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The Eco-Smart Can V2.0

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The Eco-Smart Can V2.0

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by

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ABSTRACT

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On a summer day in 2015, a maintenance worker was observed emptying a trash bin. Upon closer observation, it was noted that the bin was not full. There were other bins that were full and needed to be emptied urgently. It was confusing and problematic to see that bins that needed more attention were not prioritized. Unfortunately, this leads to overflowing trash bins in busy areas. Additionally, it may lead to a mismanagement of resources. The time, labor and other resources invested in collecting the trash could be handled better. Therefore, to tackle this issue, the author decided to use the Internet of Things (IoT) to develop a prototype that will optimize trash collection and reduce costs of waste management and pollution; this device is named the Eco-Smart Can. The long-term goal of the author is to turn the prototype into a commercial product.

DEDICATION

I dedicate this thesis to my mother and father, for their endless assistance and support during my academic life. I also dedicate it to the rest of my family and to the ETSU Maintenance Staff that works hard every day to keep our campus clean and beautiful.

ACKNOWLEDGEMENTS

I would like to thank God, my family and my friends, for supporting me during this process. They helped me in many aspects. They suggested some interesting ideas that sometimes helped me overcome some difficulties.

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ABBREVIATIONS/ACRONYMS

GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
IDE	Integrated Development Environment
IoT	Internet of Things
ISSU	In-Service Software Upgrade
LED	Light Emitting Diode
LTE	Long-Term Evolution
mA	milliamp
mAh	milliamp Hour
MQTT	MQ Telemetry Transport
OTA	Over-the-Air programming
PCB	Printed Circuit Board
PLA	Polylactic Acid
POC	Proof of Concept
TOF	Time-of-Flight Diffraction
UI	User Interface
ULP	Ultra-Low Power
USB	Universal Serial Bus

1. INTRODUCTION

With an increase in the population of East Tennessee State University's (ETSU) community and the creation of a new football stadium, the cleanliness of the campus needs to be maintained and improved. The benefits of maintaining a clean campus include the possible prevention of a few diseases caused by the sustenance of an unclean environment — for instance, diseases caused by mold. Traditionally, ETSU maintenance operates on daily or biweekly routes to pick up trash and recycle bins on a designated time, regardless of whether the containers are full or not (Figure 1.1 shows a schematic diagram as an example of such un-optimized system).

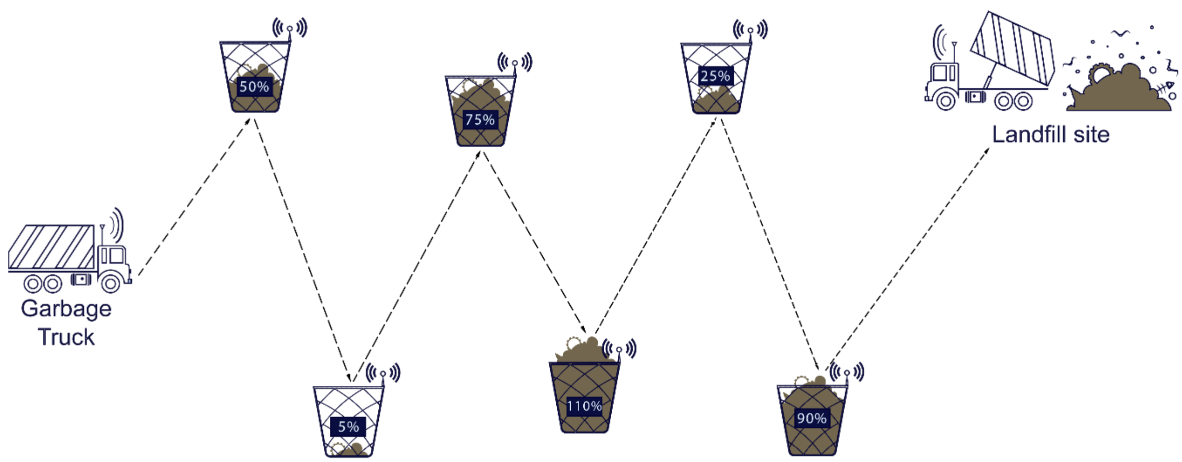


Figure 1.1, Un-Optimized System Route

Time, labor and other resources combined in collecting the trash could be saved if the ETSU maintenance knew which trash bins needed to be emptied urgently. Therefore, it has been decided that the Internet of Things (IoT) would be used to create a device that will optimize trash collection (Figure 1.2), to reduce waste management costs and pollution.

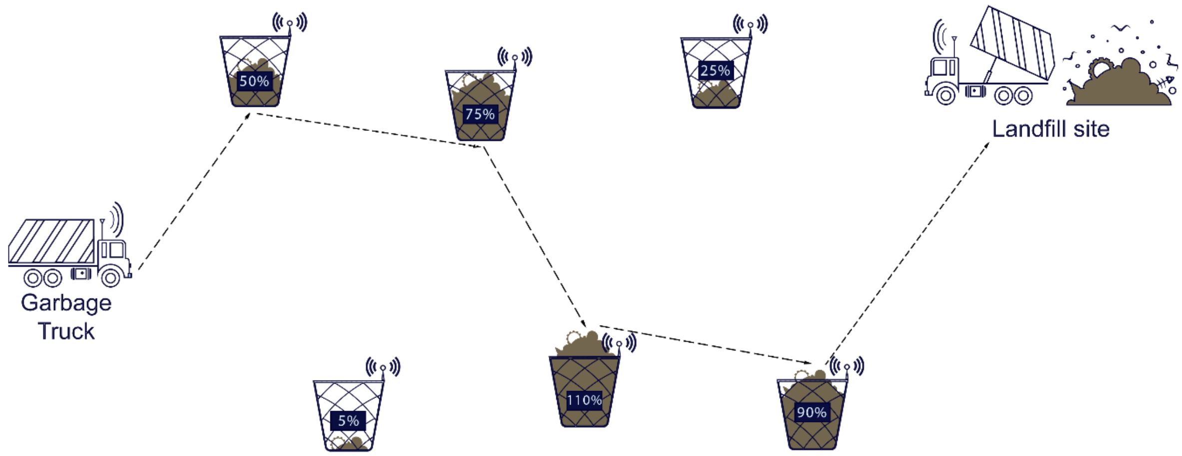


Figure 1.2, Optimized system

The purpose of this project is to develop a cost-effective smart trash can device for ETSU. This device can also be used in areas other than ETSU. This thesis presents a literature review of related research in the domain in addition to an overview of current commercial solutions. The methodology section explains how the system operates in concordance with all the hardware and software used in this project. Following this section, a discussion of the results of the system tests is provided. A marketing assessment of the Eco-Smart Can is also discussed. Finally, conclusions and anticipated future scopes and impact of the Eco-Smart Can are discussed. Although this project was started to fulfill thesis requirements, the long-term goal is to turn the product into a commercial good. Bankers and venture capitalists will be approached for funding to take this project to the next step.

2. LITERATURE REVIEW

The world population is growing, and so is the trash production; an average American throws his or her body weight in trash every month (World Bank, 2013). The World Bank reported a rise of trash daily production to more than 3.5 million tons in 2010 and predicts an increase to 6 million tons per day by year 2025 (World Bank, 2013). As trash increases, the funds required for trash disposal are also increasing. In the World Bank waste management 2012 report there is a direct relationship between the increase of the trash and the increase in disposal costs. It is reported that the world trash collection expenditure will increase by 83% in year 2025, it is predicted to a sharp increase from $205 billion in 2010 to $375 billion by 2025 (Hoornweg & Bhada-Tata, 2012), see table 2.1. It is predicted that Low Income Countries will suffer more from the waste increase. The waste disposal for Low Income Countries will cost 5 times more in 2025; meanwhile High-Income Countries such as the USA will have an estimated increase of $60 billion.

Table 2.1, Estimated solid waste management costs (Hoornweg & Thomas, 2012)

Country Income Group	2010 Cost[6]	2025 Cost
Low Income Countries[7]	$1.5 billion	$7.7 billion
Lower Middle Income Countries[8]	$20.1 billion	$84.1 billion
Upper Middle Income Countries[9]	$24.5 billion	$63.5 billion
High Income Countries[10]	$159.3 billion	$220.2 billion
Total Global Cost (US$)	**$205.4 billion**	**$375 billion**

The results shown above are alarming and hold serious penalties for public services, government budgets, and the landfills spaces used for disposal. Some parts of the world are already affected; the Bordo Poniente and Laogang landfills in Mexico City and Shanghai respectively receive over 10,000 tons of waste daily (Hoornweg & Thomas, 2012). With over 2,000 worldwide functional waste incinerators, the world is threatened with concerns about ash disposal and air pollution (Goto, 2013). Uncollected waste and landfills also affect climate changes through the production of methane, a potent greenhouse gas (Goto, 2013).

Luckily, these distressing statistics and predications have led various concerned governments and city officials to scope for different solutions to put a stop to the increase of pollution caused by garbage production and reduced funds allocated to trash disposal. For instance, many cities in the United States like Boston, New York, Pasadena, Baltimore, San Francisco, and Santa Clarita are taking positive initiative to combat the fast-growing trash production with the IoT (Shueh, 2016).

The Internet of Things, also called the Internet of Everything or the Industrial Internet is the concept of connecting any device or man-made object to the internet. It contains embedded technology that senses or interacts with their internal or external environment and transfers this data over the internet. When set up correctly, IoT has the power to communicate with other IoT devices to analyze data and make decisions. The IoT is considered as one of the pioneer future technologies and is gaining important attention from industries. Gartner (2014) forecasts that the Internet of Things will attain 26 billion installed units by year 2020, compared to 0.9 billion units in 2009, and will impact extensive sectors such as medical, industrial robotics, transportation, agricultural and waste management.

With the growth and extreme usability of IoT, the USA has made IoT a part of its national waste management trend in many cities to balance the increased waste management costs through efficiency (Shueh, 2016). Baltimore, Boston, New York, Pasadena, and Atlanta, to name a few, have already installed smart trash systems powered by IoT for their smaller sidewalk trashcans.

As reported, trash production is increasing, and yet, we still use inefficient trash collection systems that increase operational costs. Many smart waste management companies came up with smart can systems using IoT. These have shown to improve and reduce costs of waste management.

