SYDE660 - System Design Workshop

University of Waterloo

Department of System Design Engineering

Project: Ultrasonic And Gas Sensors Enhanced Smart Trash Can

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Date: June 16, 2019

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1 Introduction

1.1 Background and Motivation

Garbage disposal has always been quite a problem, especially for those who live in condos and apartments. Comparing to those who live in a house and are able to dump garbage in large trash cans in their yards, people who live in condos and apartments have no choice but put small dustbins within kitchens, bedrooms and bathrooms. Those small dustbins fill full easily, meaning that when people collect trash bags, they are very likely to dirty their hands. And as these dustbins are laid within the rooms, they smell easily too.

To fully understand, unawareness and ignorance of trashes are mainly attributed to forgetfulness of garbage disposal. No one likes garbage. People barely pay attention to the dustbins, so they cannot be alerted when the dustbin is full or smelly.

Relevant State-of-Art

Garbage disposal is rather a daily event. So unfortunately, there is no journals or papers regarding this topic. However, there are methods and several commercial products in the market.

Sticky notes is a traditional way to remind people of what to do. Simply write something on the pads and stick them to the refrigerators, they will remind people every time they open the refrigerators.

Garbage disposal alerting apps are smart phone applications with the function of alerting users to dispose garbage. For example, users can set alarm clocks at a exact time and repeat that for a certain circle.

Internet companies and housewares companies, such as Google and Xiaomi has launched a series of smart home products. Dustbin is one of them. According to different market target, these smart dustbins are equipped with different functions. The most common ones are human-approaching detection, automatic lid-open, and automatic garbage bag sealing.

Limitations of Existing Methods

Sticky notes is simple and economically saving, but unfortunately not effective. With the number of times increasing where people open the refrigerators and see the notes, people would get used to these notes and ignore them. These notes would then become meaningless and useless.

The advantage of garbage disposal alerting apps is that its alerting is more precise than sticky notes. However, for the same reason that restricts sticky notes, the inflexibility of alerting still restricts the efficiency of these garbage disposal alerting apps.

What's more, combining Smart Home system and dustbins is a positive attempt. However, the limitation of such products is the lack of alerting function. With thorough research, this project group found no existing smart dustbin that can alert users in real time.

Surveys

According to the existing method and products, as well as their shortcomings discussed above, a conclusion can be drawn that the problem of garbage disposal is not well settled. Hence, there is an urgent need in the market place of new or improved design.

To justify such need, this project group conducted a survey among 10 potential users. The interviewees includes students, young professionals and housewives who lives in apartments or condos. Figure 1 shows the results of the interviews. Almost 80 percent of the potential customers think it is necessary to improve the existing design, and the majority of the customers think it is worthwhile to try new methods even if it is more costly than that of now.

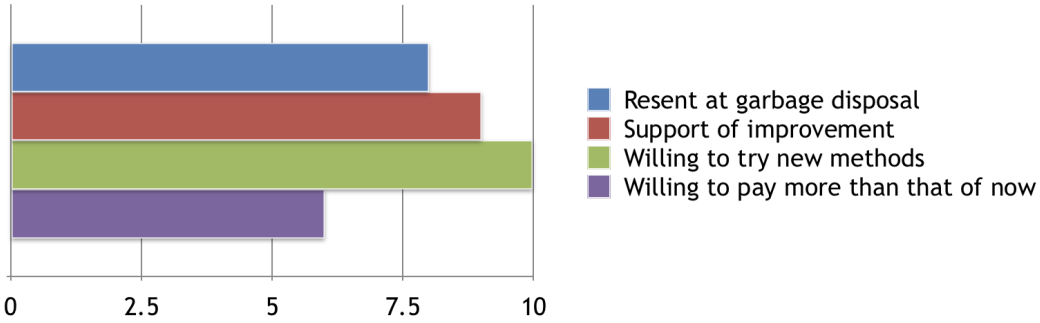


Figure 1: Interview Results of Dustbin Improvement with Potential Customers

1.2 Design Statement

The problem of dustbins clearance and garbage disposal has been bothering people. And the reason behind this is that people pay no attention to and habitually forget such matter. Since there are no effective and real-time reminding methods or products in the market, this project intended to design a smart dustbin that can detect and notify users when foul odour is produced or maximum capacity is reached.

1.3 Project Goals and Objectives

To achieve a smart trash bin with the function of monitoring the level of trash inside the bin and detecting the odor of the trash in the bin, this designed smart dust bin will send a message to customers' phone or send a notation from the app installed in peoples smart mobile when the trash is full or smelly. Meanwhile, the user can send an order to the smart dustbin to seal the trash bag.

