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Contents

1 Abstract

Design and implement a system to measure food waste in Pierce Dining Hall on Stevens campus. The system would likely utilize a camera to identify types of food waste based on a database of variations of food. Some important variables to consider are the amount of food made initially, the amount of food waste after disposal (potentially determined through weight, density, etc.), and the amount of food taken from the serving line. These data values can be analyzed and compared to allow for efficiency of food production in the future and minimization of waste.

2 Introduction

2.1 Background

According to the United Nations, roughly 1.3 billion tons of food is either lost or wasted worldwide every year, with the United States's residential food waste consisting of roughly 40.7 million tons as of 2017.[1] A major contributor to this is college dining, where the average college student wastes around 140 pounds of food each year. A 2013 study investigating the effects of written messages on food waste in college dining halls found that, over the course of just six weeks, 540 students at a single university wasted more than 1.5 tons of food.[5] While these past discoveries have offered useful insight into the food sustainability issue within dining halls, many of these studies have outdated statistics, have inconsistent definitions of food waste, including and excluding inedible parts of meals such as bones, or no longer reflect how waste can be effectively accounted for in the modern day.

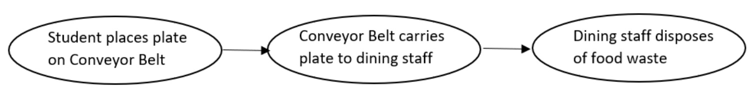
More recently, strides have been made in examining the use of deep learning to facilitate the cataloging of waste as a sustainability measure. For example, CompostNet is a recently developed program that uses deep learning to categorize waste in an effort to properly discard, compost, or recycle it.[7] This has been further extended to food waste specifically, with recent efforts conducted on behalf of the Food and Agriculture Organization of the United Nations working to create a U-Net deep convolutional network that is able to differentiate between what is defined as food waste, such as eggs, to what is defined as not food waste, such as the shells.[4] It is the goal of this project to examine how a combination of these methods can decrease overall food waste within the closed environment of a college dining hall.

2.2 Initial Research

In an effort to examine how such a system could be implemented within a college environment, and specifically, at Stevens Institute of Technology's Pierce Dining Hall, the group connected with dining administrators, both within Stevens and the dining hall's parent company, Compass One, via email. In order to gain more background information on the he group asked a series of questions regarding current sustainability and cataloging efforts, the physical setup of food waste disposal in the dining hall, and the practicality of implementing this project in the specific dining hall environment.

According to Pierce Dining Hall's Compass One liaison, Keith Marciniak, the service has been seeking a project of this type, having previously conversed with various AI companies through the National Retail Foundation(NRF), and the group's project would be able to fill this need (K. Marciniak, personal communication, July 14, 2020). Current inventories and menus are heavily influenced by past food usage data from the past five years, which is collected in an "intra-company website and tool that produces menu preparedness based on traffic and times of traffic in our [Compass One's] dining halls" (K. Marciniak, personal communication, June 22, 2020). However, the dining hall lacks data involving which specific foods are wasted by students after they are initially served. The company claims to dispose of little-to-no food waste, due in part to sustainability efforts such as batch cooking, specific sizing for plates and bowls to encourage consumption and discourage waste, and reusable dishware. However, the initiative that appeared to have the greatest impact on the group's proposal was the dining hall's use of a Bio-Digestor, which converts food waste into gray-water after student disposal. This directed the group to the current disposal setup, shown in Figure 1 below:

Figure 1: Graphic displaying disposal setup



With this information, the group began software design and the acquisition of necessary hardware.

2.3 User Stories

2.3.1 Student

Marcus is an average Stevens student getting lunch at Pierce between his classes. He waits in line and gets a mix of food he knows he will like and food he wants to try. He finishes his meal, but leaves some food on his plate because he did not like how it tasted. With 15 minutes before class, he gets up to bring his dishes to the conveyor belt. He places the dishes on the conveyor belt and notices a small light flashing as he does so. He leaves to go to his class, undisturbed by the new technology being utilized by the cafeteria staff.