3. METHODOLOGY

The IoT is the concept of connecting any device or man-made object to the internet. It provides the ability to transfer data over the internet. The project highlighted in this thesis, "The Eco-Smart Can V2.0", aims at using the same concept of the IoT and connecting a built device using an open-source computer and software to send data from a traditional trash container to the maintenance facility office. The objective of this project is to create a device that will shoot sonar waves to know the level of the trash in a container. It can also measure temperatures inside the container, because elevated temperatures can cause bacteria or germs to reproduce faster. Data collected from the sensors will be sent over the Internet (through Wi-Fi) or a cellular network General Packet Radio Service (GPRS) for analysis and displayed on Ubidots – a cloud web platform which will display collected data. The platform will be set up to alert maintenance workers that trash needs to be collected, so that they can plan an effective route, emptying the fullest trash bins first. The location coordinates of these trash bins are predefined in the code, instead of using a GPS antenna to get the location. Figure 3.1 shows the basic operation of the embedded system.

A market research was conducted to understand the current waste management system used by East Tennessee State University and surrounding businesses. Surveys were administered to local maintenance workers and other respondents. The results show that the majority of the maintenance workers wish they had a method to know the trash level before setting out to empty bins. The workers expressed their need for a device that will enable them to know the trash level and subsequently, optimize their routes to empty the bins that need the most attention first. Section one of chapter 5 outlines the full report of the market research and validation to support the need of the Eco-Smart Can device.

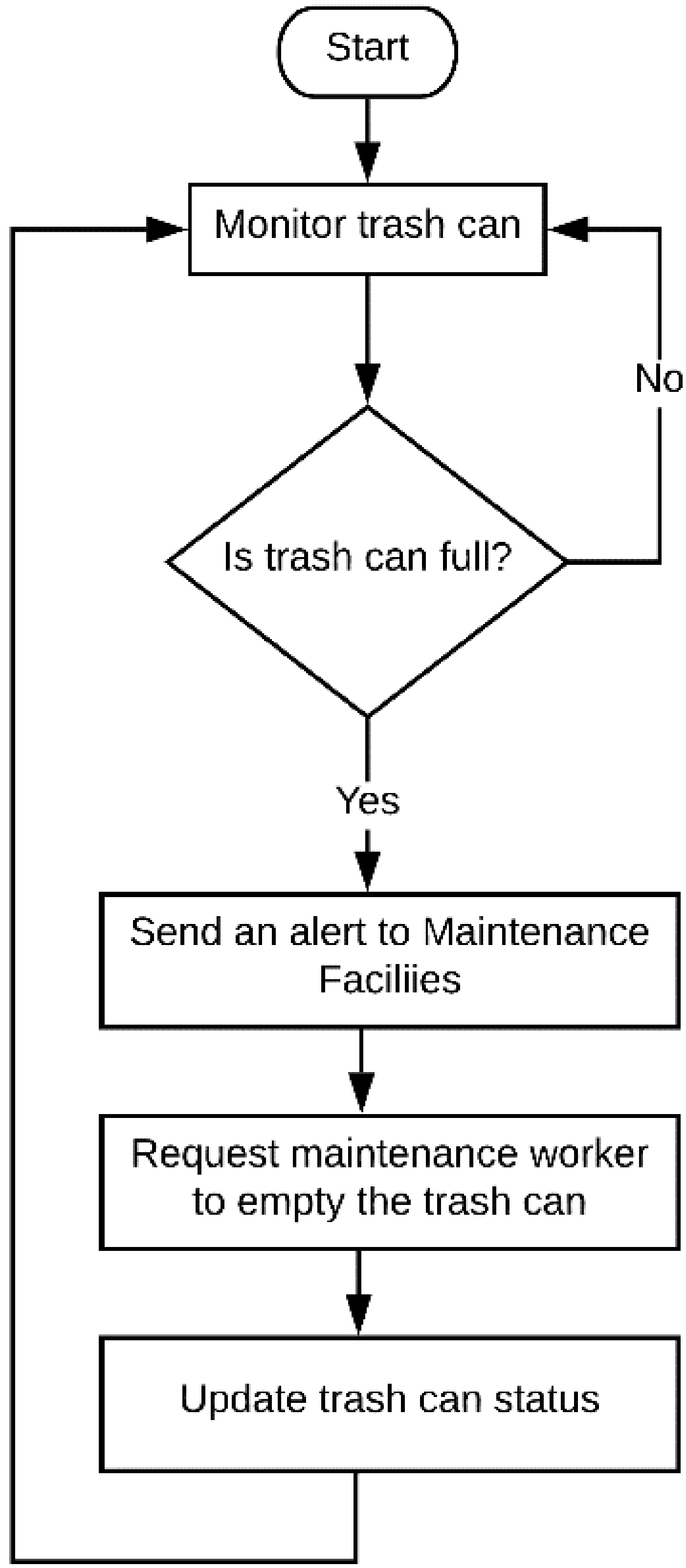


Figure 3.1, Basic process of the system

Until the trash is emptied by a maintenance worker, the system will keep outputting a sound plus a blinking red light to notify that the trash bin is still full. Once the trash is emptied, the system reinitializes and continues its operation. The data sent on the online platform is stored on the cloud service for future data analysis. A block diagram of the full system is shown in Figure 3.2.

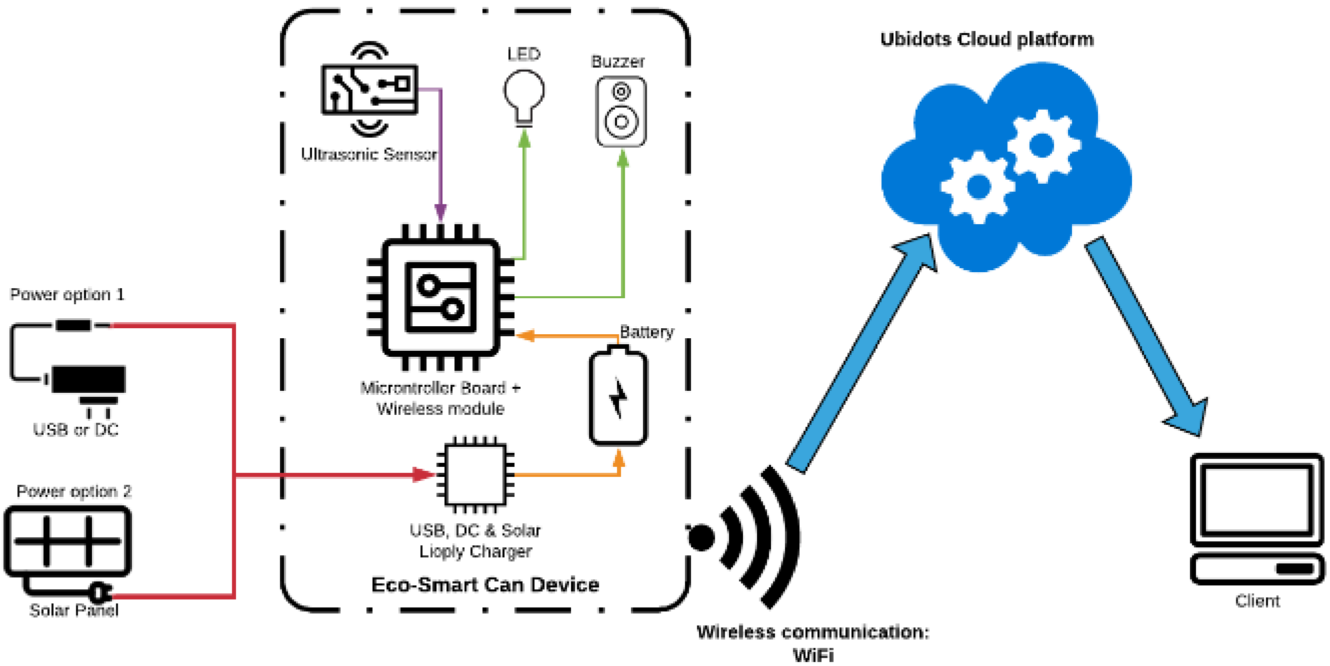


Figure 3.2, System block diagram

3.1 Design

The Eco-Smart Can design tries to be cost effective and versatile. During the design phase, the aim was to make the device mount on different trash containers. Figure 3.3 shows the container that will house all the hardware. The box is measuring 200mm by 150mm.

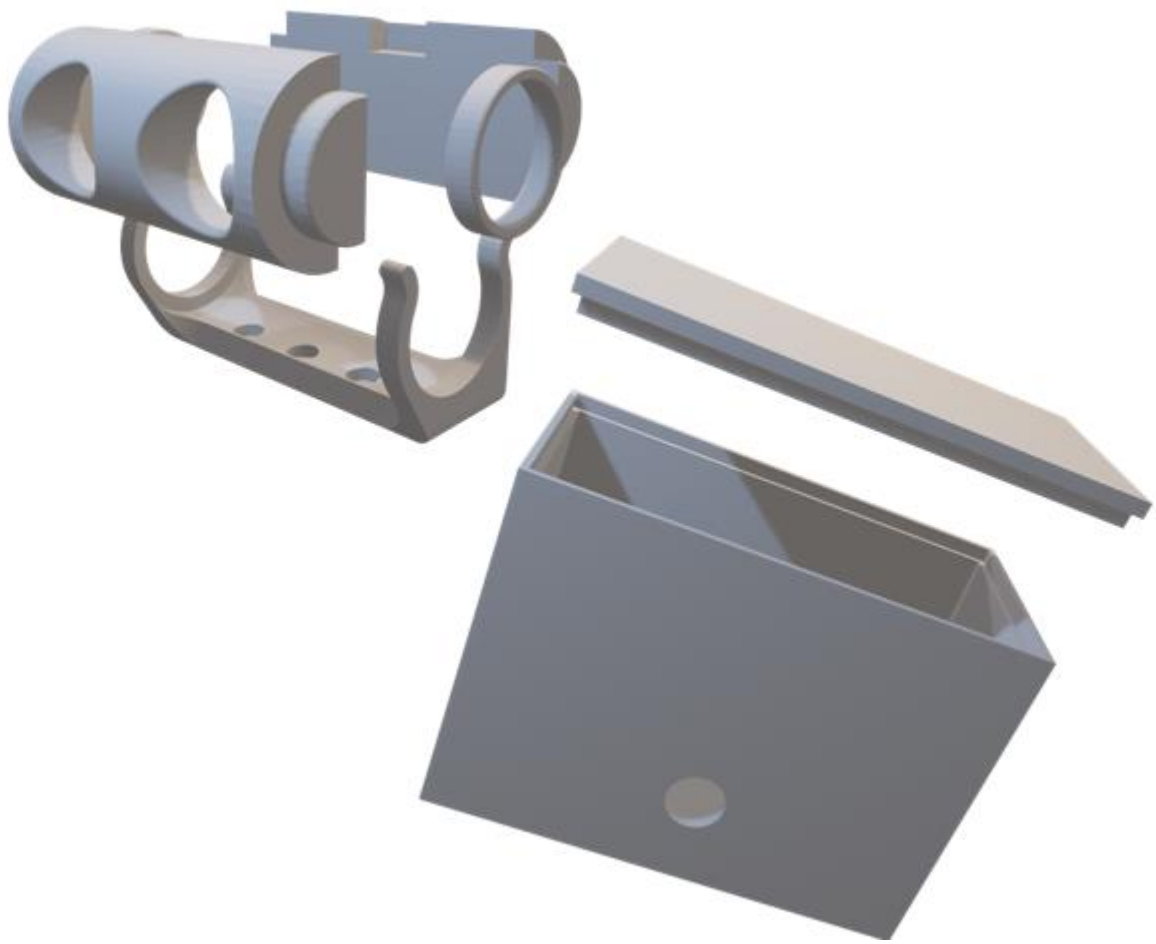


Figure 3.3, Eco-Smart Can box

The design of the trash can was primarily modelled to fit common trash containers found on ETSU's campus. The design of the box took in consideration a future expansion with a solar panel module for outdoor usage. The box uses strong magnets for mounting and can also be mounted using some adhesive. To allow a compact design and complex shape, the box is drafted with 3D software (Auto-CAD 360) and 3D printed with Simplify3D slicer. Figure 3.4 shows a sample of the box assembly with the components. The box in the figure shows a normal PVC box adapted for testing the quality of wireless antenna reception.

