W.A.S.T.E. R.E.D.U.C.E.

Shiree Hughes, Jiannan Zhai, Jason O. Hallstrom
Institute of Sensing and Embedded Network Systems Engineering
Florida Atlantic University
Boca Raton, USA
shughes2105, jzhai, jhallstrom@fau.edu

***Abstract*—Food availability and food waste are significant global problems. Current monitoring methods require manual data collection and are implemented infrequently, providing imprecise information. Smart service systems offer real-time, continuous monitoring, plus feedback to influence human behaviors. This paper presents a smart services approach to automating food waste measurement, and to influencing associated human behaviors. The work is presented in the context of a case study conducted in a university cafeteria.**

***Index Terms*—Internet of Things, ambient displays, wireless sensor networks, food waste**

I. Introduction

In the U.S., approximately 40% of the food cultivated goes to waste; yet, 1 in 6 people suffers from inconsistent access to food [9]. The cost of this waste is $165 billion per year, plus a large portion of methane emissions from U.S. landfills. Reducing the amount wasted by just 15% would generate enough food to feed approximately 25 million people, which would reduce food shortage problems by almost 50%. It is imperative that the task of educating society and encouraging changes in behavior begins.

Many institutions implement food audits in their cafeterias to collect information on how much food is wasted. An overview of the typical process is provided in Section II. Most institutions collect data for a short time and do not provide resolutions for reducing waste. Our goal is to provide ongoing measurement of food waste, coupled with ambient visual cues designed to decrease the amount each customer wastes.

Waste **A**uditing **S**ensor **T**echnology to **E**nhance the **R**eduction of **E**dible **D**iscards in **U**niversity **C**afeterias & **E**ateries (WASTE REDUCE) is a system to collect data on food waste, and relay the information to cafeteria customers via an ambient display designed to elicit behavioral change. Data was collected in the cafeteria on Florida Atlantic University's (FAU) main campus, where approximately 70% of FAU student population take classes [6].

The contributions presented in this paper are as follows: (i) the design and implementation of an automated system to monitor food waste, (ii) the design and implementation of an ambient display designed to affect behavioral change, (iii) identification of and solutions for the challenges of deploying such a system, and (iv) a case study that demonstrates the efficacy of the system.

II. Background & Related Work

Methods used to conduct food waste audits at U.S. universities were surveyed, with sizes varying from 17,000 to 50,000 students. All used manual methods to determine waste generated [7], [8], [11], [13], [17]–[19]. WASTE REDUCE provides a continuous measurement stream.

WASTE REDUCE relies on *ambient displays* for feedback, inspired by the work of Stasko et al. [15]. The authors focus on conveying information through artistic displays. The displays adapt based on data being presented, while maintaining an aesthetically appealing appearance. The aim is to reduce cognitive disruptions, so that acquiring information does not require a change in focus.

Plaue et al. [14] similarly explore the efficacy of presenting information through ambient displays using *InfoCanvas*. The authors represent 10 pieces of information, generally found on a home page, in an artistic scene, with each element mapped to a portion of the scene. For example, airfare prices are represented by a kite flying in the sky. When the kite is closer to the horizon, it signifies a low price, and when the kite is high in the sky, it signifies a higher price. In user studies, users rated InfoCanvas highest for both ease of information recall and visual appeal – though a need for adaptation to this non-conventional system was noted.

Dahley et al. [4] compare the use of ambient displays to cues from nature through *Water Lamp* and *Pinwheels*. Water Lamp uses data to simulate raindrops, computer-controlled solenoids are used to create ripples in a tray filled with water. A light shines from beneath the tray, displaying the ripple effect on the ceiling above. Water Lamp can be driven from multiple sources of information, enabling, for example, the display to behave as an indicator of weather. Pinwheels was created to convey information on air flow. Air flow data is represented using a motor, which spins a pinwheel at a proportional speed. Both devices function as a physical reminder of the associated data.

WASTE REDUCE combines prior work on ambient displays and food waste monitoring with smart service systems to produce an automated system that informs customers of their waste in real-time, while maintaining aesthetics and a low cognitive burden.