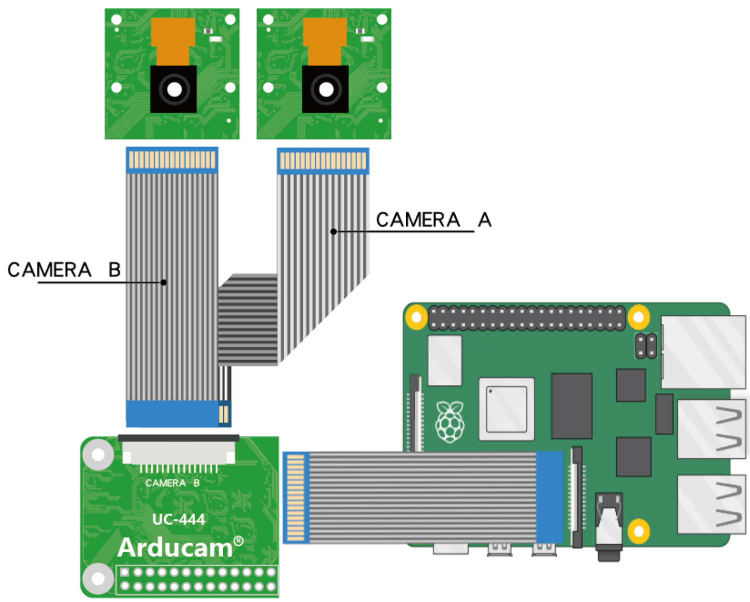
2.3.2 Staff

Laura is a worker in the Pierce Dining Hall and received an email before work saying they finished installing a new system to track food waste. Work goes by normally: food is prepared and put out for students, and dishes come in with leftovers that are thrown away. At the end of the meal period, Laura is told to go to the computer and input how many trays of each type of food were used, so she checks the inventory and fills in the information. When she is done, Laura is shown a report of how much food was wasted and details about which food items were thrown away the most. The report is submitted for review later by management, but Laura is surprised at just how much students threw away. Next month, Laura notices that there are fewer food trays of the foods that were thrown away more often. She reflects and believes that management must have seen the reports and adjusted their orders accordingly.

3 System Design

3.1 Design Diagram

Figure 2: Hardware connection setup



3.2 System Overview

3.2.1 Hardware Overview

Required materials to order for the project:

- Raspberry Pi 4 Model B [11]
- Raspberry Pi Camera Module V2 [9]
- Raspberry Pi NoIR Camera V2 [10]
- Arducam Multi Camera Adapter Doubleplexer Stereo Module V2 for Raspberry Pi Zero, Pi 4/3B+/3 [2]
- Pimoroni Raspberry Pi Camera Mount

- SanDisk Ultra 32GB MicroSDHC UHS-I Card with Adapter - 98MB/s U1 A1 - SDSQUAR-032G-GN6MA

These items were selected for the project because of the teams' familiarity with Raspberry Pi computers and the Python programming language. The Raspberry Pi 4 Model B was used as the primary unit, with plans to scale down to smaller and less expensive units such as the Raspberry Pi Zero in future. The camera modules were selected because it was determined they could produce images of a quality suitable to the project and had easy compatibility with Raspberry Pi boards. The Arducam Multi Camera Adapter was selected because Raspberry Pi boards are unable to connect to two camera modules simultaneously, this third party adapter allows the board to switch between the two cameras through the GPIO pins and I2C bus. The Pimoroni Raspberry Pi Camera Mount was used for positioning the cameras for testing, and was selected because it was simple to assemble. The SanDisk MicroSD card was selected because it had ample space for pictures taken by the device and scripts to identify food items.

3.2.2 Software Overview

The software design of the system can be split into two sections, the sensor and the database. The sensor uses the hardware listed above to collect images of food items and identifies them using machine learning. Along with this it takes an infrared image for the purpose of identifying the temperature of the item. Because the Raspberry Pi which was used for the sensor is unable to use two cameras simultaneously it must also switch between the cameras to take both images quickly. Once the images are processed, the sensor sends the collected data to the database. The database compiles this data to be presented to users so that they may investigate the sources of food waste.

Though this was the intended implementation of the project, due to technical issues the team was unable to fully complete this. However, the team is still confident that such an implementation is possible for future work. Issues such as the incompatibility of Raspberry Pi OS with the GlobalProtect virtual private network this is used by Stevens Institute of Technology made connecting the sensor to the database impossible. This could be overcome by directly connecting the Raspberry Pi to the Stevens network.

3.3 Software Requirements

All modules/libraries required for python will be kept in a requirements.txt file.

