Product: Recyclotron
Team: Group Eight

Abstract

Our main focus this demo was on fully implementing user interaction using a touchscreen. Our newly-created metric evaluated the success of Recyclotron and sound was tested as a possible input for improving accuracy.

Goals for this sprint:

- ensure we can compare our system to recycling centre sorting - achieved!
- ensure our metric is combined into one single formula - achieved!
- ensure our system is trained for this metric as well as tested for it - achieved!
- ensure that uncertain objects prompt the user via touchscreen - partly, touchscreen not fully integrated
- ensure that if user doesn't respond it goes in non-recyclable automatically - partly, has not been tested with touchscreen
- ensure that bin can update ML with unseen object's category & retrain ML
- ensure detection of empty category (when user closes lid, but doesn't put anything in) does nothing - achieved!
- ensure we have tested the performance of sound input - achieved!

1. Project Plan Update

1.1. Group Organisation

Previously we divided up tasks amongst a hardware and software team. For this demo we instead set times throughout the week to work on SDP. This was more feasible due to a limited number of tasks and the outbreak of Coronavirus making several members unwilling to come in.

Sound Team: Zhixing, Shivamm

1. Setup sound model then clean, train & test using initial dataset
2. Create and test on recyclotron test dataset

Input & Interface Team: Zhao, Martin, Zhixing, Rebecca

1. Design user interface as webpage
2. Integrate user interface with screen and pi
3. Code the prompt and movement of bins
4. Implement a backup-feature, allowing model to be restored
5. Code to send images to server for retraining

Progress and planning was also made for demo 4's goals, which will be detailed then.

1.2. Future Milestones

For our final demo, we added two new milestones, offline-mode and statistics. Offline-mode allows Recyclotron to work without an internet connection. This makes the system more reliable and cheaper to maintain. Statistics on sorting allow users (e.g. office managers) to track their progress towards targets they need to meet, e.g. pre-sorting for a recycling centre. We're also aiming to fully integrate with the 3D printed model. **Demo 4 Milestones**

- ensure that recyclotron can work offline if desired
- ensure user has access to statistics (create a dashboard on the web page)
- ensure recyclotron is fully integrated into a 3D printed model

2. Technical Details

2.1. Touchscreen and interface

Initially we considered using buttons as input and our feedback screen to provide output. However the screen is small, being only capable of displaying short text. We wanted to display more information more clearly, using pictures or graphical objects rather than text or labels. We wanted a simple yet more interactive form of input, rather than an assortment of physical buttons.

One idea was to use a mobile app where users would interact with recyclotron there. Yet we felt requiring an app and wireless connection to a phone was excessive, especially as we want to minimise the time and effort of recycling.

Finally we settled on using a webpage as our interface, with a touchscreen providing input and output. A webpage works on a multitude of devices, and can be scaled to the size of the screen required. The touchscreen provides feedback to the user by showing variations of the webpage. When recyclotron prompts the user, the webpage displays 4 buttons which can pressed. When pressed the page updates and this is detected by the pi. The category of the button is fed back to the model and recyclotron moves as normal.

We also plan to show statistics, the trash level of each bin, the user guide of the product and other various helpful infor-

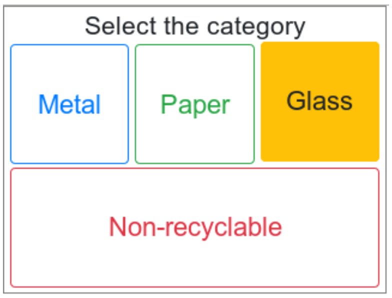

Figure 1. Webpage UI for buttons, with one button for each category. Glass is currently selected by the user so is highlighted,

mation on the webpage too. This would be accessed either by those maintaining recyclotron, or while the machine is idle.

2.2. Classifying Sound

Test results (given in demo 2) show our machine learning model performs worst on glass and paper. Glass is not detected at all. To remedy this we investigated alternative ways of detection and input.

We did consider capacitive sensors for detecting metal, plastic and glass but they were too expensive and time-consuming to implement.