III. Food Waste Monitoring

Figure 1 depicts the WASTE REDUCE architecture, consisting of four main components: a scale located within each

978-1-5386-4705-9/18/$31.00 ©2018 IEEE
DOI 10.1109/SMARTCOMP.2018.00027

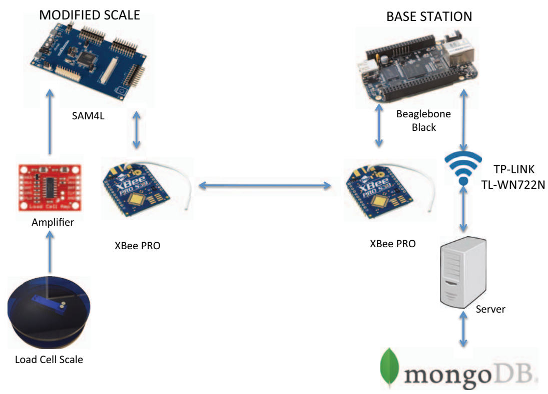


Fig. 1: Food Waste Monitoring Architecture

trash can, a base station, a back-end server, and a front-end display.

The scale comprises a 10kg wide-bar load cell [10], an HX711 [2] amplifier, an XBee-PRO 900HP S3B [5] radio, and a SAM4L Xplained Pro [1] board. The SAM4L Xplained Pro houses a Cortex™-M4 based microcontroller. The design is compact, conducive to the limited space within each trash can.

The base station comprises an XBee-PRO 900HP S3B radio [5], a TL-WN722N 150 Mbps WiFi dongle [16], and a Beaglebone Black [3]. A Java program is used to receive transmitted XBee packets, and to transmit the stored information to a server.

All data is stored in MongoDB [12]. Since the server is protected by a firewall and cannot be accessed remotely, a RESTful design was adopted. The available functions allow the front-end to query the server using HTTP-GET requests.

The scale samples and transmits once per minute. For each sample, the load cell is queried 100 times. The values are ordered and divided into thirds, and the middle third is averaged. This method serves as a low-pass filter, excluding noise and jolts to the trash can. Between transmissions, the system enters deep sleep to minimize power consumption. Using a 6Ah battery, the scale can be powered continuously for just under one month. Figure 2 depicts the hardware setup.

The front-end display is shown in Figure 3. The top of the screen displays the date and location. The left side of the display contains an image of a beach. The more food is wasted, the more littered the beach becomes. The litter in the image consists of a trash can, followed by a number of garbage bags, where the number of bags depends on the amount of waste currently observed for the day. Using preliminary data, it was determined that the average weight of the trash when emptied was approximately 20 lbs (9.07 kg). Therefore, for every 20 lbs wasted, a new trash bag is added to the beach scene in the display. The right side of the display consists of 3 graphs: (i) a gauge comparing the current day's total food waste accumulation in comparison to the previous week's maximum waste accumulation, (ii) a gauge comparing the current day's total food waste accumulation in comparison to the previous week's minimum waste accumulation, and (iii) a line graph showing accumulation over time for that day.

Note that the scale reports the weight of waste *currently* in the can. *Accumulated* waste is calculated as the sum of local maxima. Since the cans are completely emptied throughout the day, this should, in principle, be effective. In practice, however, the scale rarely measures exactly zero pounds, and anomalous measurements occur (e.g., heavy jolts, force exhibited from bag tying). These issues are addressed in software through approximation (i.e., 0.00 gte zero gte 0.05) and exclusion of local maxima that are not followed by a return to zero (e.g., resulting from someone tying the garbage bag).

IV. Deployment Challenges

Several difficulties arose during the initial deployment, all applicable to other university cafeterias.