Figure 3.4, Box design

3.2 Hardware

This section lists and describes the components used to prototype the Eco-smart Can.

Table 3.1 describes the hardware requirements for the Eco-Smart Can basic system.

Table 3.1, Hardware

Hardware	Description
Espressif ESP32-WROOM-32	The ESP32 is a wireless module used mainly for prototyping. **Main Features:** Tensilica Xtensa 32-bit LX6 microprocessor, dual core, Clock frequency up to 240 MHz, performance up to 600 DMIPS, Ultra-low power co-processor: allows you to do ADC conversions, computation, and level thresholds while in deep sleep. Wi-Fi: 802.11 b/g/n/e/i (802.11n @ 2.4 GHz up to 150 Mbit/s) Bluetooth: v4.2 BR/EDR and Bluetooth Low Energy (BLE). IEEE 802.11 standard security features all supported, including WFA, WPA/WPA2 and WAPI, Secure boot, Flash encryption. Peripheral input/output: Rich peripheral interface with DMA that includes capacitive touch, ADCs (analog-to-digital converter), DACs (digital-to-analog converter), I^2C (Inter-Integrated Circuit), UART (universal asynchronous receiver/transmitter), CAN 2.0 (Controller Area Network), SPI (Serial Peripheral Interface), I^2S (Integrated Inter-IC Sound), RMII (Reduced Media-Independent Interface), PWM (pulse width modulation), supports deep sleep mode etc. (Espressif Systems, 2019). See Appendix A.
HC-SR04 Ultrasonic Sensor	The HC-SR04 sensor uses sonar to determine distance of an object. It offers excellent range accuracy and stable readings. **Features:** Working Voltage: +5V DC, working current 10mA, working frequency: 40KHz, Range: 2cm – 4m, Measuring Angle: 30°, Ranging Distance: 2cm – 500 cm/1" to 13ft, Resolution: 0.3 cm. See Appendix B.
USB, DC & Solar Lipoly charger module	This module created by Adafruit allow the device for system load sharing and Li-Ion / Li-Polymer battery charge management with ac-dc wall adapter and USB port power sources selection. This module contains an MCP73871 chip which facilitate the load sharing system. See Appendix C.
Lithium Ion Polymer Battery	A 3.7 V2000 mAh battery to enable the system to work without using a power outlet. See Appendix D.
CEM-1203 magnetic buzzer	Magnetic buzzer is an audio signaling device. The sound is produced by the movement of the ferromagnetic disk like the cones in a speaker creates sound. **Features:** Sound pressure: 85 dB, working voltage: 3.5, operating temperature: -20 °C to +60 °C. See Appendix E.

Breadboard	This board with holes helps to connect all the different components of the system. It is suitable for this project because of the constant change of the circuitry. But a PCB will be used for a final product.
LED light	The light used to blink to signal a certain event in the system.
Jumpers Wires	Wires cable from DuPont to connect different components of a circuit. Male to Female, Female to Female and Male to Male terminals.
Wi-Fi	It is a wireless network that allows device to communicate or exchange data over a network. In the project the author tested the prototype with an Enterprise Encryption type network.

The Eco-Smart Can system relies on a microcontroller module with integrated Wi-Fi – ESP32 made by Espressif. This microcontroller is a 2.4 GHz band Wi-Fi and 4.2 Bluetooth combo chip design with Ultra Low Power (ULP) technology and Long-range Wi-Fi. ESP32 was designed especially for IoT, wearable and mobile application. It has robust and versatile features, making it suitable for a wide variety of applications. With a dual-core processor running at 160 MHz and internal memory of 4MB, it can support up to 20 components. All these features come on a small PCB of 48.2 × 27.9 mm and weigh 9 grams (Espressif Systems, 2019), see Figure 3.5.

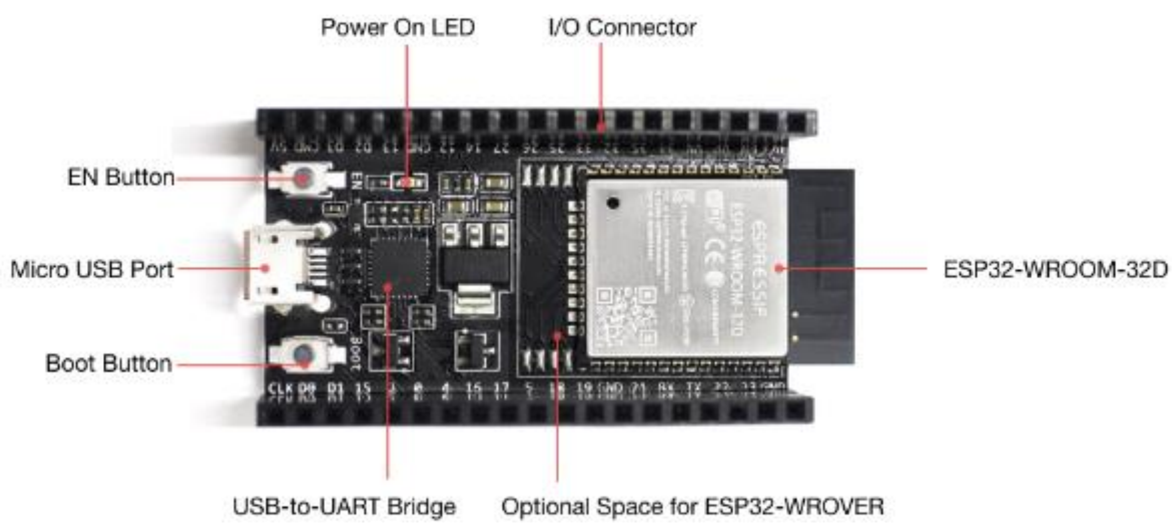


Figure 3.5, ESP32 Development Board (Espressif Systems, 2019)

The ESP32 development board was chosen for the Eco-Smart Can device because of its high-performance cores, Ultra Low Power co-processor, Long-range Wi-Fi, highly integrated platform to meet the continuous demands for efficient power usage, and its reliability (see Appendix A). Most importantly, this microcontroller is one of the few on the IoT market that allows a connection to an Enterprise security type wireless network. It is important in this project because using the available internet connection on campus to send the data is desired. Doing so brings some costs down, because this is cheaper than using cellular networks. However, the Eco-Smart Can device is still designed with adaptability to connect to cellular network in areas with no Wi-Fi access. The EPS32 can connect to access points that are 200 meters (656 ft) away. Additionally, the ESP32 can operate within –40°C to +125°C, making it suitable for outdoor usage.

Figures 3.6 and 3.7 show the schematic of the circuit board and how the hardware in table 3.1 are connected. The ultrasonic sensor (HC-SR04) is used to detect the trash level of the container. This sensor, despite its simplicity, can detect liquid and solid objects. The sensor's embedded chip was engineered to decrease the effects of outdoor interference sources. The circuit comprises a battery that can be re-charged through a USB port.

