SORT: A Device for the Self-Operated Organization of Recyclables and Trash

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Abstract

At our high school, the amount of recyclable and compostable trash being put in the proper bin is a meager 30%, and non-recyclable trash comprises 35% of all waste placed into compost and recycling. This problem is not just localized to our high school, as improper waste management is an issue which plagues the entire world. Although many Americans have recycling bins, most recycle incorrectly, and fail to compost all together. Recycling and composting are critical to environmental sustainability and it is encouraged and required by the policy in our community. To alleviate the problem of improper waste disposal, and to gain insight on waste disposal patterns, we propose SORT, a device for the Self-Operated Organization of Recyclables and Trash—a system which automatically sorts and records disposed waste based on decisions from an array of sensors (e.g. a camera and a contact microphone) which classify the type of waste item disposed in real time. SORT is intended to be installed locations with high traffic such as academic institutions, offices, and public spaces. Unlike other self-sorting waste bins which are generally costly and contain extraneous features, our goal is to make SORT simple, affordable and accessible; which is achievable by minimizing component count and cost. We plan to develop and deploy a prototype SORT unit at our high school and compare recycling rates in regions where SORT is deployed to original recycling rates.

Table 1: Counts of Items Placed into Bins for Reuse

Location	Metal	Paper	Food	Non-Reusable	Total
Library	14	47	23	61	145
Cafeteria (Lowerclassmen Sec.)	33	51	72	81	237
Cafeteria (Upperclassmen Sec.)	41	55	82	85	263
Total	88	153	177	277	645

Table 2: Counts of Items Placed into Trash Cans

Location	Metal	Paper	Food	Non-Reusable	Total
Library	17	57	32	113	219
Cafeteria (Lowerclassmen Sec.)	43	43	83	123	292
Cafeteria (Upperclassmen Sec.)	53	54	91	121	319
Total	113	154	206	357	830

1 Proposal

A study we conducted concerning recycling rates at three high traffic locations at Horace Greeley High School counting frequencies of waste type[1] against their disposal location (N=1145) found that the amount of recyclable/compostable trash being put in the proper bin was a mere 30%. Compounding to this problem we also found that the non-recyclable trash comprised 35% of all trash placed into compost and recycling. (More detailed information can be found in Tables 1 and 2.)

This problem is not limited to our school. The United States Environmental Protection Agency (EPA) estimates that around 75% of America's waste stream (which contains 258 million tons of municipal solid waste) is recyclable. However, only 30%is recycled.(*Municipal Solid Waste* 2016) This is all given the fact that half of Americans claim they recycle, and a third of Americans claim they compost. (LeBlanc 2018)

The underlying problem is that many Americans don't consider the waste they throw into their bins, a problem which is particularly rampant at our high school. Even those who are educated on proper waste disposal, which comprises the large portion of our high school population, still often make mistakes or simply forget to sort their trash—a problem which is only exacerbated by the

[1] Garbage, food, metal, and paper

fact that throwing one wrong article into the wrong bin often results in either having to retrieve the incorrectly sorted article, or in more extreme cases simply the disposal of that bin into non recycled and composted trash.

To reduce the amount of waste being brought into landfills and incinerators and encourage the reuse of waste products, we propose a device for the Self-Operated Organization of Recyclables and Trash (SORT), which acts as an extension to a typical multi-bin waste disposal unit with may consist of receptacles for bottles, paper, general recyclables, compostables, non-recyclable trash, etc. As the name implies, a given unit would, through a series of mechanical actions determined by an algorithm acting on an array of sensors, automatically sort waste into some categories: e.g. paper, metal, compost and garbage. These units are to be deployed in various key points of interest where diverse waste is being disposed at a high frequency, such as an educational institution, office, tourist attraction, or busy street corner, where they will also passively collect data about waste disposal patterns.

Although other autonomous sorting waste disposal units (though uncommon) have been proposed, designed, and implemented, in the past, they have many shortcomings which limit their implementation in public areas. Such problems include inaccuracy in the sorting, high cost, being too complex, and being only appropriate for the industrial scale. Some self-sorting trash cans on the market can go for around $1000 to $2000, while the average trash can cost only about $20 to $50, a price gap which is unattractive to the average consumer. Surprisingly, most of the money to produce these machines are not invested in critical mechanical components like motors or sensors, but rather the user interface. Many autonomous trash cans tend to be made from steel, which can be very expensive, and have superfluous design features such as touchscreens. Not only is the hefty design more expensive to acquire, operate and maintain, but it's also too massive to implement in the average household or school. To avoid these flaws, our product selects certain design strengths of previous models while reducing costs by simplifying the design and focusing on what's important to create a viable product for offices, schools, and public areas.