1.4 Expected Impact

By the end of this project, this project is expected to achieve an impact of:

1) Efficient monitoring by users;
2) This leads to no more reluctant to take away trash;
3) This leads us to the gradual elimination of health and environmental issues related to open disposal of trash.

2 Requirements and Specifications

2.1 Design Requirements

Functional Requirements

The smart trash bin with the function of monitoring the level of trash inside the bin and detecting the odor of the trash in the bin. If the trash is full or smelly, our smart bin will send a message to customers' phone or send a notation from the app installed in people's smart mobile.

User Requirements

There are mainly two status while a dustbin is in use, which is static status and garbage-disposing status. The static status refers to the period when the users are throwing and the dustbin is collecting garbage. In this period, end users might expect that the dustbin is easy to clean, so it wouldn't look messy. And the dustbin should in suitable size and volume, so it can fit in the kitchen, bedroom or bathroom. What's more, long-lasting battery and sustainable product are also expected by the users, so they do not have to replace or repair it frequently, which means they can save trouble and money. On the other hand, the garbage-disposing status refers to when the trashes are above the threshold and needs to be disposed. During this period, end users might expected a fully functional notifying function, including the punctuality of notification and the convenience of checking notification. Only when this two user requirements are guaranteed can this product show its advantages and competitiveness other than existing products.

Engineering Requirements

With regard to physical properties, the material and size of the target object are important. Generally speaking sonic waves are best reflected from hard surfaces. Detection of sound absorbent materials will result in a reduction of the maximum sensing distance. The maximum sensing distance can be achieved as long as the maximum roughness of the object does not exceed 0,2 mm. Typical sound absorbing materials are: foam rubber, cotton, wool, etc. The intensity of the signal depends on the size of the object. The standard target is usually defined as a square flat object of following sizes - 15 x 15 mm for Sde up to 250 mm, 30 x 30 mm for Sde up to 1000 mm and 100 x 100 mm for Sde ¿ 1000 mm. The standard target is defined as a square, level object with an edge length of 30 mm which is perpendicular to the sensor reference axis.

Since the smart dustbin which this project intends to design contains electronic elements, the flow of energy is essential too. There should be a power supply to maintain the running of

Arduino, ultrasonic sensor, gas sensor and Twilio. Generally speaking, there are four ways to supply power for the system: via USB, via Vin pin, via 5v pin and via power pin. Since the Twilio uses USB to connect to Arduino, and there is only one USB port on Arduino, this project considers one of the pins mentioned above. Different pins requires different direct current voltage. Details are shown in Figure 2.

Considering the movable requirement of a dustbin, this project intends to use batteries as power supply. Common voltage of batteries in the market is 3.75V(18650 Battery) and 9V, and 18650 is lower in price. So this project is going to connect two 18650 batteries in series as power supply to Vin pin on Arduino.

Pin Name	Vin Pin	5v Pin	Power Pin
Suitable Voltage	7V-12V	5V	9V-12V
Dangerous Voltage	>12V		>12V
Unstable Voltage	<7V		<9V

Figure 2: Suitable Voltage for Vin pin, 5V pin and Power pin on Arduino

As dustbin it is, this product is expected to be used for a long time. Hence maintainability is essential. This project design should maximize a product's useful life, prevent unexpected working condition, maximize efficiency, reliability and safety, and be easy to fix.

Dustbins are one of the dirtiest home and kitchen products. Being easy to clean is very important for dustbins. To achieve cleanability, this project intends to build an integrated design, where there is no cleaning blind zone.

Operation should be easy, and the number of steps should be minimized. This product should be usable for everyone with basic cognitive abilities. There should be no specific background or environment to use this product. The operational steps are shown in Figure 3.

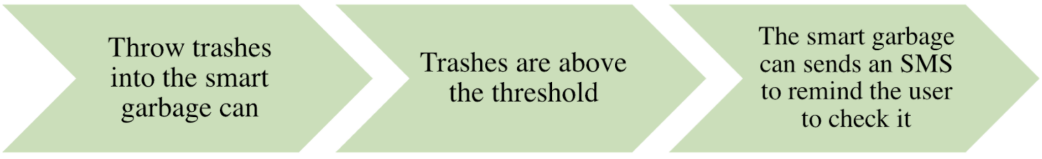


Figure 3: Suitable Voltage for Vin pin, 5V pin and Power pin on Arduino

3 Engineering Analysis

3.1 Design Analysis

Problems of packing congruent circles in different geometrical shapes in the plane were raised in the 1960s, and many results were obtained. The development of new, effective optimization algorithms for packing problems and the ever-increasing performance of computing systems have recently brought these problems into focus again; computer-aided methods can now be used to construct good large packings.