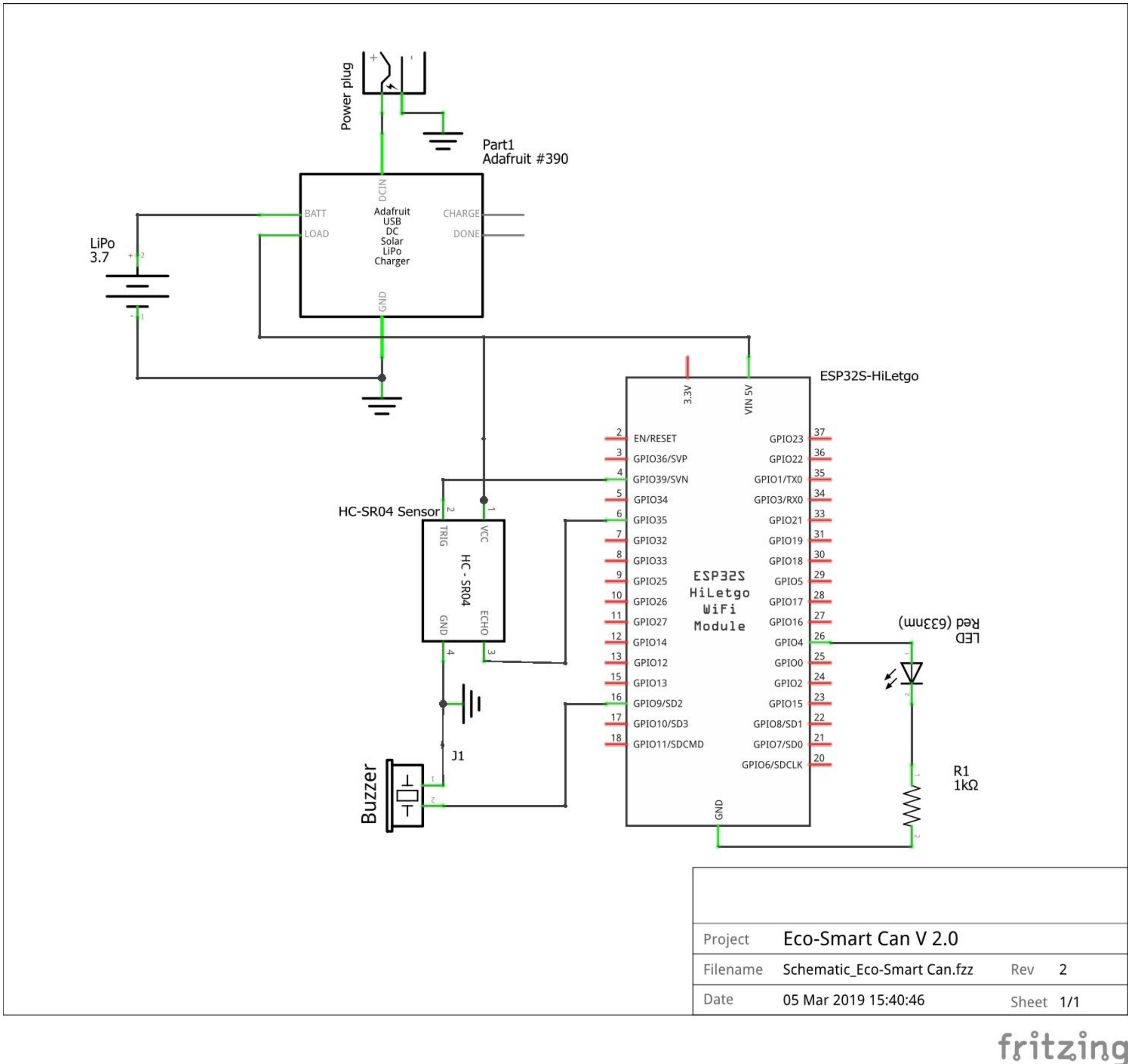


Figure 3.6, Circuit board schematic

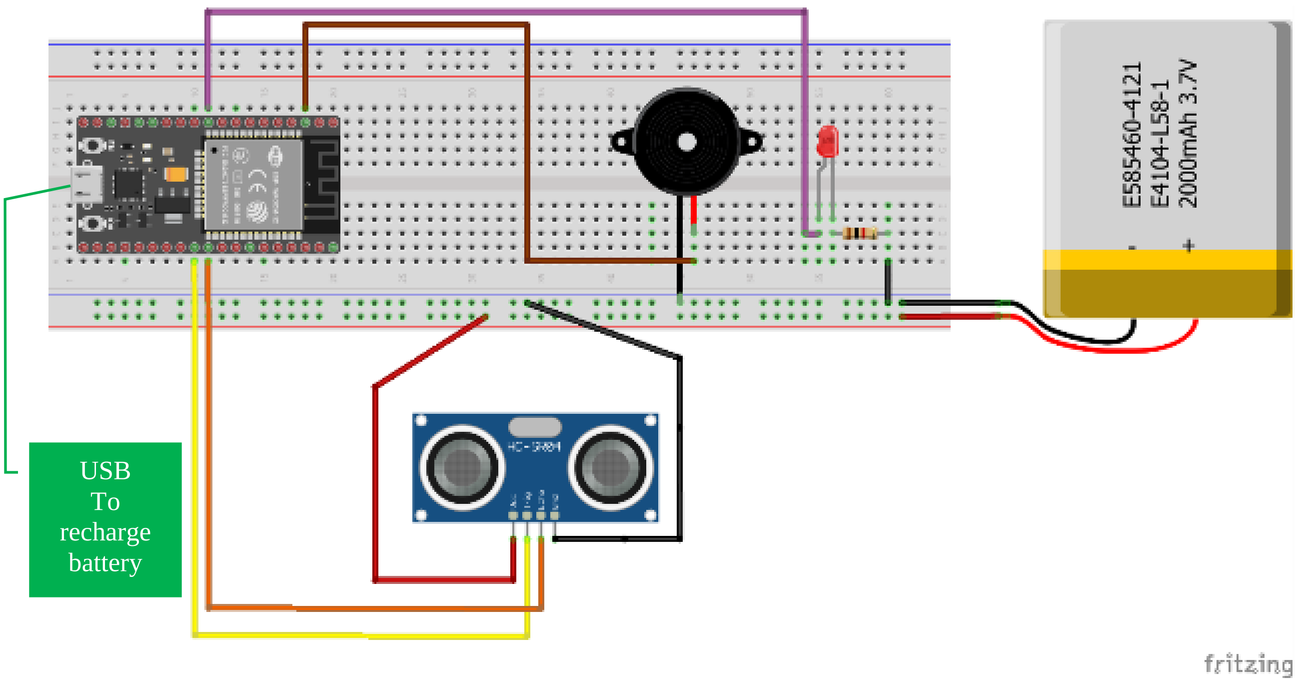


Figure 3.7, Circuit bread

The Ultrasonic sensor (HC-SR04), shoots a sonar wave that travels from the sensor to the object and back to the sensor when the wave touches an object. This is called the Time-of-Flight (TOF). Distance of the object or trash is then calculated using the below formula (Charlesworth & Temple, 2001).

$$Distance = \frac{TOF \times Speed\ of\ Sound}{2}$$

The system uses the ESP32 module to send the data collected by the ultrasonic sensor to a web platform dashboard. The ESP32 module connects to the local Wi-Fi of the campus using a dedicated username and password. An LED light with a 1kΩ resistor is used to give a visual alert of the trash bin's fullness. The LED light signals users that the container is filled up, therefore preventing other potential users from putting more trash in the bin. Additionally, a magnetic buzzer is used to output a sound alert when the trash is filled up. Finally, the whole circuit is powered by a Polymer Li-ion battery with an integrated mini circuit that does not allow over charge and limits overheating. This mini circuit enables the device battery to be charged through solar energy or USB. The system battery is backed up by mini USB charging port in this project, which can be an alternative for indoor usage when solar charge is not an option. Figure 3.8 shows the final hardware setup.

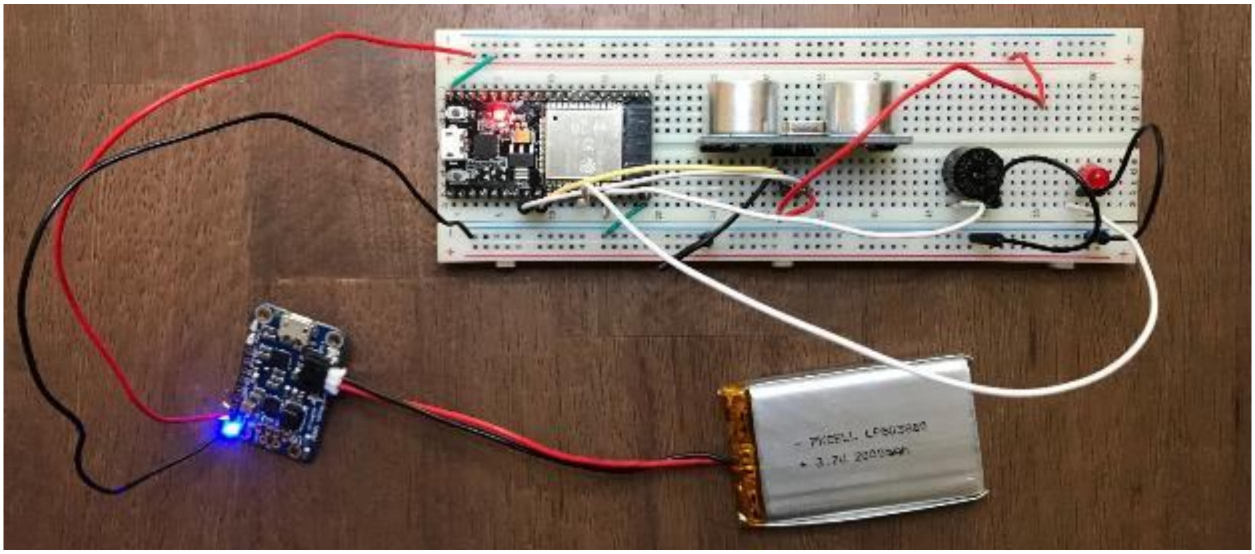


Figure 3.8, Hardware setup

3.3 Software

Table 3.2 describes the hardware requirements for the Eco-Smart Can basic system.

Table 3.2, Software

Hardware	**Description**
Arduino IDE	Arduino IDE is a software that allows the user to write and upload programs to board or microcontroller.
Ubidots	Ubidots is web platform that allows the collection and storing of sensor data in the cloud from IoT devices.

The system software was enacted using Arduino IDE. Multiple libraries were used to facilitate a harmonious communication between the different components. Figure 3.9 shows a flowchart of the program written for the basic Eco-Smart Can system.

When the Eco-Smart Can is powered, the program starts initializing all the modules in the system. Then, the Wi-Fi module attempts to connect to a predefined wireless network with the correct credentials. The current prototype is regulated to connect to ETSU's Wi-Fi network. Credentials can be modified to suit other customers' network types. If the connection between the Eco-Smart Can device and the Ubidots platform is not successful, it will continue to reconnect until the connection becomes successful. The communication between the device and the web platform uses MQTT protocol. The MQTT is a lightweight messaging protocol designed by IBM and Eurotech in 1999. It was designed for constrained devices and low bandwidth networks (MQTT, n.d.). This communication protocol is ideal for the project due to its low power consumption, reliability and assurance of delivering the data to the web platform or application. When the connection is successful, the device uses the embedded ultrasonic sensor to read the trash content. The trash level is computed based on the capacity of each trash container. The level data is sent to the Ubidots cloud platform. This allows the client to monitor trash level in real time. A loop function is used to check the trash level every 30 minutes. This time can be customized to adapt with real life operating cases. A loop function iterates when the trash level is less than 90% full. The loop runs until the trash level reaches the set threshold of 90%. When the trash level reaches 90% or more, a while loop is activated. A combination of blinking LED and buzzer are emitted by the Eco-Smart Can device. This gives a visual and sound notification signal to users in case they want to put more items in the trash bin. This can also help custodians or maintenance staff to easily identify the trash bin needing attention. An alert system (SMS, Email, etc.) is sent to the dispatcher, requesting that a staff member gets sent to collect trash. The trash alert stops when the trash is emptied, and the Eco-Smart Can device resumes its normal operations.