3.3.1 Libraries

Run the following command:

```
C:\> pip install -r code\requirements.txt
```

requirements.txt

```
asn1crypto==0.24.0
astroid==2.1.0
asttokens==1.1.13
automationhat==0.2.0
beautifulsoup4==4.7.1
blinker==1.4
blinkt==0.1.2
buttonshim==0.0.2
Cap1xxx==0.1.3
certifi==2018.8.24
chardet==3.0.4
Click==7.0
colorama==0.3.7
colorzero==1.1
cookies==2.2.1
cryptography==2.6.1
docutils==0.14
drumhat==0.1.0
entrypoints==0.3
envirophat==1.0.0
ExplorerHAT==0.4.2
Flask==1.0.2
fourletterphat==0.1.0
gpiozero==1.5.1
html5lib==1.0.1
idna==2.6
isort==4.3.4
itsdangerous==0.24
jedi==0.13.2
Jinja2==2.10
keyring==17.1.1
keyrings.alt==3.1.1
lazy-object-proxy==1.3.1
logilab-common==1.4.2
lxml==4.3.2
MarkupSafe==1.1.0
mccabe==0.6.1
microdotphat==0.2.1
mote==0.0.4
motephat==0.0.3
mypy==0.670
mypy-extensions==0.4.1
mysql==0.0.2
mysql-connector-python==8.0.21
mysqlclient==2.0.1
numpy==1.16.2
oauthlib==2.1.0
olefile==0.46
pantilthat==0.0.7
parso==0.3.1
pathlib==1.0.1
pgzero==1.2
phatbeat==0.1.1
pianohat==0.1.0
picamera==1.13
piglow==1.2.5
pigpio==1.44
Pillow==5.4.1
protobuf==3.12.4
psutil==5.5.1
pycrypto==2.6.1
pygame==1.9.4.post1
Pygments==2.3.1
PyGObject==3.30.4
pyinotify==0.9.6
PyJWT==1.7.0
pylint==2.2.2
PyMySQL==0.10.0
pyOpenSSL==19.0.0
pyserial==3.4
python-apt==1.8.4.1
pyxdg==0.25
rainbowhat==0.1.0
requests==2.21.0
requests-oauthlib==1.0.0
responses==0.9.0
roman==2.0.0
RPi.GPIO==0.7.0
RTIMULib==7.2.1
scrollphat==0.0.7
scrollphathd==1.2.1
SecretStorage==2.3.1
Send2Trash==1.5.0
sense-hat==2.2.0
simplejson==3.16.0
six==1.12.0
skywriter==0.0.7
sn3218==1.2.7
soupsieve==1.8
spidev==3.4
ssh-import-id==5.7
tflite-runtime==2.1.0.post1
thonny==3.2.6
touchphat==0.0.1
twython==3.7.0
typed-ast==1.3.1
unicornhathd==0.0.4
urllib3==1.24.1
webencodings==0.5.1
Werkzeug==0.14.1
wrapt==1.10.11
```

4 Software

4.1 Machine Learning — Image Recognition

One of the major aspects of the overall system falls into food recognition using the hardware components available for input data. To achieve a useful degree of accuracy, machine learning with a convolutional neural network was viewed as the optimal implementation. Using a convolutional neural network would be able to recognize a hamburger on a plate mixed in with other waste, rather than confuse the entire plate of waste as possibly something else entirely.

TensorFlow was used inside a Jupyter Notebook for all data fitting, model tuning, and model training; in order to run the trained model for prediction on the raspberry pi, the model was converted to a TensorFlow Lite extension, which greatly reduced the size and runtime while having negligible impact on prediction accuracy.

Diving further into the specifics, it was a sequential model — having one input and one output — that used RMSprop as an optimizer to increase the learning rate. Since there was a set number of foods to be trained on with distinct labeling, sparse categorical cross entropy was the loss function for the model.

Images for training and testing were amassed through a kaggle database [3] and through a google extension used on Google and Bing image search.

4.1.1 Improvements

Over the course of the training improvements were made to ensure more accurate results. Most effective, the introduction of the pretrained model MobileNetV2 [6] as a base model served well as it provided an excellent jumping off point for edge detection.

Further improvements can come in the form of image data augmentation to provide more images and encourage new patterns for the model to pick up on. For example, the current images the model is trained with can also reappear as flipped — horizontally or vertically, discolored, or zoomed in.

4.2 Database

A MySQL database has been allocated with a table to keep track of the information of food that is put through the camera's prediction. The table consists of information including:

- Unique ID
- Name
- Date
- Time

Further information like weight and temperature would be useful to keep track of, if a future implementation included hardware sensors capable of logging that data.