We settled on testing an additional sound input to the model, which behaves much like user input. Another reason to use sound is there's already a microphone on the web camera, so it would not require additional hardware or components.

We trained our sound model on audio clips of dropping objects, which we retrieved from soundsnap.com. [1]

Once trained we implemented the following process.

Firstly, Recyclotron starts to record the sound of the trash item dropping once the lid is opened.

After the lid is closed, our software stops recording and extracts the clip when the item makes the impact (called a hit point). This is done by selecting the clip (which has a fixed-length) that yields the highest energy.
The clip is then transformed into a vector using Fast Fourier Transformation.

Finally, the transformed vector is fed into the sound model to get the classification of the corresponding trash item.

3. Evaluation

3.1. Sound Classification

Firstly, we created a test set with random audio samples from Soundsnap. Secondly, we recorded our own sound effects inside Recyclotron. We saw that the model performs only marginally better on Recyclotron's test data than those randomly sampled from Soundsnap.

Figure 2 shows the confusion matrix with performance of different categories using sound. Examining the performance of glass classification we see that glass is successfully detected as glass 69% of the time. We can also see that only 44% of other items are misclassified as glass.

	Metal	*Glass*	*Plastic*	*Paper*	*Trash*	*Precision*
Metal	4	2	2	1	0	0.44
Glass	5	9	1	0	1	0.56
Plastic	1	1	3	0	3	0.38
Paper	1	1	0	7	2	0.64
Trash	3	0	0	1	2	0.33
Recall	0.29	0.69	0.5	0.78	0.25	

Figure 2. Confusion Matrix for Sound Model

We suspect this is probably due to ambient noise and the presence of multiple hit points (the point at which recyclotron starts recording audio).
A possible solution could be to use a pre-trained sound classification model (e.g. FreeSound audio-tagging model) and fine-tune it for our needs. As this is is the penultimate demo we've decided not to further improve it or fully implement it, instead focusing on achievable goals we can test and implement.

3.2. Metric Research

Before deciding on how to measure our system, we researched standards for waste sorting that we could compare Recyclotron to. We wanted to see what was a realistic example of success for recycling and sorting.

The British government's 2018 Resources and Waste Strategy [2] helped us compare metrics, with their strategic indicators helping us model success better. Unfortunately the metrics focused on measuring national recycling performance (in terms of tonnes per year etc), rather than a single location's sorting performance. We also discovered similar smart-bin projects such as Trashé [3] and SortBot [4]. Only Trashé had performance we could compare with (precision, recall & mAP), as SortBot didn't do any tests on we can compare with.

We found a BBC article stating the sorting performance of three English recycling centres. They both successfully recycle around 85% of recyclables they receive.[5] The other 15% of recyclable material is lost due to contamination or being sorting errors.[5] This informs us that we should be classifying no more than 15% of our recyclables as trash.

Finally we found a case study comparing various sorting standards in England, Europe and North America. It gave us a measure of how pure recycled categories need to be, before they can be re-sold on the market as new materials. Generally, UK Markets forbid the resell of materials that are more than 1% contaminated with other materials.[6] For the French Market, Eco-Emballage specifications gave targets for precision in various categories of rubbish.[6]

Now with some indicators of performance to aim for, we had to decide how best to measure them.

All our targets (particularly those used by the French Market) relate to precision in each recycling category. This justifies the use of precision as a test metric.
However we also want to retrieve as many recyclable items as possible to minimise landfill waste, so we need a metric that considers recall and precision.

As a compromise, we're using mean Average Precision (or mAP) as our overall metric, as mAP's calculation incorporates precision and recall for every category.
Average precision is a commonly used in information retrieval contexts, which is similar to our 'recyclable retrieval' use case. AP is defined as the average precision across different thresholds for the predicted probabilities. AP is computed as area under the precision-recall curve. mAP is simply the mean AP across categories.