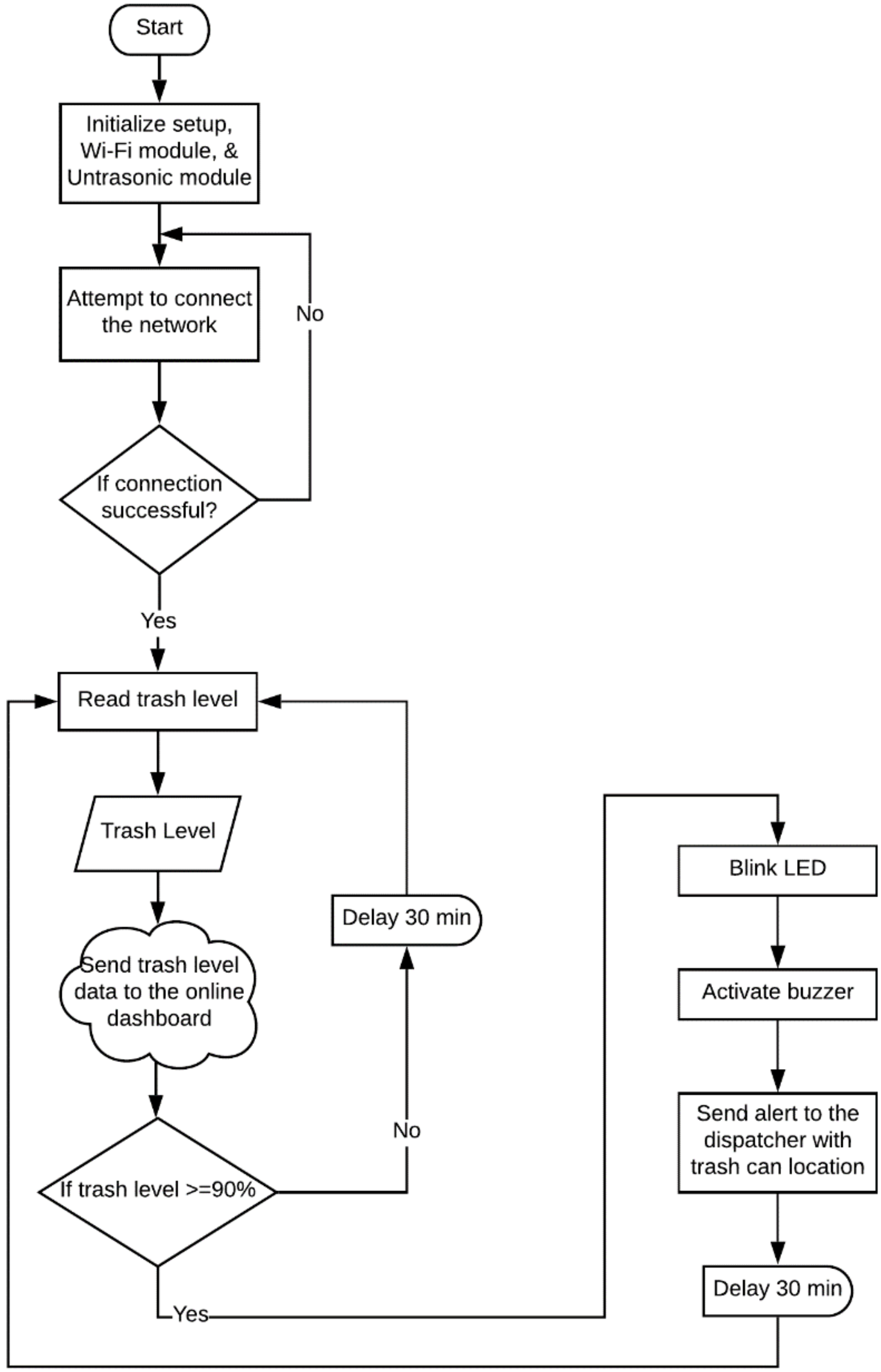


Figure 3.9, Program flow chart

4. RESULTS AND DISCUSSION

The Eco-Smart Can prototype was first tested indoors without a trash can. It was then tested in a trash container. Below is the final prototype of the Eco-Smart Can assembled and mounted in a standard trash bin found on the author's campus.

Figure 4.1, Eco-Smart Can prototype and testing

The prototype worked as intended. The trash level was successfully reporting to the online dashboard as shown in figure 4.2. The dashboard was set to show a gauge to see the trash level and a graph to display the graph filling chart. The dashboard can be customized further to suit customers' need. When the trash level was higher or equal to 90% an email was sent to report the fill level, see Figure 4.3. The alert template can be customized further, and the alert can be sent via SMS, phone call, telegraph etc., see Figure 4.3 for a sample of email alert.

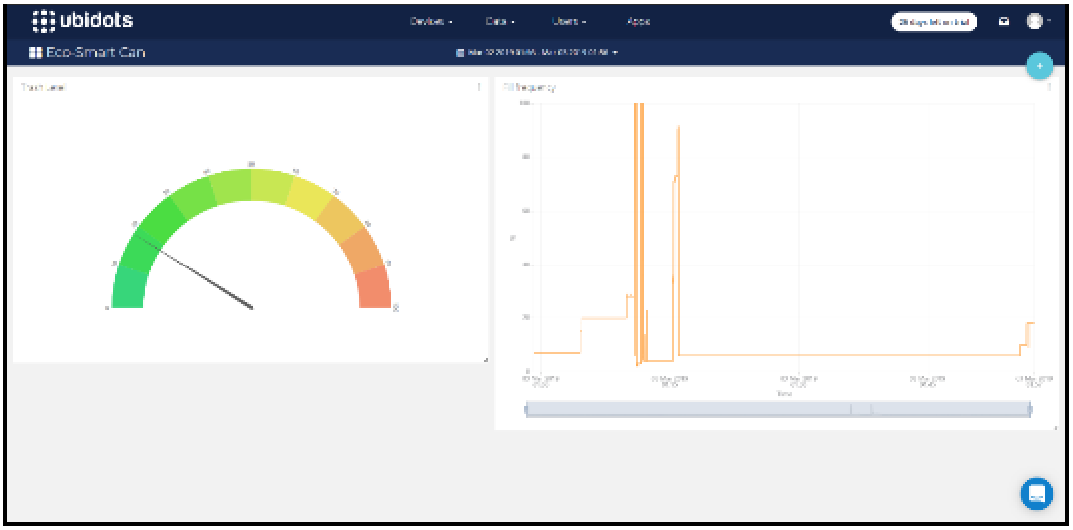


Figure 4.2, The Eco-Smart Can Dashboard

At first, the trash level was not accurately reported. However, it was due to the placement of the device in the trash container, which was solved by offsetting the measurement in the codes. After that, the trash level measurement were accurate. During the testing, it was noted that the angle at which the device is mounted affects the reading. Therefore, the placement of the device is highly significant; if placed at a poor angle it will results in many false readings.

According to the datasheet of the HC-SR04 ultrasonic sensor, the best reading angle is 30° (Appendix B). Solutions to reduce the number of errors and false reads include creating a shield around the sensor and reducing the frequency at which pulses are sent.

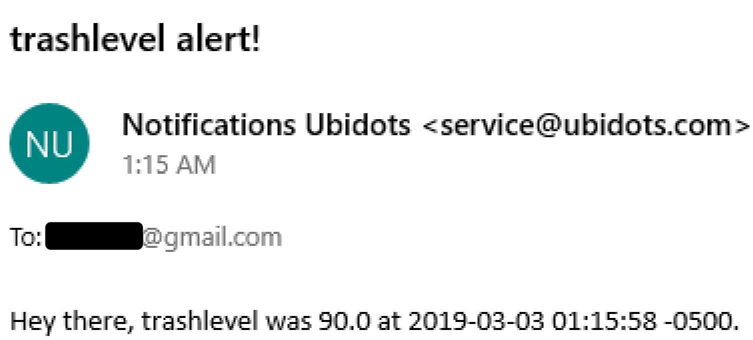


Figure 4.3, Alert sample

During the test of the prototype, it was discovered that the magnetic buzzer had a higher current consumption – 35mA. This contributed to the fast discharging of the battery when buzzing. An alternative with lower current consumption will be to use a piezo buzzer. The buzzer can be temporarily removed from the system to optimize battery life.

When all the components (ESP32, HC-SR04, magnetic buzzer and LED) are active, the system consumed an approximate total of 170mA. During the testing period a fully charged 2000mAh battery was able to last 23hrs with an interval reading of 60 minutes, which gives a total of 23 readings. The battery was prolonged by making some adjustments in the code to send the microcontroller board in Deep-sleep mode. A Deep-sleep mode is when the board disables all the modules on the board except the processor needed to operate the system. During the Deep-sleep mode, required processors can wake up to perform the necessary task and go back to Deep-sleep mode. The ESP32 offers a great Deep-sleep mode. According to the manufacturer datasheet, the board will consume as low as 0.01 mA when in idle period (Espressif Systems, 2019). After enabling the Deep-sleep mode, the ESP32 microcontroller was not able to attain the 0.01mA stated by the manufacturer. But the consumption of the microcontroller drastically decreased from 120mA to 20 mA, which is a significant improvement. With further research, the reason of not attaining the Deep-mode metric of the manufacturer was due to the usage of the first ESP32 release board. Thus, the design of the board was not optimized for power consumption. The following board that was released had some updates and successfully enabled users to reach the manufacturer metrics (See Appendix A for revision history).

Table 4.1, System power consumption

Mode / Components	***Normal mode (mA)***	***Power saving mode (mA)***
ESP32 module	120	20
HC-SR 04	15	15
LED	0.023	-
Buzzer	35	-
Total	**170.023**	**35**
System running time: (with a 2000 mAh battery)	**11 hours**	**57 hours**

Table 4.1 shows a breakdown of the power consumption of the different components in the system. The above table was generated with setting the system to continuously read the trash level until the battery got low. When the system was running with all the components, it drew a total ~ 170 mA, which took up to 11 hours to discharge a fully charged battery. The power saving mode was achieved by enabling the microcontroller (ESP32) in ULP mode with a line of code in the software (See appendix A for manufacturer specification). To reduce the power consumption further, the Buzzer and the LED were disconnected from the circuit. This resulted in a ~ 35 mA draw from the battery, which makes a fully charged battery run for 57 hours, or approximately 2.5 days. These tests were done with continuous readings, making the system run without a break. In a real-life scenario, the system will be set to run at an interval of time, enabling the battery to run longer before recharging.

In terms of cost, most components used for this project were at a reasonable price. The monthly payment for the online platform was found satisfactory for giving access to 10 devices and 10 million data points sent per month. Table 4.2 shows the total cost of the system without labor hours. The buzzer and LED were considered as extra features, and therefore were not accounted in the device price calculation. Overall, the Eco-Smart Can device will cost approximately $100. The cost for the device can be further decreased when mass produced.

Table 4.2, Components prices list

Component	Cost
ESP32 Microcontroller	**$20**
HC-SR04 Ultrasonic sensor	**$2**
Lithium Ion Battery 3.7v 2000mAh	**$13**
USB / DC / Solar Lithium Ion/Polymer charger	**$18**
3D printed enclosure - PLA	**$5**
Online cloud platform – Ubidots	**$20 / month for 10 devices**
Other part and soldering	**$20**
Total	**$98**

The results provided in this research show that a smart trash management system can be successfully managed and that normal trash cans can be turned into smart trash cans with minimum cost. Furthermore, an online user-friendly application was designed to enable clients to have access to different functions or the activities display of the device. Figures 4.4 & 4.5 showcase the Eco-Smart Can end user dashboard login pages.