A. Dynamism

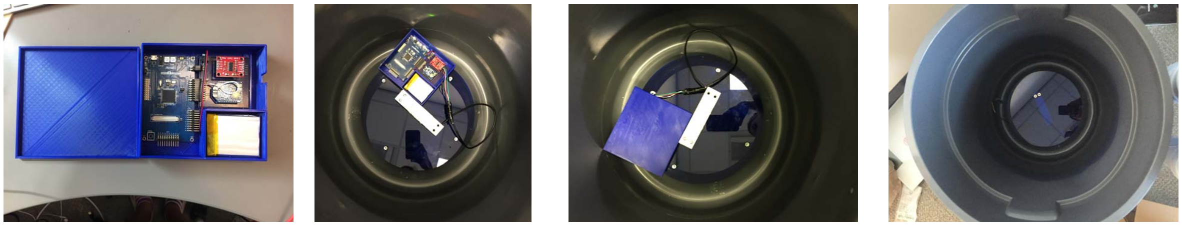
The first challenge stemmed from the flexibility of the environment. The initial scale design was based on specific trash cans used by the cafeteria. Upon completion of the design, new trash cans had been adopted, and the method used to empty the trash cans had changed. Damage resulting from jolts to the trash can through accidental kicking and bumping were also observed. This required securing the device to the bottom of the can. Figures 2c and 2d illustrate the scale as it sits in the trash can. For the sake of the pilot project, two instrumented cans were used. Thus, all results represent a minimum bound on food wasted in the cafeteria.

B. Resistance to Water

While it is not expected that the scale would be completely submerged in water, it is possible that liquid waste may leak from the trash bag into the bottom of the trash can, where the scale is secured. The electronics were placed in a 3D-printed enclosure, shown in Figures 2a and 2c. Clear coat paint sealant was used to make the box water resistant. To improve the likelihood of a water-tight seal in the base of the can, pilot holes for the screws were drilled smaller than the diameter of the screws to enable a tighter fit, and o-rings were used at the head of each screw. After installing the screws, the design was verified to be leak free.

C. Range

Another challenge stemmed from movement of the trash cans. Trash cans are often moved to the kitchen, or outside to be emptied. This distance is too far for XBee radio transmission. Since the weight should be constant as the trash can moves to the dumping location, any data lost during this time period is not of interest. It is also possible that the cans may be left where customers do not discard food. Although the initial goal was to make the sensor-equipped trash cans blend in, addressing this challenge required marking the cans to ensure employees placed them in the proper locations. With the cooperation of cafeteria management, the sensor-equipped trash cans were marked, and the importance of placing the



(a) Electronics (b) Before Sealing (c) Sealed (d) Fully Constructed Scale

Fig. 2: Electronics Inside Trash Can

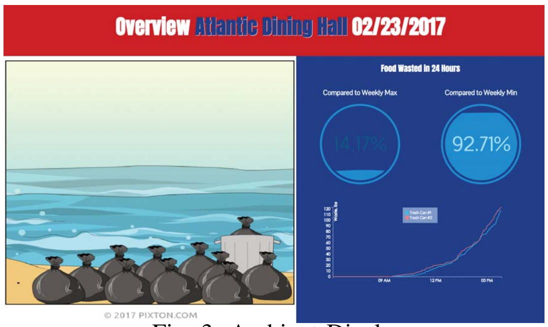


Fig. 3: Ambient Display

marked trash cans in the location for consumer waste was stressed to employees.

D. Wireless

Another set of challenges resulted from the use of WiFi. During the preliminary deployment, maintaining a constant connection to the access point from the base station was virtually impossible. The university has 3 wireless networks: one for guests, an unsecured network, and a secured network. The initial deployment relied on the popularly used unsecured network due to complications connecting to the more reliable secured network. After two weeks of near-constant failure in connecting to the Internet, a Sprint Hotspot was added to the base station setup.

E. Failures

During the deployment, complications with the underlying `HTTP-Client` library allowed scenarios where the base station application could deadlock. To guard against this, an external chron job was created. Periodically, the program running on the base station touches a dummy file. The chron job periodically pulls the last modified timestamp of the file; if it has not been modified in the last 5 minutes, it restarts the program. A similar chron job was created to maintain WiFi connectivity.

F. Communication Protocol

The dining hall proved to be susceptible to heavy packet loss due to metal serving stations, tables, office walls, and other obstructions. To mitigate packet loss, high gain antennas and an ack-based retry protocol were used.