The problem of packing congruent circles inside a larger circle which, without loss of generality, is assumed to be of unit radius. Given n, we want to place n congruent circles without overlaps inside the larger circle in such a way that their common radius is as large as possible. the maximum attainable radius of the circles was denoted by r, and the corresponding placement was called an optimal packing. Instead of fixing the radius of the larger circle and searching for the maximum radius of the circles in the packing, one can equivalently search for the minimum ratio of the radius of larger circle to the radius of the circles in the packing without fixing either one.

To generate packing one algorithms is implemented, which is stochastic. It uses ordinary non-linear optimization algorithms with an approximate cost function. The computer programs have been executed repeatedly for each value of n, and the best packing found in these runs have been chosen.

The minimum pairwise distance is tried to maximized among n points spread in the unit circle centered in the origin. This minimum distance is denoted by the objective function.

$$\mathbf{d(S) = min}\ \{\ \|\ \mathbf{s}_i - s_j\| : \mathbf{1} \le i < j < n\}\ \mathbf{d(S) = min}\ \{\ \|\ \mathbf{s}_i - s_j\| : \mathbf{1} \le i < j < n\}\ \mathbf{d(S) = min}\ \{\ \|\ \mathbf{s}_i - s_j\| : \mathbf{1} \le i < j < n\}\ \mathbf{d(S)}$$

where S = [s1, s2 ..... sn] is the set of points in the unit circle. Now the packing problem can be formulated as an optimization problem

$$\mathbf{max\ d(s)} \tag{2}$$

whose global optima are the optimal packing. A packing found by one of these methods can be further improved by identifying the contacts between the circles and solving numerically the corresponding system of equations.

Optimization by repulsion forces

It can be noticed that equation (1) is not smooth, and most of the first derivatives of the function are zero almost everywhere in the feasible region. To overcome these difficulties, we approximate the original problem (2) by minimizing the objective function.

where lambda is a suitable scaling factor. This can be seen as a potential energy function when there are repulsion forces between the points. The parameter m controls the strength of the repulsion forces. The optima of (3) approximate those of (1) in the sense that as m tends to infinity, only the shortest distance between the points becomes significant. The cost function (3) is smooth everywhere except where two points coincide.

$$\sum_{1 \le i < j \le n} \left(\frac{\lambda}{\left|\left| s_i - s_j \right|\right|^2} \right)^m$$

In the beginning of each optimization stage we use a simple steepest-descent search with Goldstein-Armijo backtracking line search. When the gradient becomes small enough we switch to a modified Newton method to get a higher convergence rate.

By the optimization methods, this project chose to use four ultrasonic sensors instead of one in the prototype.

By choosing four ultrasonic sensors, the benefits are as follow: If choosing one ultrasonic sensor, the detect angel is only 15 degree, so it will need the trash bin to be very high, so that the sensor can detect all the bottom area. Using one sensor will cause the limited detect area at the threshold height, which lead to the increase of the missing area. Once the trash higher than the threshold height, but not fall into the limited detect area, the Smart Bin will not send message to user to inform them that the trash is full. However, using 4 ultrasonic sensors will decrease this to a small chance. Because as the optimization results shows that four ultrasonic sensors cover 68.64 percent of the threshold area, which will satisfy the demand of the majority users. This also help us make sure the threshold height. The equation is as below:

$$\mathbf{R=2.45r} \tag{3}$$

$$\mathbf{H = r*cotangent(15/Pi)} \tag{4}$$

Where:
R is the radius of the bottom of the smart trash bin;
r is the radius of the detect area on the threshold section;
H is the height of threshold.

3.2 Final Detailed Design

In order to achieve the function of detecting and alerting when the dustbin is full or smelly, this project decided to use 3 ultrasonic sensors 1 gas sensor to detect distance and odour. The components used in this project is listed in figure 4.

The pin connection of hardware components are shown in figure 5. And the work flow of this project is demonstrated in figure 6. The circuits, including Arduino Ethernet, ultrasonic sensors and the gas sensor is attached below the dustbin lid. Ultrasonic and gas sensors keeps working,

Number of unit circles	Enclosing circle radius	Density	Optimality	Diagram
1	1	1.0000	Trivially optimal.	
2	2	0.5000	Trivially optimal.	
3	$1+\frac{2}{\sqrt{3}}\approx 2.154...$	0.6466...	Trivially optimal.	
4	$1+\sqrt{2}\approx 2.414...$	0.6864...	Trivially optimal.	
5	$1+\sqrt{2\left(1+\frac{1}{\sqrt{5}}\right)}\approx 2.701...$	0.6854...	Trivially optimal.	
6	3	0.6666...	Trivially optimal.	