Figure 3 is a table of performance (or success) indicators. Total Truly Recycled is our overall measure of performance, which is represented by mAP. Level of Trash Contamination indicates how much trash is misclassified. This is helpful in showing us false positives, which we want to eliminate to reduce recycling centre costs (as per report 2). The final 5 performance indicators show us how well recyclotron performs in specific categories. These measures of purity are included more as guidelines or benchmarks to compare against (which differ from UK benchmarks anyway), rather than a firm target to aim for. As such they are not specifically accounted for in the mAP metric.

Performance Indicator	*Tells us...*	*Why we need to know*	*Metric*	*Desired Target*
Total Truly Recycled (Overall Performance)	How much recyclable material we successfully sort as recyclable	Comparable to Trashé and the Kirklees, Hull & Greenwich recycling centres performance.	mAP	>=85% overall
Level of Trash Contamination	How much trash falls into other categories	Comparable to UK Market standards of contamination	1 - Trash Recall	<= 1% overall categories
Metal Purity	How much category consists of metal	Comparable to French Market standards of recycling purity	Precision of Metal Category	>=45%
Paper Purity	How much category consists of paper	Comparable to French Market standards of recycling purity	Precision of Paper Category	>50%
Cardboard Purity	How much category consists of cardboard	Comparable to French Market standards of recycling purity	Precision of Cardboard Category	~95%
Plastic Purity	How much category consists of plastic	Comparable to French Market standards of recycling purity	Precision of Plastic Category	>90%
Glass Purity	How much category consists of glass	Comparable to French Market standards of recycling purity	Precision of Glass Category	100%

Figure 3. Table of Performance Indicators, their metrics and their targets

3.3. Recylotron's Overall Performance

In figure 4 we can see Recyclotron compared with other sorting systems such as Trashé and the 3 English Recycling Centres. As we're using mAP to measure the Total Truly Recycled (see figure 3), we can use it to compare to what recycling centres truly recycle.

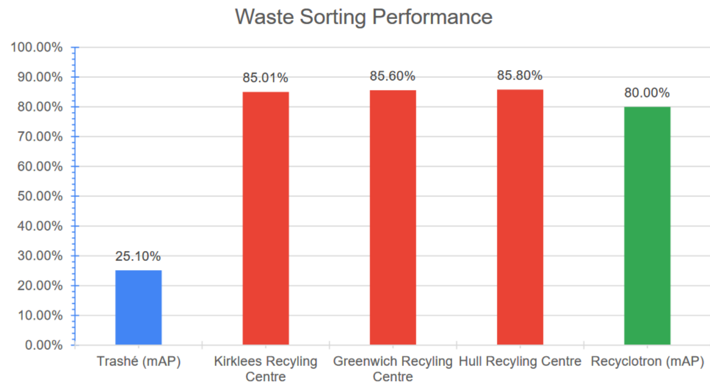

Figure 4. Sorting Performance for Waste, comparing recycling centres against smart bins

Trashé performs notably poorly, and this is something the developers themselves acknowledge.[3]
More helpful is that we can see that recyclotron truly recycles 80% of objects that can be recycled, only behind the recycling centres by 5%.
Keep in mind we are all testing on different data. Even our own testset is small and is very disproportionate. For example, we have only 1 glass object and 2 metal objects. It's quite likely our test dataset is too small and simple in comparison to the centres, but it's still worth comparing to see how succesful Recyclotron is on a smaller scale.

We're expecting User Input to improve our mAP by roughly 5% so these results seem promising.

3.4. Comparison of Purity

Figure 5 shows a the purity of each category. Once again, we are using these targets from the French Market as benchmarks to compare against, rather than goals to reach for. Overall Recylotron performs well, with only glass (which we attempted to improve using sound) and metal performing below the Eco-Emballage standard.