Currently, for the purpose of classifying waste, we propose a technique which uses image

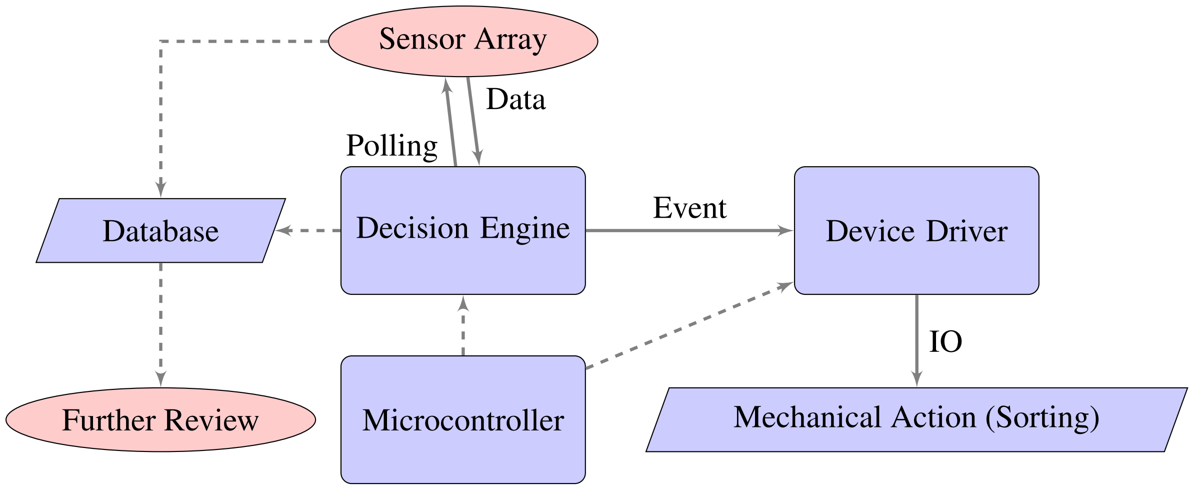

Figure 1: Process Diagram of SORT micro-controller software

recognition supplemental to a contact microphone (to sort waste and identify events based on the sound produced when thrown into the intake bin) along with other sensors. The output from these sensors will then undergo processing and serve as an input to a robust ensemble of inference models that continuously analyzes the environment. When an event is detected, the SORT software will automatically classify the object and put in into the appropriate receptacle by interfacing with the hardware components.

Data from all levels (e.g. inference data, environment data, and data about waste disposal trends) will be automatically recorded by the SORT software and logged in a database which will be easily accessible for future review, something which can be done at a minimal cost. Figure 1 outlines the overall software, data, and information pipeline of the SORT. We will utilize a series of models running on a microcontroller (abstracted as the "Decision Engine") to analyze the sensor inputs and send the appropriate signals to the mechanical components (which also controlled by the microcontroller).

This design is intended to be as cost effective as possible. This is achievable as small-scale components used for fields such as consumer robotics have seen declines in prices and are now accessible to the average consumer thanks to their increased demand due to use in hobbyist activities such as competitive robotics. These components offer precise and reliable control over the mechanics which will perform the actual movement of waste from an entrance point to the proper bin.

Other designs for automatic waste sorting systems have used slow moving conveyor belts or racks and pinions, in contrast to our simpler design proposal which consists of an intake bin mounted on a gear that spins to different waste receptacles and drops the waste into the correct category. This design only requires two motors: a servo and a stepper.

Recent advances in embedded computing, and the Internet of Things (IOT) have also allowed for powerful inference models to be run on minimal hardware which has then in turn lead to the feasibility of this project. In the past decade the cost of small cameras and other sensors has gone down rapidly due to the increasing demand for miniaturized, low cost components in embedded devices and smartphones. In addition, the processing capabilities of low-power embedded processors has advanced to such a degree that it is now possible to run powerful image recognition models, such as the Single Shot Multibox Detector (Liu et al. 2016), and other inference models that, if properly implemented, can achieve very high levels of classification accuracy.

The operation of this device requires a device a nontrivial quantity of electric power. To resolve this problem, the device will need to have an adequate power source. In indoor public installations, this should not be a major problem. However, in outdoor and other adverse situations we will strive to make our device low powered enough to be run on solar and battery power, and in the event of loss of power due to unfavorable conditions we will strive to make sure the system will report the situation and can still be used manually.