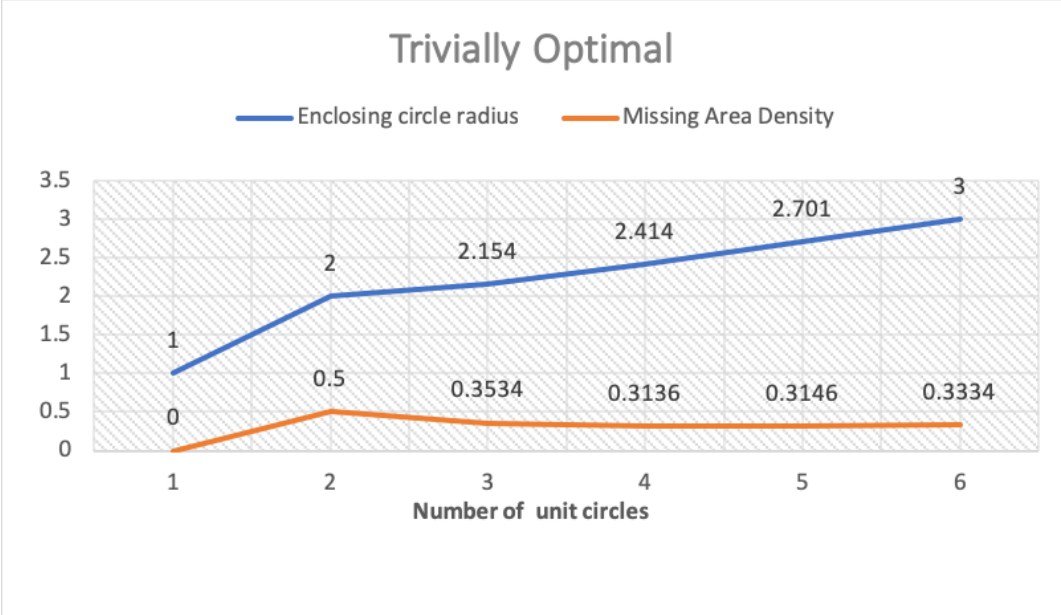
sending back some values that represent distance and gas density to Arduino Ethernet. When the values reach the pre-setting threshold, the code module for sending Gmails is triggered. And then emails are sent through cloud communicator Twillio to uses as notifications.

4 Design Progression

4.1 Technical Challenges and Solutions

Threshold Determination

The first challenge is to determine the threshold for gas sensor's sending back values. The sending back values for gas sensor is from 0 to hundreds. When the gas sensor is put in the open air, the value is around 50. When the surrounding gas environment changes, the values increase. This group did a experiment to determine the threshold that would indicate when the gas inside dustbin is smelly. The experimental results is shown in figure 6. According to which, this project



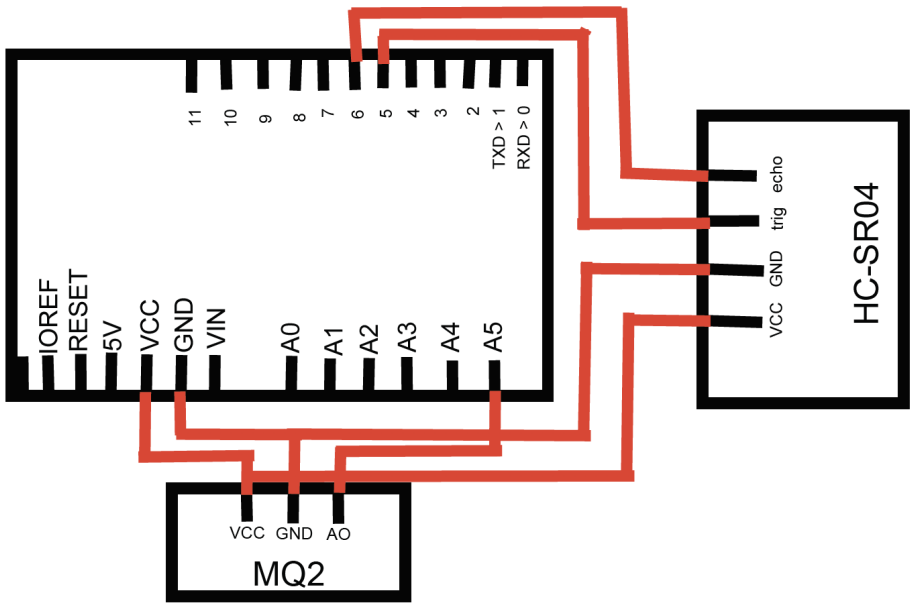


Figure 4: Bill of Components

set the threshold to 120.