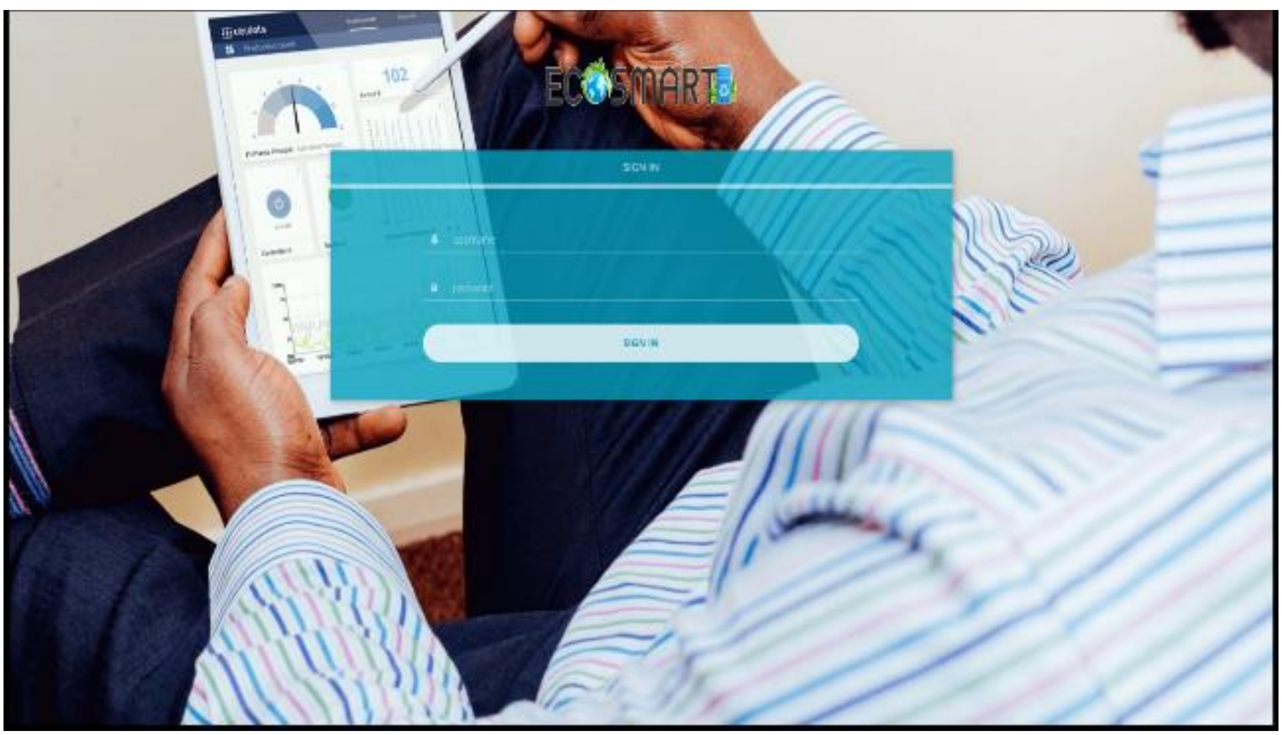


Figure 4.4, Desktop and tablet output

Figure 4.5, Eco-Smart Can Mobile app

Table 4.3, Advantages and Disadvantages

Advantages	Disadvantages
Low cost	Short Battery life
Low operating cost	Requires a monthly subscription for the online platform
Different powering option	Wi-Fi only version
Retrofit design	
User friendly dashboard and support end-user	
Dedicated app and responsive UI	
Compact and ruggedized design	

Overall, the current Eco-Smart Can device V2.0 is a successful prototype. However, it does have some disadvantages. A few advantages and disadvantages of the prototype are listed in Table 4.3. The paragraph below discusses possible solutions to improve these issues.

One of the crucial issues of the prototype was the power source. This problem can be resolved by plugging the device into an outlet when indoors. When outdoors, the trash bin can make use of a solar panel to keep the system powered. With the solar panel, the author has identified that a solar panel of 6V with 3.5 watts will work best with the circuit. The 6 V panel can output 530 mA when it receives maximum light. Appendices C shows the recommended voltaic system suitable for the system. This voltaic system will be able to charge the 2000 mAh to a capacity of 90% within 3hrs. Figure 4.1 illustrates a charging chart of different stages a lithium ion battery goes through until fully charged. Full charge is reached when the current drops to certain level, or precisely, when the current decreases between 3 and 5 percent of Ah rating of the lithium ion, as seen in stage 3 of Figure 4.1 (Battery University, 2018).

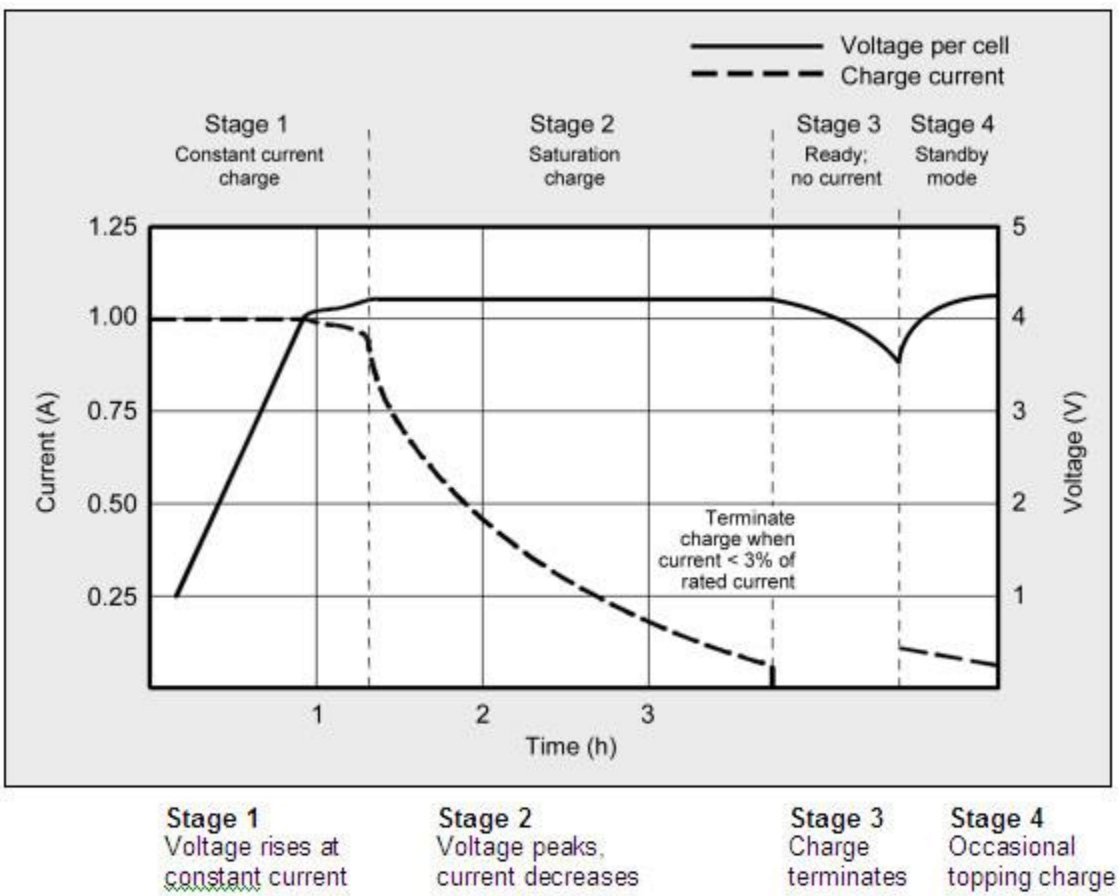


Figure 4.6, Charge state of lithium ion (Battery University, 2018)

The solar system can help trash bins that are isolated and get little attention to continue to operate with low human interventions. A battery with more storage capacity can be placed in the system to allow the system to be powered for a longer period in case of consecutive cloudy days. Decreasing the frequency at which the trash level is read can save power. Setting the device in sleep mode will allow the system to only wake up to perform its duty and go back to sleep mode after the operation is completed. This will prolong the usage of power when the system is inactive.

5. MARKETING

To validate customers' needs and tackle the problem efficiently, a partnership was formed with Professor Sonu Mirchandani, who taught the Marketing class (MKTG 3200) of Fall 2018. Potential customers such as janitors/custodians, administrators, and dump truck drivers were interviewed.

5.1 Market research and validation

Table 5.1, Feedback obtained

What size of trash can do you have on your embedded base?

- Standard size
- Recycle bins
- Dumpster bin

What problems do you have in your existing trash can collection model?

- Unknown when the trash can gets filled
- Labor costs
- Spend gas and resources
- Waste of plastic
- Can't predict volume collection

How do you hope the Eco-Smart device will make your life better?

- It will minimize labor cost
- It will automate dispatch
- Reduce amount of plastic bags
- Reduce amount of volume collection
- It will generate some savings

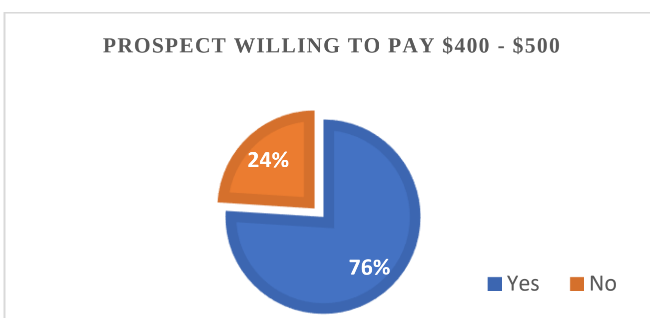
What type of support would you need?

- Device installation support or guide
- Troubleshooting documention
- Support team and after sale service
- Training on device and user interface
- Abilities to create report and track custom metrics

What feature do you want to see in your deployment?

- Technical support
- Fast shipping
- Long lasting battery
- Batery replacement service
- Diagnostic capabilites

Would you pay for $400-$500 for the Eco-Smart device?



