to control them in software (code). This consisted of two iterations: a system that compared an absolute change of CO_2 concentration from a baseline (absolute system), and one that compared a relative change of CO_2 concentration (relative system). Initially, the code to identify if the material was organic or inorganic required the material to emit CO_2 to a specific threshold. This required a varying wait time between 3-4 minutes for an organic material to emit CO_2 to pass that threshold, and a varying time between 3-5 minutes for the CO_2 to fall back to baseline environmental ppm levels after the organic material was passed through. However, this was ineffective as environmental ppm levels changed too frequently for the design to remain accurate for long periods of time and required a long time to sort each individual item.

These results led to the relative system, which used relative changes in CO_2 concentrations to classify organic and inorganic materials. Rather than comparing a change from a predetermined environmental value, the system would simply see if there was an increase in ppm from the time an object entered the box compared to the time when the object left the box. An experiment was conducted to determine the ppm changes when an organic material was introduced, and an inorganic material was introduced over a 10 second interval. These 20 trials determined that the average ppm change for organic material was a 7-ppm rise, which was much higher than the 2-ppm drop for inorganic materials.

The final testing was done on the completed project to determine the accuracy and speed of the system. The goal was for our system to have over 10% accuracy when sorting organic and inorganic waste, as this was the accuracy of existing solutions. Each fruit mentioned in the sensor testing section was tested in the final system ten times, randomly alternating between a fruit and a plastic item (which should not produce any CO_2). Both the overall accuracy of sorting and each specific item was tracked, with the overall being 55% and the latter described in Table 2. Ultimately, the final design produced an accuracy greater than 10%, with each item taking 1 minute to sort, which meets the success metric goal.

Design Test (Experimentation)		Build Test	
ITEM	ACCURACY (%)	ITEM	ACCURACY (%)
Avocado	80	Avocado	80
Banana	70	Banana	70
Apple	20	Apple	30
Orange	30	Orange	40
Inorganic	90	Inorganic	70

Table 2: Accuracy results from testing the final prototype with various inputs. Tests were conducted with less than 10 people in the room, minimizing the effect of breathing. On average, organic materials were correctly identified 55% of the time, while inorganic materials were correctly identified 70% of the time, averaging to 62.5% accuracy

Conclusion

From the results, the solution has a 62.5% accuracy when identifying and sorting organic waste, decomposing fruits, which exceeds the 10% goal. The lower accuracy was due to many variables in the testing, the waste itself, and the environment. For example, the fruits showed different CO_2 emissions despite decomposing for the same amount of time. It is difficult to create a standardized detection system for all organics because each organic material decomposes at its own speed. As mentioned earlier, the banana was sorted accurately more than the apple and the orange because of its faster decomposition. This finding can be generalized for all fruits, as Table 2 showed how the more decomposed fruits (avocados and bananas) were sorted more accurately than fresher fruits (apples and oranges).

Despite the high error, it is notable that organic materials incurred more error than inorganic ones. This was, again, in line with our success metrics, if a bit suboptimal, since it means that inorganic material is less likely to be put in with organic material. Inorganics render organic waste and compost unusable, causing the entire batch of material to be sent to landfills [13]. Consequently, it is preferable for our solution to have higher error when identifying organics than it is when identifying inorganics. As that is the case for the final prototype, the seemingly high errors with organics contribute slightly to its environmental benefits.

However, with the end goal of implementing this system into apartment complexes, the findings from experimentation with the final design raise issues. Accuracy in sorting organic waste would be expected to decrease in a real-life scenario since residents can throw out food that isn't decomposed greatly, which would make it harder to detect. Our testing also utilized fruits, which have some of the highest rates of decomposition due to their water and sugar content [14]. In the future, with the incorporation of different types of sensitive sensors, such as ethylene sensors (most fruits and vegetables emit ethylene as a natural ripening hormone [15]), the accuracy of the system could be improved as there are more measurements to categorize organic waste. The final prototype, as noted earlier, runs on weak motors and fans, so the replacement of those with stronger motors and fans will also increase accuracy and efficiency.

For future iterations of these designs, there needs to be more consideration for what is considered organic, which would require more sensors and criteria would have to be considered to more accurately classify something as organic. In landfills, there are more organic materials with properties that are shared with inorganic materials, such as rise in humidity, size, and weight. Some properties considered in the ideation of this project, but not implemented, were rise in humidity, ethylene and various proteins, which are all equally valid methods or trying to differentiate organic and inorganics. Other solutions may involve types of imaging technologies such as thermal imaging to detect the resultant heat from microbial action or X-ray imaging to differentiate objects based on density. These solutions are still imperfect, and, in some cases, pose ethical complications in their implementation. As these designs are intended to be implemented on the scale of apartments, the machinery involved must be safe for extended use in public. Poorly ventilated rooms with high concentrations of carbon dioxide or methane may pose health hazards to sanitation workers, and certain machinery, such as X-ray imaging technology, cannot be considered safe for constant use. The solution to organics sorting is complicated as it is, but it is further complicated when considering the health and safety of the people who must interact with these solutions. However, as the problem of sorting organic waste is meaningful due to its environmental impacts (landfill methane emissions), ignoring the environmental impact of the solution is not only ethically questionable but counterproductive. Overall, waste management is often an overlooked but significant and incredibly complex problem. Based on testing results, the final prototype still needs more development to become more effective while remaining a safe and ethical solution.

Process Reflection

As the problem of sorting organic and inorganic waste is complicated because of so many variables to account for and the great scale of the problem, this project was difficult to design and execute. The team came up with three to four variations of the solution, each with its own method of sorting. As the team decided between the designs, it was concluded that many of the designs were too difficult to create with a limited budget and time. This decision process, however, spanned a few weeks. Moreover, necessary components such as the conveyor belt didn't arrive until December, and therefore certain components of the solution weren't started until after parts arrived. Luckily, the team was able to build the final prototype after meeting for extra time.

Dealing with issues during the engineering process taught the team that oftentimes, the results did not turn out as expected. For instance, the methane sensor did not give useful information as the fruits didn't emit noticeable concentrations of methane, and the CO_2 sensor was more sensitive than expected, affecting data and creating false positives. As such, it was emphasized throughout the design process how much testing must be conducted and how often a design must be adapted before the final product, as seen in the Testing and Results section.

In terms of teamwork, the team gained knowledge on how to settle disagreements and manage differences in opinion for the direction of the project, as well as how to distribute workload and come together to integrate parts. Over time, this helped members build trust in one another and learn how to communicate clearly. The lessons this project taught on teamwork, as well as planning, perseverance, and problem-solving, will be carried with team members into future engineering and general endeavors.s

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Contributions

Introduction – All

Design and Build – Dionisio, Amelia, Sebastian

Testing and Results – Aidan, Amy

Conclusion – All

Process Reflection – All

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