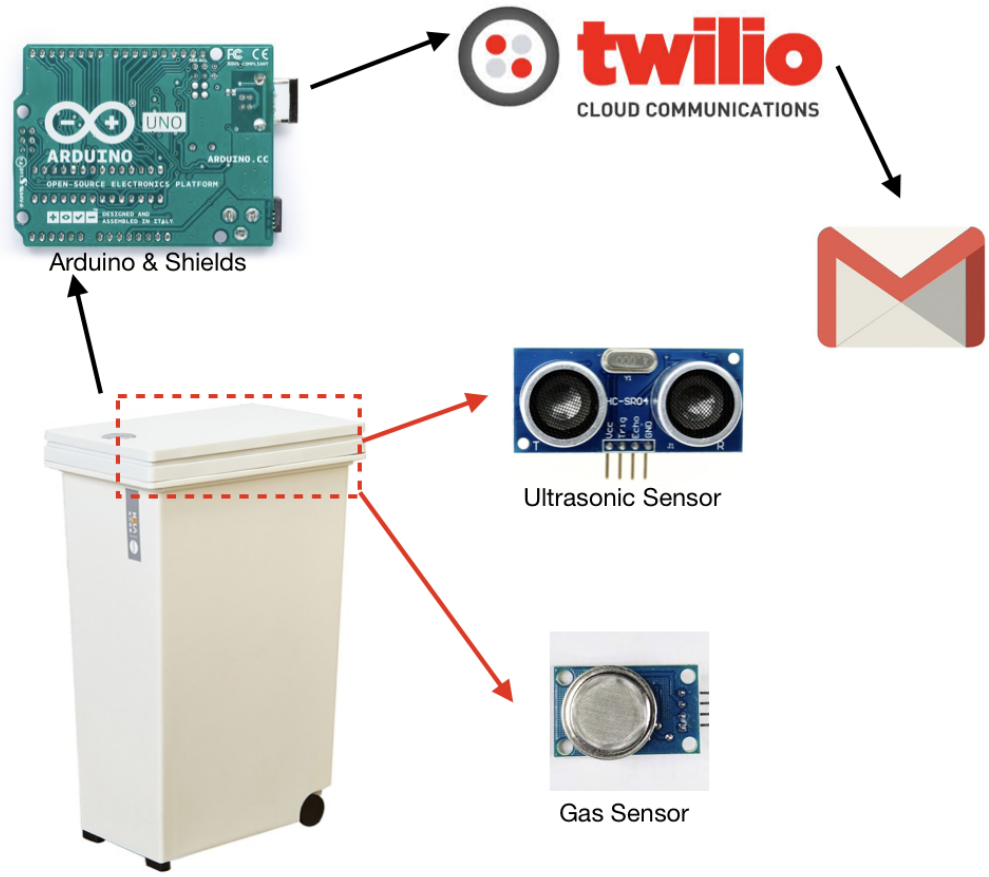


Figure 5: Circuit Graph

Avoid of Mis-Notification

Initially, this project would send notification to users when 1 out of 3 ultrasonic sensors detects the distance from dustbin lid to garbage is less than a threshold distance, 8cm. However, the group members later realized that there is a chance of mis-alert when a very long and thin trash is thrown into the dustbin, but the rest of the room is empty. This situation would lead to one of the three ultrasonic sensors to show that the distance is close. But actually, this dustbin is no full.

To eliminate such mis-notifications, this project decided to set the alerting principles to that 2 out of 3 ultrasonic sensors is sending distance values less than 8cm. In this case, the probability of mis-alert decrease a lot. The changed ultrasonic sensors sketch is shown in figure 7.

Solution for Hardware Crash Down

While assembling the electric circuits and dustbin lid, the circuits crashed down, sending back wrong signals or no signals. And Arduino Ethernet began to heat and spark. In order to locate