5.2 Competitive analysis

Companies leading the smart waste management field are: Bigbelly, Compology, Ecube Labs, Dublin, Bruno Smart Can, Smartbin. They have served and left many citizens and cities satisfied. These companies claim to reduce waste collection costs by more than 30% with their Internet of Things devices and cloud-based solutions. Most of these companies have the same features as the Eco-Smart Can. Such features are: monitor trash level, self-powered (solar energy), built in compactor, and cloud system to optimize trash collection. Ecube Labs is particularly relevant to this project because of their fast-growing company and technology innovation.

Ecube Labs (2011) is a Korean company established in 2011, with the aims to provide an eco-friendly waste management solution for smart cities and keep the environment greener and cleaner. As of now, their product lines provide only IoT-based solution to improve waste collection. Currently, Ecube Labs is considered as one of the best smart waste management companies, with over 4,500 installed bins in 100 different cities on 4 different continents. With their efficient cans, they recently won a contract of $15 million to equip Baltimore, MD with over 4,000 solar-powered smart cans (Duncan, 2018).

The Ecube Labs (2011) currently have two products in their catalog: the Clean Cube (solar-powered waste compacting bin) and the Clean Cap (wireless ultrasonic fill-level sensor). The Clean Cube will be the focus since it has the features that the Eco-Smart Can V 2.0 looks to implement. The Clean CUBE (2011) houses sensors that measure the trash level and automatically trigger their patented X-Frame compaction module of waste as seen in figure b., which efficiently increases the waste bin capacity up to 6-8 times. It reduces the operation costs of waste collection by 80%. The real-time data collected from the embedded sensors are sent to the Ecube Labs Clean City Networks (CCN) through the Global System for Mobile (GSM) communication technology. CCN is a cloud-based waste analytics platform responsible to monitor the entire waste management operation of a city, keep historical data and analytics reports, predict collection, trigger notification for trash collection etc. The Clean Cube is completely powered by a solar panel with a built-in rechargeable battery (see Figure 5.1). It can also be converted to a plug-in or hybrid system (Solar and Plug-in) to allow indoor usage.

Figure 5.1, Clean Cube: Solar-powered (Ecube Labs, 2011)

5.3 Market segmentation

This section breaks down the large market into smaller homogenous groups to help narrow marketing. The focus of the segmentation is the Tri-Cities and the surrounding areas. The segmentation uses different approaches. The tables below show a breakdown of these segments in the following categories: users, schools, airports and shopping malls.

Table 5.2, Users

Market Segments	Age Range	Occupation description	Income
Janitors/ Custodians	23-60	Ensure that the environment is clean	**$25,398** To **$34,362**
Administrators	30-65	Manager of company/school/airport	**$34,000** To **$68,000**
Dump-truck Driver	32-70	Pick-up dumpsters and take the trash to landfills	**$34,000** To **$37,700**

Table 5.3, Schools

Market Segments	School District	Schools	School Areas
Elementary	Johnson County, Watauga County, Etc...	Rock Springs, Miller Perry, Jefferson, Indian Springs, Etc…	Bristol, Kingsport, Johnson City, Elizabethton (Tri-Cities Area)
Middle School	Johnson County, Sullivan County, Carter County, Watauga County, Etc...	Colonial Heights, Sevier, Robins, Holston, Ketron, Boones Creek, Gate City, Etc…	Bristol, Kingsport, Johnson City, Elizabethton (Tri-Cities Area)
High School	Johnson County, Sullivan County, Carter County, Watauga County, Etc...	Sullivan South, Dobyns-Bennett, Boone, Central Greeneville, Elizabethton, Etc…	Bristol, Kingsport, Johnson City, Elizabethton (Tri-Cities Area)
College	Johnson County, Sullivan County, Carter County, Watauga County, Etc...	North East State Community College, East Tennessee State University, Milligan, King, Etc…	Bristol, Kingsport, Johnson City, Elizabethton (Tri-Cities Area)

Table 5.4, Airports, Shopping mall

Market Segments	**Location**
Tri-Cities Airport	Blountville
Pinnacle Mall	Bristol
Johnson City Mall	Johnson City
Kingsport Mall	Kingsport

5.4 SWOT assessment

Here the SWOT analysis of the Eco-Smart Can is discussed, and table 5.5 shows a summary.

Table 5.5, Eco-Smart Can SWOT analysis

○ ○Strengths ○- Ruggedize design ○-Scalable report ○- Resilience communication ○-OTA diagnostic and upgrade capabilities	○Weaknesses ○- Wi-Fi only release 1 ○- Phase 1 battery powered ○- Dedicated dashboard ○- Social media marketing ○ - Manufactuing design
○Opportunities ○- Transform the environment ○- Big market ○- Retrofit design ○- Partnership	○Threats ○- Service model

SWOT

Strengths

- Ruggedize design: Eco-Smart Can device is designed to resist multiple weather condition and can operate in extreme temperatures. The design offers better casing, seal, shock resistance and locking mount mechanisms.
- Scalable report: The online Eco-Smart Can dashboard enables customers to create reports and analyze different data patterns, savings, cost etc.
- Resilience communication: In case the Wi-Fi goes down, the cellular network can take over as a backup and to permit internet communication.
- OTA diagnostic and upgrade capabilities: The Eco-Smart Can device rollout firmware’s and updates are done over the internet, with no required physical access to the device.

This facilitates the technical support team tasked in assisting and diagnosing customer systems.

Weaknesses

- Wi-Fi only Release 1: The first release only uses Wi-Fi. The updated version in the future offers multiple communication features such as LTE, GSM or GPRS to fit customer needs.
- Phase 1 battery powered: The first version of the Eco-Smart Can is powered by battery only; therefore, the device needs regular battery replacement or charge. The upcoming phase of the Eco-Smart Can includes solar charging.
- Dedicated dashboard: Right now, the Eco-Smart operates on a third-party cloud platform Ubidots. There is a monthly fee associated with the usage, and the price increases with the more devices you have. To bring costs down in the future it will be necessary for Eco-Smart Can to create its own cloud platform and mobile app.
- Social media marketing: Marketing is important to attract customers and make the Eco-Smart Can product known to prospect customers. The marketing campaign will use a combination of different social media platforms. Some marketing techniques include hiring marketing representatives and working with distributors. The above strategies will help Eco-Smart Can have a successful marketing campaign and reach out to potential customers.
- Manufacturing Design: Currently, Eco-Smart Can device is a working prototype. The bill of all components in addition to an online platform is $200. To get it to the manufacturing stage, manufacturing design companies need to be contacted to help integrate the system and do the form, function and packaging.

Opportunities

- Transform the environment: The Eco-Smart Can does not just help customers to save money and other resources. It reinvents the whole trash management and collection system. It creates a new workplace and environment.
- Big market: IoT is a fairly new system, and smart waste management is gradually helping governments and industries to make profits. It is not a widespread resource, making it suitable for the Eco-Smart Can to have a big market opportunity and reach out to developed or developing countries.
- Retrofit Design: Most of the competing companies require the clientele to buy a dedicated trash can for their smart trash solutions. Meanwhile, the Eco-Smart Can device is retrofit; it can be adapted and mounted onto existing trash containers, bins or dumpsters. Therefore, there is no need for the client to get rid of old trash containers.
- Partnership: There exists opportunities for the Eco-Smart Can to partner with trash can manufacturers who supply businesses, cities, counties and households with cans. The manufacturers can supply their trash cans with the Eco Smart Can device preinstalled.

Threats

- Service model: If waste management companies offer a fixed lower price for unlimited trash collection, the Eco-Smart Can service can become obsolete.

6. BUSINESS MODEL

Table 6.1 is an overview of the Eco-Smart Can business model canvas (BMC). This table outlines nine segments, which are the building blocks of the Eco-Smart Can.