2 Implementation

The robust, automatic, timely, and accurate classification of waste will require great amounts of data collection the for the design, optimization, and rigorous testing of the inference models. Thus, this is the first step and is to be done well in advance. Our plan is to develop strong statistical models for sensors that output low dimensionality data and neural based models for image data with spatial relations which will be packaged into a single inference engine program with a uniform interface. We will optimize for the following: robustness in the case of failure, accuracy is sorting, and speed of classification and detection of events.

The various models will be ensembled together to form the inference engine, which will use robust logic to ensure that waste is disposed of regardless of what is put in the in a timely manner. Computationally intensive methods such as object recognition should be scheduled only to run after an event has been confirmed by other sensors and algorithms which are able to be run in less time, e.g. the analysis of audio when waste comes in contact with the unit or the analysis of the change in brightness of image data. In the event of darkness, the unit will use an LED strip to illuminate the receptacle to gather data.

Although this is a daunting task that requires fine tuning, we believe it to be feasible. Object detection has been done on small development boards before such as the Raspberry Pi and a great amount of well supported libraries exist to make this task easier. The gathering of data and the creation of the models will be done in parallel to the actual development and construction of a prototype unit as the two can be separated into discrete, mostly independent problems. Fine tuning and making the system viable in real time may be an area where MIT expertise would be useful.

In terms of the mechanics of the product, we plan to minimize the number of motors used for cost and efficiency reasons. To accomplish this task, our preliminary plan is that SORT will use two motors: a stepper motor and a servo. The stepper motor will spin connected to a gearbox with a gear ratio of 2:3. The gearbox will contain a small gear, directly mounted on the motor shaft, and a large gear that is in contact with each of the four disposal bins. Mounted on top of the large gear will be the intake bin that is lined with the LED strip described above. Inside the box will be a flap connected to a servo, which opens the intake box, so waste can be dropped into the proper bin. For this to happen, the stepper motor shall turn the larger gear, so the waste is directed to the correct bin. Since such large gears are typically hard to find on the market, we plan to fabricate this gear to our specific dimensions using a laser cutter. The gearbox and motor are to be mounted on a custom 3D printed frame that sits upon the array of waste bins. The whole unit is estimated to take up a little less than a square meter of space and can be scaled according to the traffic of the area it is placed.

We foresee three main risks to our project in both the design and operation phases. The first, and most likely is the failure of mechanical components, whether it is a failure to design the system altogether or failure during operation. To mitigate this risk, this is an area in which we plan to devote significant amounts of time and resources and will actively seek the help of experts and is another area where MIT expertise may offer valuable insight and funding.

Another problem is a potential failure to meet economic constraints, as historically units like ours have been high cost installations. It is clear that our system will be more expensive than a traditional waste disposal system. However, we hope with the reduction of components, careful design, and use of more cost-effective material, we can reduce costs to affordable amounts which can be offset by the environmental benefit of increased recycling and compost rates as well as labor savings by mostly eliminating the need for manual sorting of trash. In addition, we hope an installation and demonstration of the technology will inspire discussion about the topic of proper waste management in general.

The final problem is that of robust logic and sensing in terms of trash removal, as a failure of a sensor would mean the entire unit could break down, and a misclassification would require digging through the trash to remove the incorrectly sorted article. To this end we will implement multiple fail safes and verbose logging. Socially, it may also require a great amount effort to garner trust in the reliability of the system so outreach may be necessary to ensure the proper usage of the machine.

We will only use commonly available materials to construct this project to keep costs down. Many structural components to build a prototype such as wood can be easily acquired locally. Electronic components such as sensors and microcontrollers can be sourced online. However, as we already own some of these components, the upfront cost is less than if we were to construct a unit completely from scratch. A breakdown of project components is listed in table 3. Although we can source the components to design and prototype our machine independently, MIT funding would be of great help in terms of supplying funding for outreach and further and more robust

Table 3: Breakdown of Project Prototype Components by Cost

Component		Qty.	Est. Unit Price	Total
Computing and Sensors	LED Strip	1	$5	$5
	Microcontroller	1	$35	$35
	Camera	1	$25	$25
	Contact Microphone	1	$18	$18
Mechanical Components	Misc. electrical components	-	$15	$15
	Lazy Susan	1	$5	$5
	Motors	3	$10	$30
Miscellaneous and Structural Components	Trash cans and skeleton (custom)	-	$20	$20
	Fasteners, mounting, wheels, etc.	-	$20	$20
			Total	$173

Table 4: Proposed Timeline of Events

Date	Milestones
1/13	Completion of the CAD models and design of the unit. Preliminary software development. Contact with administration.
3/31	Completion of the construction of the physical unit and additional software development.
4/1	Start of preliminary real world tests at Horace Greeley High School.
5/1	Completion of the refinement of classification models. Comprehensive Report and analysis on unit health and waste disposal

development of the unit. MIT expertise would be great of help in terms of further selection of sensors and materials choice to reduce costs and make the unit more effective.