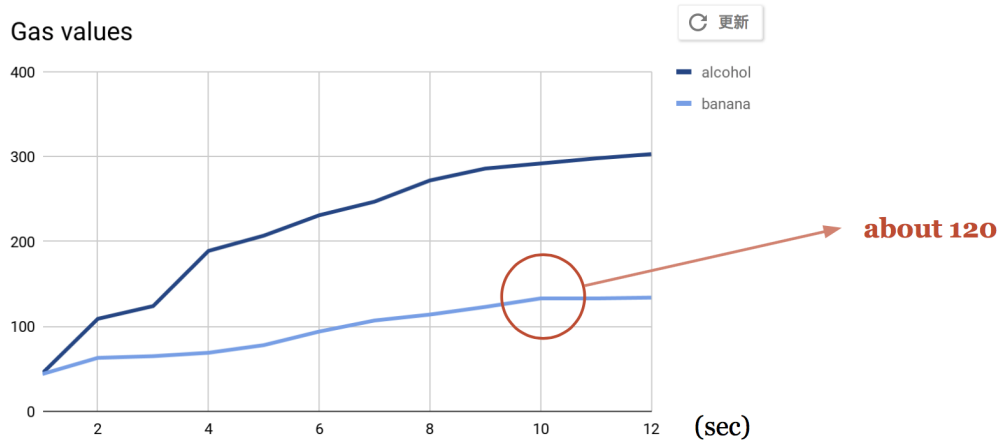


Figure 6: Changes of Gas Sensor's Sending-Back Values

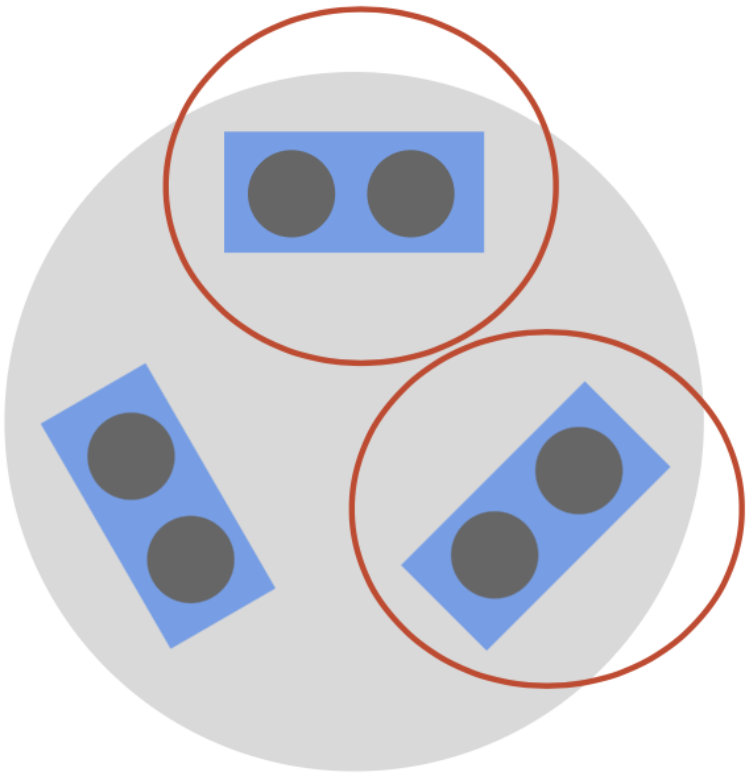


Figure 7: Ultrasonic Sensors Sketch to Avoid Mis-Notification

the problem, this group detached the electronic components and dustbin lid, and then tested the circuits again. Circuits ran smoothly this time. So this group figured it might be an isolation problem between the circuits and the lid. Therefore, a cardboard is added in between. Problem solved. Pictures of the assembling before and after the improvement is shown in figure 8.

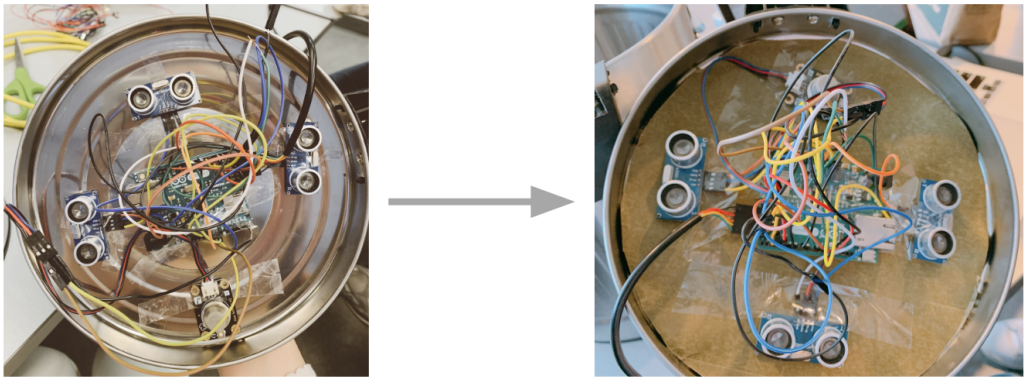


Figure 8: Problem and Solution for Hardware Crash Down

4.2 Design Prototype

Due to the restriction of time and outlay, this project use Arduino Ethernet instead of Arduino Shield for Internet Connection, meaning that this product cannot use Wifi, but use a wire to connect to computers.