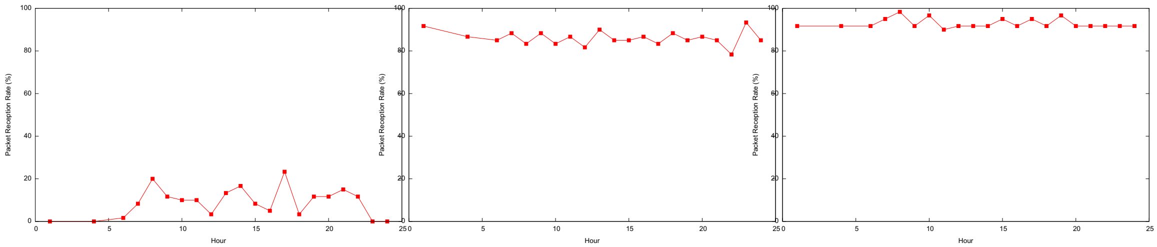
Figure 4 shows the reduction in packet loss associated with each solution attempted. Figure 4a shows the packet reception rate for preliminary data collected with the initial whip antenna. Figure 4b shows the packet reception rate for preliminary data collected with the high gain antenna. Figure 4c shows the packet reception rate for preliminary data collection with both the high gain antenna and ack-based protocol. The x-axis for each figure represents hours, and the y-axis represents the percentage of packets received. Given the sample rate of approximately one sample per minute, approximately 1,440 samples should be recorded for each trash can. With the whip antenna, fewer than 15% of packets were reaching the base station. The high gain antenna improved the reception rate to approximately 86%. The ack-based protocol, coupled with the high gain antenna, improved the rate to approximately 93%. Even with buffering and retries, packets may still be lost due to limited memory. During periods of prolonged interference, new data overwrites old data.

G. Identification of Food Waste

Another challenge lies in ensuring that the waste being quantified is in fact food waste. One reason for choosing a campus cafeteria for the initial testing is that the equipped trash cans are only used for discarding food related items. Any waste present in the trash can that is not edible is still related to the consumption of food. Observed items include napkins and straws. Both items have insignificant weight and are not likely to have a significant impact on results. Future work includes equipping the lid of the trash can with imaging sensors that could be used to classify waste items.

V. Case Study

A case study was carried out in the campus dining hall to determine the efficacy of WASTE REDUCE. Data was collected over three weeks. The first week serves as a baseline; the monitoring system was active during this week, but no feedback was provided. During the second and third weeks, the ambient display was introduced. Due to the cafeteria closing for Spring Break, there is a one week gap between Week 1 and Week 2. There were technical difficulties during the first two days after Spring Break, in which data was not collected. The monitor that allows students to view the display experienced



(a) Whip Antenna (b) High Gain Antenna (c) High Gain Antenna + Ack-Based

Fig. 4: Illustration of Packet Loss

TABLE I: Scale Accuracy (in lbs)

	Empty	Power Drill	Cell Phone
Actual	**0.000**	**3.200**	**0.284**
Trash Can #1	0.047	3.220	0.345
Trash Can #2	0.000	3.200	0.293

technical difficulties the Monday of Week 3; therefore the display was not visible until mid-afternoon for that day. The cafeteria was closed the weekend before and after Spring Break; therefore, a baseline for Saturday and Sunday could not be determined. In addition, the cafeteria has restricted hours, a different meal service, and receives significantly less traffic during the weekends. Saturday and Sunday are not included in the analysis. The campus cafeteria provided the number of meals sold each day during this time period. This information was used to normalize the data (i.e., waste per meal sold) on a daily basis.

A. Scale Accuracy

To determine the accuracy of the scale, measurements were taken for two objects of known weight, as well as when the scales were empty. Results are shown in Table I. Differences in scale accuracy are attributed to the physical construction of the scale, which may include slight variations in screw tightness, for instance. Trash Can #1 was found to be accurate within .02 lbs at best, and .061 lbs at worst. Trash Can #2 was found to be perfectly accurate at best, and within .009 lbs at worst. This is sufficient to maintain high confidence in the readings from the scale.

B. Display Setup

Figure 5 illustrates the setup of the display inside the cafeteria. The cafeteria has a single point of entry for students. The display is mounted near to where students enter, beside the pay stations. Every patronmust pass this location, and many are forced to linger in the vicinity as they wait in line to pay, providing more time to view the display.