We hope to be able to deploy a fully functioning prototype by the end of April and put it in for long term testing at our school. We are currently in contact with our local administration and custodial staff to test run the unit once a prototype is built. Extensive testing will be performed both before and during the early phases of trial deployment and waste disposal data will be diligently gathered for further analysis. A timeline for our intended milestones is given in Table 4.

To test for real world effectiveness, we will prepare a comprehensive analysis of unit success after a period of deployment, this data will be tested against the status quo at Horace Greeley High School which we have analyzed. Practically, in terms of the product, the CAD models can be collaborated upon easily and both of us will contribute to the software development. The work will be divided based on our skill sets, as while the two of us possess qualifications with great amounts of overlap, one of us has greater experience with mechanical engineering and robotics, having participated in FTC Robotics, while another has a comprehensive knowledge of present machine learning and statistical models as well as data analysis and software development skills.

3 Personal Motivation and Qualification

The environment in which we live is very important us, both from the practical standpoint that we should dispose of waste properly for safety reasons and from the moral standpoint that doing so will benefit all of those in our community and our world.

We got inspired to pursue this project after witnessing the carelessness of students when throwing their waste away in the school cafeteria. Trash is often strewn about the floor and around the disposal bins at our school. Not only were the students not recycling their waste, but they were making a mess for the custodians to clean up. Our school principal's response to this problem was that our school strives to recycle but struggles to do it correctly. And in fact, this is a serious problem because the school is fined for all the waste that's disposed of incorrectly. We then decided to gather data and find exactly how much the school recycles, and how correctly they do it. Having surveyed the waste receptacles at our school, we came to realize that the students at our school struggle with disposing their waste correctly.

We decided to start brainstorming possible ideas to solve this problem and decided to begin the initial prototype phase to designing SORT. We decided upon this technological solution given that other more passive solutions to this issue such as putting up posters or maintaining a reward system for good recycling and composting practices were not as effective in terms of greatly increasing proper sorting of waste. Rather than making people do something they might not care for, our solution increases composting and recycling by doing the work for the people. Even if our approach ultimately doesn't work, we will have still gained valuable insight about waste disposal patterns in our school as learning a great deal through the design and implementation process itself. The school will also have greatly benefited due to the increased amount of conversation around recycling and composting.

In terms of qualifications both us are competent in computer programming, software design, CAD, and designing real world products. Noa is the programmer on her FTC robotics team where she uses Java to control the robot and has developed several iOS apps. She is an avid RC hobbyist and has built drones, hovercrafts and helicopters before. She plans to use her experience with building, designing and programming for the development of the SORT. Jonathan has great amounts of experience with implementing and utilizing machine learning and statistical models for real world inference as well as having developed application in numerous programming languages such as Python, C, Java, and R along with a great breadth in terms of general knowledge in computer science and applied mathematics.

Work Cited

DoSomething.org. (2015). 11 facts about recycling. DoSomthing.org. Retrieved from https://www.dosomething.org/us/facts/11-facts-about-recycling

LeBlanc, R. (2018). Recycling facts and figures. The Balance Small Business. Retrieved from https://www.thebalancesmb.com/recycling-facts-and-figures-2878049

Liu, W., Anguelov, D., Erhan, D., Szegedy, C., Reed, S. E., Fu, C.-Y., & Berg, A. C. (2016). Ssd: Single shot multibox detector. In *Eccv*.

Municipal Solid Waste. (2016). United States Environmental Protection Agency. Retrieved from https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/

Synced. (2018). "trashbots" boost recycling at pittsburgh airport. *Synced*. Retrieved from https://syncedreview.com/2018/03/02/trashbots-boost-recycling-at-pittsburgh-airport/

Waste, N., & Association, R. (2014). National waste and recycling association survey finds most americans would compost if it was more convenient in their community. National Waste and Recycling Association. Retrieved from https://www.prnewswire.com/news-releases/national-waste--recycling-association-survey-finds-most-americans-would-compost-if-it-was-more-convenient-in-their-community-239232261.html