5 Final Results

5.1 End Product

At the conclusion of our project, the system has been trained to recognize following 10 food items commonly found in a dining hall setting:

- Chicken Wings
- French Fries
- Grilled Cheese Sandwich
- Hamburger
- Hot Dog
- Ice Cream
- Macaroni and Cheese
- Ramen
- Steak
- Waffles

The system uses two cameras to capture images and recognize items. The NoIR camera is best used in low lighting settings, while the PiCamera V2 is most useful in daylight settings. Currently, there is no implemented way of measuring the weight of food items.

5.2 Possible Next Steps

As the group looks to the future, there is significant progress that can be made regarding the project's implementation, particularly when normal campus operations resume following the COVID-19 pandemic, which will allow for direct connection with the Stevens network interface as well as the dining hall itself.

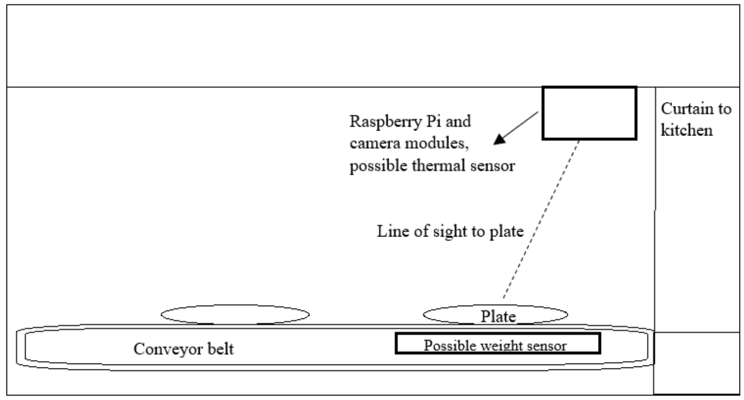
First, the group will seek to improve the usage of the database. Over the course of the project, the group developed a local database using thousands of downloaded images, which was improved in capacity and accuracy through increases in data collection and training of the image recognition model. This prototype database was eventually converted into a mySQL database to increase its scope and reliability. However, in order to access the mySQL database and integrate it with the Raspberry Pi and its sensors, the Raspberry Pi must be connected to servers housed at Stevens Institute of Technology. Due to the remote nature of the project, the group was required to use Stevens' GlobalProtect VPN, which was unable to interface with the mySQL database on the Raspberry Pi. Once on campus, the group will be able to effectively utilize mySQL and further test the accuracy of the model on this platform.

Additionally, the group will continue exploring resources to increase the database's capacity and design it more specifically to fit the needs of Pierce Dining Hall. The dining hall already has a website that the company uses to catalog food usage, and the project would be intended to supplement this platform so that the project can benefit the dining hall and its sustainability initiatives without causing significant disruption to the institution, dining hall staff, or Compass One management. The goal will be to collect data on food items, both in name and in image, that are served most often as well as recipes that are unique to the dining hall. These data points will be a necessary add-on to transition the project from one that can assist all dining halls to one that will catalog waste specific to Pierce more accurately.

Furthermore, the group will look toward employing the physical setup of the model in Pierce Dining Hall when it resumes normal operations. Since the project will be conducted in a dining hall setting, the group will conduct further research on protective waterproof enclosures for the hardware that do not inhibit functioning. This will be further incorporated into the mounting technique for the project, which will be guided by investigation of the infrastructure already in place in the dining hall. The proposed model is shown in Figure 2 below.

This proposed model includes two additional categories for data collection, for weight and thermal imaging. While the existing camera modules will be able to capture the types of food wasted by students, there is no current hardware to explore these additional data points that may be useful to the dining hall. A weight sensor will allow for cataloging to go beyond food waste varieties into the specific weight of wasted items, offering more detailed insight toward food waste that can lead to more cost-effective production. The thermal sensor, on the other hand, can be useful in determining the temperature at which food items were wasted, which can offer useful information on student preferences outside of the amount of food that students take.

Figure 3: Graphic displaying disposal setup



The final issue group aims to tackle in the future is in the project's triggering mechanism, which will enable the sensors to function as desired. There are several different types of triggering mechanisms, including time-based, where data is collected on user-determined time intervals, motion/distance intervals, where data is collected at specific locations based on movement, pressure-based, which would induce collection when pressures are detected, or other methods using external receptors.[8] Current research has not yet determined the most effective method for this project. With the proposed measures in mind, research will continue with the goal of improving sustainable practices at Pierce Dining Hall, and, potentially, in dining services across the Compass One platform.

References

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