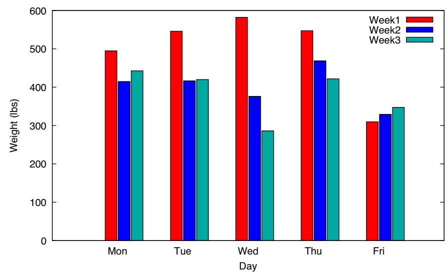
C. Results

Figure 6 shows six graphs that illustrate the average waste for each day, comparing the weeks in which the display was present with the baseline week. Figures 6a, and 6b compare the waste generated each day, organized by week. Figures 6c, 6d, 6e, and 6f compare the waste generated each day during the baseline week to the waste generated each day for one of the weeks the display was visible. In each graph, the x-axis represents the day of the week. The y-axis for Figures 6a, 6c, and 6e represents the total waste, in pounds, at the end of each day. The y-axis for Figures 6b, 6d, and 6f represents waste per meal sold, in pounds, for each day.

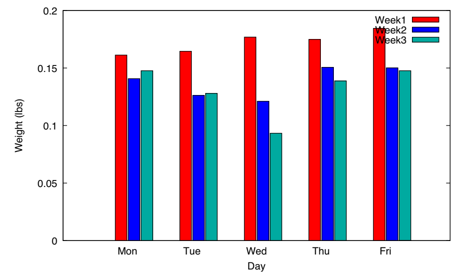
Fig. 5: Display in Cafeteria

Figures 6a, 6c, and 6e help illustrate why comparing total waste generated is not sufficient. In these figures, Friday is the only day in which the amount of waste generated did not decrease once the display was present. This is because the Friday of Week 1 was the beginning of Spring Break, and fewer people were present in the cafeteria. This led to lower food waste accumulation overall for that Friday.

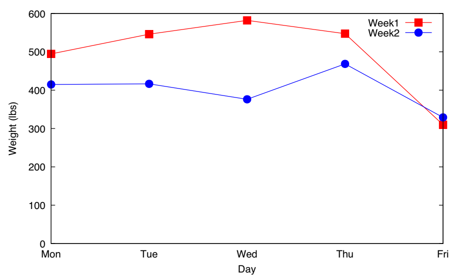
Figures 6b, 6d, and 6f show the normalized data. Once the data is normalized, it becomes apparent that there was a reduction of waste each day the display was visible. Figures 6c and 6d compare food waste during Week 2, the first week without the display, and Week 1, the baseline week. Figure 6d shows the normalized data. Before normalizing the data, an overall decrease in food waste for each day the display was present, with the exception of Friday. The normalized data again shows a decrease in waste for the entirety of Week 2. Figures 6e and 6d compare food waste during Week 3, the second week with the display, and Week 1. A slight decrease can be seen when comparing most days from Week 3, the second week the display was present, to Week 2. The increase in waste on Monday of Week 3 compared to Monday of Week



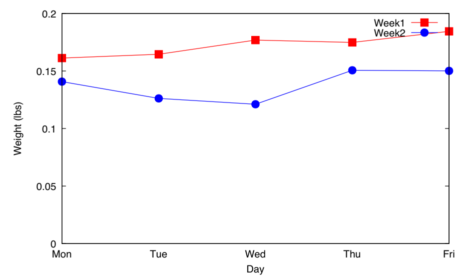
(a) lbs Wasted per Day



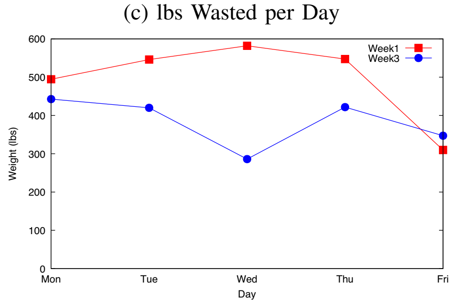
(b) Normalized (Waste per Meal)



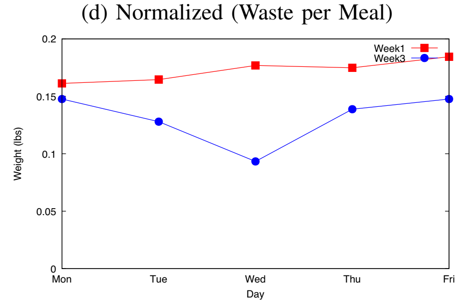
(c) lbs Wasted per Day



(d) Normalized (Waste per Meal)



(e) lbs Wasted Per Day



(f) Normalized (Waste per Meal)

Fig. 6: Comparison of Weeks

2 is likely due to the technical difficulties experienced with the monitor that day. Once again, there is a decrease in food waste for every day of Week 3 after the data is normalized. These figures show a consistent decrease in waste per meal for each day the display was present.