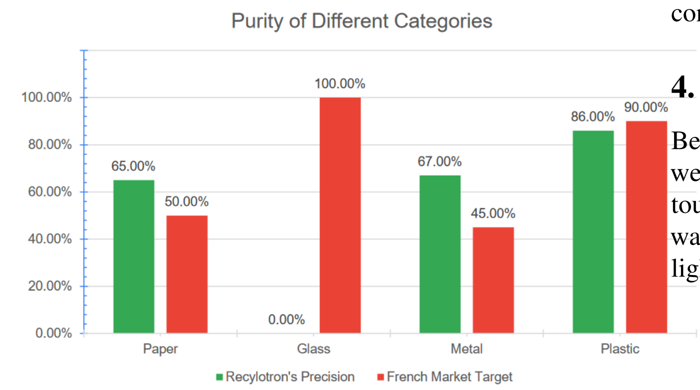

Figure 5. Purity in Various Recycling Categories, comparing the precision of Recyclotron against the Eco-Ecollage specifications

3.5. Comparison of Trash Contamination

In figure 6 we compare the level of trash contamination. Although Recylotron has a high level of 24% contamination, it's important to note that out of 107 objects we tested on, 55 were trash. The high level (when compared to the low 1% and 3%, the national average [5]), could be due to having 51% of our sample as trash.
In our research we found no numbers to give us a proportion of trash vs recyclables that the centres deal with. If we did we could balance our test set to reflect it.

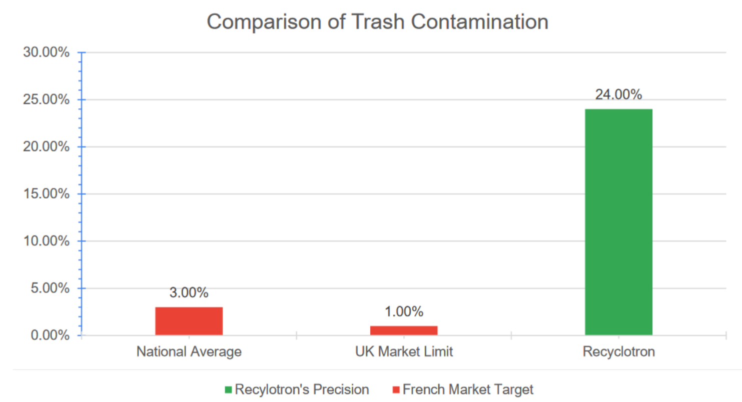

Figure 6. Comparison of Trash Contamination, national average retrieved from the BBC article, UK Market Limit retrieved from case study

3.6. User Input

We fully implemented the webpage with recylotron and the machine learning model. Unfortunately due to the outbreak of Coronavirus and delayed delivery of the touchscreen, neither the touchscreen nor those working on it were around. As a result we could not fully test our user input with the touchscreen or rest of the hardware. Hence we did not perform any further testing. As outlined in demo 2's report, we still expect a 5% increase in performance using confidence intervals and user input.

4. Budget

Below is a table showing our budget so far. For this demo, we purchased what should be our final component, the touchscreen. The cost of the LCD screen was removed, as was the cost of LEDs which we thought we would need to light the chamber. We are not using either of these items.

Component	Cost
Touchscreen	£10
3D Printed Body/Lid	£65
3 Electromagnets	£4
2 Ultrasonic Sensors	£5
2 Webcams	£15
5 EV3 Motors	£130
2 Steel Railings	£10
Higher End Raspberry Pi	£50
Total Cost	£280
Total Spent	£100

References

[1] Soundsnap, Soundsnap Sound Library
https://www.soundsnap.com/

[2] UK Government, Our Waste, Our Resources: A Strategy for England, 2018
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[3] Nathan Glover & Stephen Mott, Trashé, August 2019
https://www.bbc.co.uk/news/uk-37159581.com

[4] Boskovic et Al, SortBot: Self-sorting Recycling Machine, 13 March 2017
http://www.ee.ic.ac.uk/guo.liew15/yr2proj/Group%2006_Self%20Sorting%20Recycling%20Machine_Cong.pdf

[5] BBC News, Rejected recyclable waste up 84% in England since 2011, 23 August 2016
https://www.bbc.co.uk/news/uk-37159581.com

[6] The Dougherty Group LLC on behalf of WRAP, An introduction to MRFs and comparison of sorting operations based on site visits to selected facilities, September 2006
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