Final design prototype is shown in figure 9. The whole system is built with a home-using sized trash can. The electronic components are assembled below the trash can lid. Arduino Ethernet is located in the center of the lid. Three ultrasonic sensors are located around Arduino Ethernet with a measured distance, so that the covered detecting area is maximized, while the ultrasonic sensors will not be affected by the walls of the trash can. Gas sensor is located around Arduino Ethernet as well to monitor odour. This prototype is powered and connected to Computer by the black wire, 6-serial pin to usb wire.

5 Design Testing and Evaluation

The smart bin designed in this project meets the scope of design project, which is to design a smart trash bin to fulfill the trash level monitor and odor detect bin to improve the live standard of users. This smart bin design allows users to efficient monitor the trash; leads to no more reluctant to take away trash and leads us to the gradual elimination of health and environmental issues related to open disposal of trash.

The test process needs to confirm the smart trash bin works well with the function of monitoring the level of trash inside the bin and detecting the odor of the trash in the bin. If the trash is full or smelly, our smart bin will send an email to customers' email address.

5.1 IoT Receiving Function

The first thing this design need to assure that the IoT platform receive the data send from the board. The first try without install into the lid of the trash bin works well. However, after all the board and sensors are fixed on the lid, the IoT platform cannot receive the data send from the

Figure 9: Design Prototype

board. After the discussion, the problem is solved, as the lid is made by metal, when it contacts with the board and sensors directly, the board and sensors short. Once the board and sensors detached from each other, all of them function well again. Learn from this, the carbon board was

added between the lid and the board and sensors.

5.2 Testing the level of trash inside the bin

Then if the sonicate sensors can test the trash level correctly has been tested. The firs-time testing, the lid put on to the top of the bin, the IoT platform receive the data send from the board constantly informed that the bin is full, however, it should be empty. Then the problem was solved by bounding all the wires together. Because the wires influent the detection of testing.

5.3 Odor of the trash inside the bin testing

If the odor sensor can detect the bad smell, is it too sensitive, whether or not we need to tune the threshold parameters? These are the things will be solved. After putting into one cup of the 70 percent alcohol, the IoT platform receive the data send from the board informed the value is around 150, the baseline is around 35. This shows the odor sensor is very sensitive to alcohol. Consider the organic trash will not produce those much high concentration of alcohol air, the threshold of this sensor will be lower than this value. The sanitationer solution contains 70 percent alcohol gives the similar results. Then the peel of banana been used as an organic trash. The fresh peel of banana gives us the value approximate of 50, yet the next day, it raised to 60, and then the third day, it increased to 80. Based on these results, the value 80 has been chosen as a threshold value.

5.4 If the user can receive the email from the IoT platform when the trash bin if full?

At this step, it works well with the sensors. Once the values of ultrasonic sensors or odor sensor pass the thresholds, the users will receive an email informing them the bad smell or the trash bin is full.

Circle packing in a circle is a two-dimensional packing problem with the objective of packing unit circles into the smallest possible larger circle.

5.5 Code Testing

This project wrote unit testing code to test and guarantee that there is no bug in the arduino programming. The modules and functions that have been tested in the code are listed in figure 10, along with their expected results and actual results. All the actual results are identical with the expected results, showing that the programming runs safely and reliably.

Tested Situation	Input	Actual Output	Expect Output
Gas Signal is below the threshold	Gas signal = 0, 50, 100, 120	None	None
Gas Signal is beyond the threshold	Gas signal = 150, 180, 200, 500	“Smell Alert”	“Smell Alert”
Ultrasonic Signal is beyond the threshold	Ultrasonic signal = 10cm, 20cm, 50cm	None	None
Ultrasonic Signal is below the threshold	Ultrasonic signal = 3cm, 5cm, 7cm	“Distance Alert”	“Distance Alert”
Gas sensor is broke	Gas signal = None	“Gas sensor is broke”	“Gas sensor is broke”
Ultrasonic sensor is broke	Ultrasonic signal = None	“Ultrasonic sensor is broke”	“Ultrasonic sensor is broke”

Figure 10: Modules and Functions Tested in Code Testing

6 Recommendations

6.1 Smart dustbin App

First of all, we consider designing a smart dustbin App would be a great future direction. The functions of the App might include keeping tracking the level of the garbage so that users are able to know the situation of the dustbin without checking by themselves regularly. Furthermore, we would like to add more gas sensors on the dustbin in order to notify the users what kind of garbage gas is over the threshold that might affect users’ health. Users can also setup the time they want to be notified, and every family members can track the dustbin through the app. After the app sends the notification of fullness, any of the family member can deal with the garbage and it’ll show on the app. Therefore, even though some of the family members are busy for their work, they do not have to worry about the garbage anymore. This function is able to make the family have a stronger bond. We aslo realized that most people don’t realize they are out of trash bags until they are out. The app might alert you when supply is low and one button reordering delivers trash bags to your door step for the same price as the grocery store.