An interesting observation is the trend in food waste over the week. In the normalized data, it can be observed that without the display, food waste increased until Wednesday, dropped slightly on Thursday, then rose again on Friday. With the exception of Thursday, waste increased each day. During the weeks in which the display was present, the opposite effect occurred Monday through Wednesday; each day less food was wasted. Food waste increased Thursday and Friday, and once again, Friday showed the most waste per meal for the week. Currently, the motivation of this trend is unknown and it has not been proven to be statistically significant. Future work includes investigating this trend. A possible explanation could be the meals that are served.

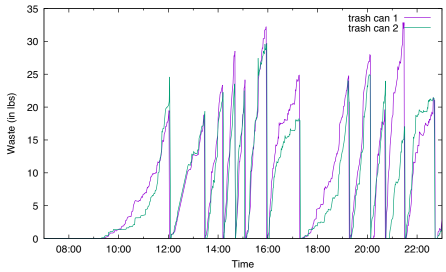
The mean over each week was .1724 lbs per meal, .1378 lbs per meal, and .1311 lbs per meal, respectively. A standard Z-Test was applied to the normalized values to determine if the decrease in waste was significant. Weeks 2 and 3 were compared to Week 1 individually. Table II shows the values used to calculate the p-values for each set. The p-value was calculated to be .035 for Week 2 compared to Week 1; the results are significant at the .05 level. For Week 3 compared to Week 1, the p-value is calculated to be .046; the results are also significant at the .05 level.

TABLE II: Significance of Display

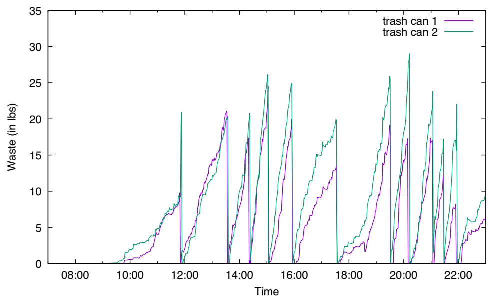
	Week 2	Week 3
Overall Mean	0.15507700	0.15172786
Sample Mean	0.13776508	0.13106232
Overall StdDev	0.02133164	0 .0272312
n	5	5
Z	-1.8151757	-1.6969344
p-value	0.0351	0.0446

D. Observations

Figure 7 depicts the general pattern of waste over a day. The x-axis represents time of day, and the y-axis represents the amount of waste, in pounds. Figure 7a illustrates the pattern for the Wednesday during Week 1, before the display



(a) Week 1 (Wednesday)



(b) Week 2 (Wednesday)

Fig. 7: Pattern of Waste

was implemented. Figure 7b illustrates the pattern for the following Wednesday during Week 2, after the display was implemented. Although the general trend remains the same, it can be observed that before the display was implemented, the trash needed to be emptied more quickly during the lunch hour. In both figures, the busiest hours of the cafeteria can be observed: lunch and dinner. The cafeteria has 4 meal periods throughout a day: (i) breakfast (07:00-10:00), (ii) lunch (10:30-14:00), (iii) limited service (14:00-16:00 and 19:00-22:00), and (iv) dinner (16:00-19:00). Given these hours, waste was expected to begin accumulating around 07:00, and to stop at 22:00; however this is not what is observed. One reason for this is the delay between when people receive food and when they discard waste. The customers who enter the cafeteria at 07:00 may not leave until 07:30 or 08:00. The delay in food waste gives the impression that the most food is wasted during the hours of limited service. However, a large portion of this waste is likely from the lunch or dinner services that precede it. Similarly, students who enter the cafeteria near closing may be allowed to stay to finish their meals. In addition, it was confirmed that a clean-up crew places waste in the trash after hours. To avoid confusing waste placed in the trash can by the clean-up crew with the post-consumer waste, only waste generated between 07:00 and 23:00 is included in the analysis.

Breakfast service generated the least amount of waste, regardless of the day or presence of the display. There are three possible explanations: (i) fewer people use the cafeteria's services during breakfast, (ii) breakfast foods weigh less (e.g. leftover scrambled eggs versus a leftover piece of chicken), or (iii) students who attend breakfast waste less.

VI. Conclusion

WASTE REDUCE provides a real-time, accurate, robust, and sustainable system to improve post-consumer food waste measurement in campus cafeterias. In addition, the display component of the system suggests behavioral change in consumers can be affected to reduce the amount of waste generated in a campus cafeteria. Through the case study, discoveries were made for possible improvement of the design, which will be implemented in the future.

VII. Acknowledgment

This work was supported by NSF awards CNS-1541917. The authors would also like to acknowledge Mr. Chancey Kelley and Mr. Nicholas Lee Yee for their work in designing the electronics enclosure, and Chartwells for their assistance and cooperation in using the Florida Atlantic University dining hall for the case study.

References

[1] Atmel Corporation. Sam4l xplained pro evaluation kit. http://www.atmel.com/tools/ATSAM4L-XPRO.aspx, 2016.

[2] AVIA Semiconductor (Xiamen) Co. LTD. Hx711: 24-bit analog-to-digital converter (adc) for weigh scales. http://www.aviaic.com/UpLoadFile/hx711_brief_en.pdf, 2016.

[3] Beagleboard.org. Beaglebone black. https://beagleboard.org/black, 2016.

[4] Andrew Dahley, Craig Wisneski, and Hiroshi Ishii. Water lamp and pinwheels: Ambient projection of digital information into architectural space. In *CHI 98 Conference Summary on Human Factors in Computing Systems*, CHI '98, pages 269–270, New York, NY, USA, 1998. ACM.

[5] Digi International Inc. Xbee-pro 900hp. https://www.digi.com/products/xbee-rf-solutions/modules/xbee-pro-900hp, 2016.

[6] FAU. Campuses & sites, 2015. http://domain.edu/campus-info.

[7] FIU. Sustainability solutions opportunity assessment report. *Waste Management Sustainability Services*, May 2011. Florida International University. http://gogreen.fiu.edu/_assets/documents/topics/Waste-Audit-Report.pdf.

[8] GT. Admissions & enrollment, 2016. http://factbook.gatech.edu/quick-facts/admissions-enrollment/.

[9] Dana Gunders. Wasted: How america is losing up to 40 percent of its food from farm to fork to landfill. *Natural Resources Defense Council Issue Paper*, August 2012. IP: 12-06-B.

[10] HT Sensor Technology Co. Limited. Tal201 parallel beam load cell. http://www.htc-sensor.com/products/87.html, 2016.

[11] Samantha Lubow, Shaina Forsman, Steganie Scott, Linnea Whitney, Isaac O'Leary, and Amy Wang. Love food, don't waste: Resident dining commons food waste report, 2015. http://dining.ucdavis.edu/documents/SP15WasteAuditReport.pdf.

[12] Inc. MongoDB. Mongodb. https://www.mongodb.com/, 2016.

[13] MSU. Msu facts, 2016. https://msu.edu/about/thisismsu/facts.html.

[14] Christopher Plaue, Todd Miller, and John Stasko. Is a picture worth a thousand words?: An evaluation of information awareness displays. In *Proceedings of Graphics Interface 2004*, GI '04, pages 117–126, School of Computer Science, University of Waterloo, Waterloo, Ontario, Canada, 2004. Canadian Human-Computer Communications Society.

[15] John Stasko, Todd Miller, Zachary Pousman, Christopher Plaue, and Osman Ullah. Personalized peripheral information awareness through information art. In *International Conference on Ubiquitous Computing*, pages 18–35. Springer, 2004.

[16] TP-Link Technologies Co. Ltd. 150mbps high gain wireless usb adapter: Tl-wn722n. http://www.tp-link.com/en/products/details/cat-11_TL-WN722N.html, 2016.

[17] UC-Davis. Waste reduction and elimination, 2015. http://dining.ucdavis.edu/sus-recycling.html.

[18] UC-Davis. UC Davis profile, March 2016. https://www.ucdavis.edu/sites/default/files/upload/files/uc-davis-student-profile.pdf.

[19] UM. Student enrollment – fall 2015, 2016. http://www.miami.edu/index.php/about_us/fast_facts/student_enrollment_--_fall_2015/.