6.2 Hands Free Lid

We found touchless feature important for people’s health. The cans lid is automatically opened by an infrared motion detector. This facilitates health in a home because one does not get into contact with the garbage in the can. It is also useful because it allows for both hands to be free in the process. Compare with the step-on trash can, the hands free lid can be opened by simply motioning your hands across the top to open the stainless lid which is more convenient and usually guaranteed to have better quality. As long as your hand or object is within the

sensing area of the trash can, the sensor garbage can will automatically open.when your hand or object leave,it will automatically close lid,It does not need to touch at all,and reduce contact with bacteria, and avoid cross-contamination with bacteria to enjoy a healthier life.

6.3 Built in Charging and Filter

A small flip of a secondary lid gives you access to the built-in charging and filtration area. Rechargeable lithium battery (included) and USB charging cable (included). The dustbin can be charged with a rechargeable lithium battery for 4-8 hours, can be used for 2-6 months (20 times per day), and the user don't need to spend extra money to buy battery. It normally work when the users are charging the trash can, they can use the touchless garbage can anytime and everywhere. The built in charging could be more environment-friendly and easier for users to track the battery level.

6.4 Trash bag storage pod

No fuss, no muss of trash in the trash can because someone forgot to replace the trash bag. If trash bags are stored right where the users want them, when the users need them. The bags will fit perfectly and can be stored within hands reach. The storage pod will give users a more convenient experience.

7 Conclusion

The proposed project successfully demonstrates its capability of real time monitoring of the dustbin level. Our project provides accurate measurements as soon as possible. Compared to other systems, ours is cheap, non-intrusive, free of calibration or labeling, and can detect the garbage smells effectively. It can also detect the fullness of special lightweight garbage such as empty cans and bottles. Moreover, it will avoid to notify user when it is only partially full. Here the sensors are going to sense the gases and keep tracking the level of the garbage and send the notification to the cloud and an Gmail will be sent to the user. The alert email will save the time spent by the user in manually tracking the dustbin regularly.

Regarding to the garbage gas, if the level of Methane gas crosses 500ppm, it may cause severe effect on the environment and to the people around. Also, if Carbon dioxide gas crosses 1000ppm and Carbon monoxide crosses 70ppm it cause severe head ache for the people around. The system works fine in the range 120 to 1000ppm within the dustbin. We've tried different food from fresh fruit to rotten fruit and alcohol as well. The gas sensor responded perfectly which gives user the prompt notification of the horrible garbage gas. We can easily dispose the waste present in the garbage bins as early as possible when compared to the previous methods without it affecting to the people and keep the surroundings clean.

We also conducted a complete user test. We came up with a thoroughly test plan, Recruit people at different age and with different jobs. The testing results show that eight out of nine users are satisfied with our system.

8 Project Management

The optimization of ultrasonic sensors' quantity is particularly well-done and it is a significant step for this project. It indicated the quantity of ultrasonic sensors that should be used in this project, and assisted to raise the accuracy of 'Dustbin is Full' notification. Besides, the observation of gas sensors' back-sending value is a well done significant step. Such observation reveals how the gas sensor works. And it helped this group to set the threshold for odour detection. Without this observation's assistance, it would be very difficult to achieve precise notification of 'Dustbin is smelly'.

During this project, challenges keep showing up, but the group members managed to locate the problems promptly and tried to find solutions actively. For example, when this group was programming, the group members anticipated that a threshold was needed to make the Gmail notification work. This group arranged an experiment to test what value the gas sensor would generate with different types of consumer wastes. This group divided the preparation up and conducted the experiment together. The experiment was a success. And the results were used in the threshold setting, which works perfectly in this project.

During this project, every group member were assigned with one main aspect of this design, namely programming, hardware and mathematical optimization. Group members demonstrated different technical skills in the specialized fields including coding and programming, debugging, selecting and electronic components, assembling electronic circuits, mathematical analyzing and calculating. Meanwhile, this project shows the ability of experiment, technical writing, literature searching and reading, and project management. What's more, this group has reached out to lecture instructor, Prof. Jonathan Kofman, and the E7 Project Shop of University of Waterloo for instructions and opinions.

Group members maintained highly connected and informed during this project. Group members reported individual progress every week, and met additionally if there was problems and challenges to handle together.

For the next step of this project, the group members should keep the cooperated and communicated project management as this group has done in the former stage. Besides, this group could enhance the time management as the improved project management.

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