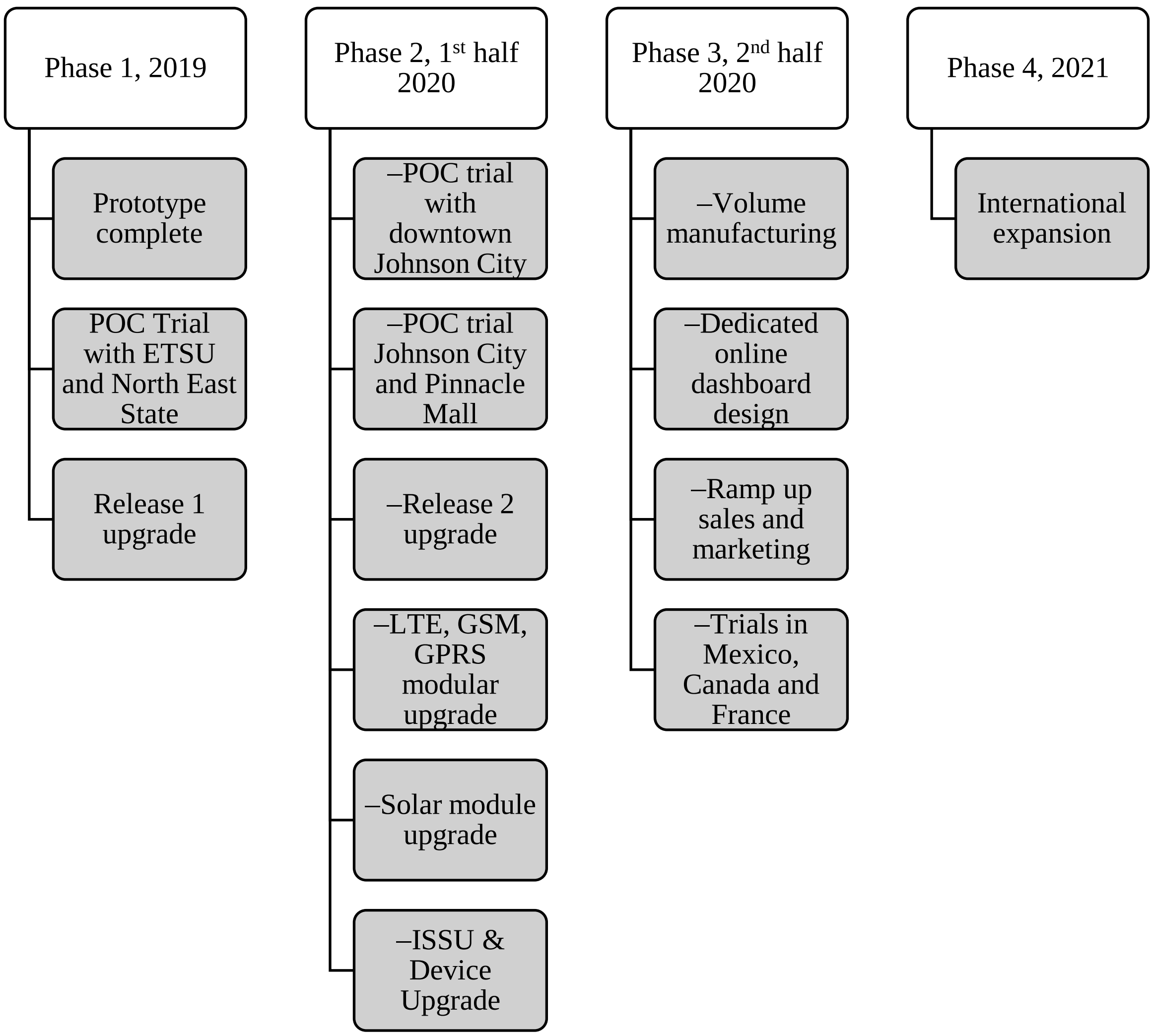
Table 6.1, Business Model

<table>
<tr>
<td rowspan="2">Key Partners
•Hardware retailers
•Cities waste management
•Microprocessor company
•Cloud platform
•Trash can manufacturer</td>
<td>Key Activities
•Development of smart waste management system and device
•Dashboard and device maintenance
•Product assembling, testing and packaging
•Product distribution in point of sales and online</td>
<td rowspan="2">Value Propositions
• Managing waste in a smart way with less trash pickup trips and reduced labor.
• Only pickup of filled trash, save plastic bags, predict fill up time.</td>
<td>Customer Relationship
• Product website/blog/online chat
• Social Media Interactions
• App
• Customer congress</td>
<td rowspan="2">Customer Segments
• City parks
• Government infrastructures
• Airports and malls
• College campuses
• Janitors or custodians</td>
</tr>
<tr>
<td>Key Resources
• SW/HW development team
• Consulting services for patents and marketing
• Financing sources</td>
<td>Channels
• Partner channels
• Marketplaces</td>
</tr>
<tr>
<td colspan="2">Cost Structure
• Labor
• Monthly cloud service provider fee
• Freight, storage and distribution
• Advertising and disclosure</td>
<td colspan="3">Revenue Streams
• Fee for additional services, such as battery replacement or onsite training
• Expertise consulting
• OEM sales</td>
</tr>
</table>

7. FUTURE SCOPE

This section describes the Eco-Smart Can implementation plan. Table 7.1 summarizes the Eco-Smart Can action plan for the coming years.

Table 7.1, Phases plan



Phase one consists of finalizing the prototype. The working prototype will be duplicated to perform a POC trial on the ETSU campus. The data collected during the trial will be used to adjust on the Eco-Smart Can device and do a Release 1 upgrade.

In the first half of 2020, phase 2 will focus on expanding the trials in different environments other than campus. This trial will target malls, parks and downtowns. Through the data collected and observations, another adjustment will be made on the device with the Release 2 upgrade. As explained earlier in this project, trash containers might be in areas with no Wi-Fi access. Therefore, an Eco-Smart Can LTE/GSM/GPRS module version will be developed. Furthermore, the solar charging system will also be developed to add to the existing design. An In-Service Software Upgrade (ISSU) of the running Eco-Smart Can devices will take place and upgrade the devices with new modules.

In the second half of 2020, phase 3 will see partnerships with manufacturing companies to manufacture The Eco-Smart Can devices. An online cloud platform and a dedicated mobile application will be created with a web developer. This will reduce the reliance on third party cloud platforms and decrease operation costs. The marketing team will work on an aggressive marketing campaign to get the word out and attract potential customers. To better prepare for an international market, trials will be run in Mexico, Canada and France. This will provide an insight about how trash systems work in other countries and how the Eco-Smart Can may succeed on an international level.

Finally, in Phase 4, the Eco-Smart Can will expand worldwide by first targeting neighboring countries to USA and then expanding to other continents.

8. CONCLUSION

When this project was started, it was believed that it would be completed in a semester period. However, the first prototype was completed after almost three semesters. The main difficulty when developing the prototype was trying to find a solution to counter the instabilities of the microcontroller. Since the IoT technology is a recent technology, most microcontrollers on the market are unstable and often carry very limited support. A lot of microcontrollers had to be tested in order to find adequate ones that would connect to different network types. This project provided insight on multiple things, especially from fields other than Engineering, such as business and marketing concepts, which are useful tools in developing careers.

All in all, this research manages to present a cost effective and user-friendly waste management system. The Eco-Smart Can system can be reproduced and used for small-scale areas. Despite the successful completion of this project, there is still room for improvement. Hopefully, this project will encourage others to develop better IoT waste management systems. The main goal of the system is to contribute to the universal community and improve the quality of life in the world.

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Appendix A: ESP32-WROOM-32 Microcontroller

1. Overview

ESP32-WROOM-32D and ESP32-WROOM-32U are powerful, generic Wi-Fi+BT+BLE MCU modules that target a wide variety of applications, ranging from low-power sensor networks to the most demanding tasks, such as voice encoding, music streaming and MP3 decoding.

ESP32-WROOM-32U is different from ESP32-WROOM-32D in that ESP32-WROOM-32U integrates a U.FL connector. For detailed information of the U.FL connector please see Chapter 10. Note that the information in this data sheet is applicable to both modules. Any differences between them will be clearly specified in the course of this document. Table 1 lists the difference between ESP32-WROOM-32D and ESP32-WROOM-32U.

Table 1: ESP32-WROOM-32D vs. ESP32-WROOM-32U

Module	ESP32-WROOM-32D	ESP32-WROOM-32U
Core	ESP32-D0WD	ESP32-D0WD
SPI flash	32 Mbits, 3.3 V	32 Mbits, 3.3 V
Crystal	40 MHz	40 MHz
Antenna	onboard antenna	U.FL connector (which needs to be connected to an external IPEX antenna)
Dimensions (Unit: mm)	(18.00±0.10) × (25.50±0.10) × (3.10±0.10) (See Figure 6 for details)	(18.00±0.10) × (19.20±0.10) × (3.20±0.10) (See Figure 7 for details)
Schematics	See Figure 3 for details.	See Figure 4 for details.

At the core of the two modules is the ESP32-D0WD chip that belongs to the ESP32 series* of chips. The chip embedded is designed to be scalable and adaptive. There are two CPU cores that can be individually controlled, and the CPU clock frequency is adjustable from 80 MHz to 240 MHz. The user may also power off the CPU and make use of the low-power co-processor to constantly monitor the peripherals for changes or crossing of thresholds. ESP32 integrates a rich set of peripherals, ranging from capacitive touch sensors, Hall sensors, SD card interface, Ethernet, high-speed SPI, UART, I²S and I²C.

Note:
* For details on the part numbers of the ESP32 family of chips, please refer to the document *ESP32 Datasheet*.

The integration of Bluetooth, Bluetooth LE and Wi-Fi ensures that a wide range of applications can be targeted, and that the module is all-around: using Wi-Fi allows a large physical range and direct connection to the Internet through a Wi-Fi router, while using Bluetooth allows the user to conveniently connect to the phone or broadcast low energy beacons for its detection. The sleep current of the ESP32 chip is less than 5 μA, making it suitable for battery powered and wearable electronics applications. The module supports a data rate of up to 150 Mbps, and 20 dBm output power at the antenna to ensure the widest physical range. As such the module does offer industry-leading specifications and the best performance for electronic integration, range, power consumption, and connectivity.

The operating system chosen for ESP32 is freeRTOS with LwIP; TLS 1.2 with hardware acceleration is built in as well. Secure (encrypted) over the air (OTA) upgrade is also supported, so that users can upgrade their products even after their release, at minimum cost and effort.

Table 2 provides the specifications of ESP32-WROOM-32D and ESP32-WROOM-32U.

Table 2: ESP32-WROOM-32D and ESP32-WROOM-32U Specifications

Categories	Items	Specifications
Certification	RF Certification	FCC/CE-RED/IC/TELEC/KCC/SRRC/NCC
	Wi-Fi Certification	Wi-Fi Alliance
	Bluetooth certification	BQB
	Green Certification	REACH/RoHS
Test	Reliablity	HTOL/HTSL/uHAST/TCT/ESD
Wi-Fi	Protocols	802.11 b/g/n (802.11n up to 150 Mbps)
		A-MPDU and A-MSDU aggregation and 0.4 μs guard interval support
	Frequency range	2.4 GHz ~ 2.5 GHz
Bluetooth	Protocols	Bluetooth v4.2 BR/EDR and BLE specification
	Radio	NZIF receiver with –97 dBm sensitivity
		Class-1, class-2 and class-3 transmitter
		AFH
	Audio	CVSD and SBC
Hardware	Module interfaces	SD card, UART, SPI, SDIO, I^2C, LED PWM, Motor PWM, I^2S, IR, pulse counter, GPIO, capacitive touch sensor, ADC, DAC
	On-chip sensor	Hall sensor
	Integrated crystal	40 MHz crystal
	Integrated SPI flash [1]	4 MB
	Operating voltage/Power supply	2.7 V ~ 3.6 V
	Operating current	Average: 80 mA
	Minimum current delivered by power supply	500 mA
	Recommended operating temperature range [2]	–40 °C ~ +85 °C

Notice:

1. ESP32-WROOM-32D and ESP32-WROOM-32U with 8 MB flash or 16 MB flash are available for custom order.
2. ESP32-WROOM-32D and ESP32-WROOM-32U with high temperature range (–40 °C ~ +105 °C) option are available for custom order. 4 MB SPI flash is supported on the high temperature range version.
3. For detailed ordering information, please see *Espressif Product Ordering Information*.

2. Pin Definitions

2.1 Pin Layout

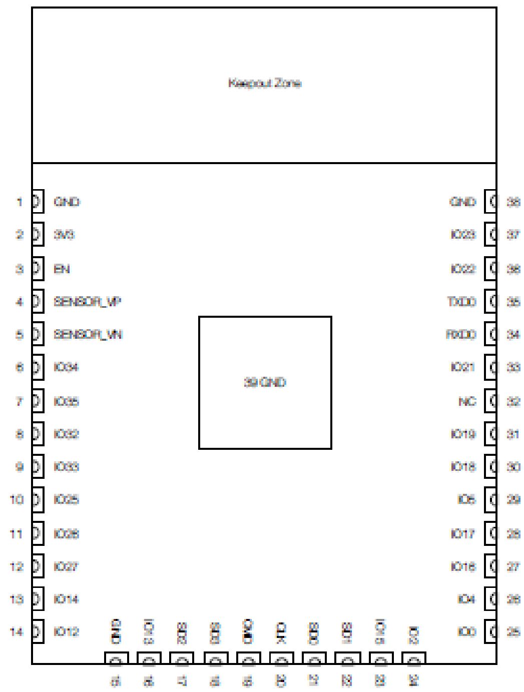


Figure 1: ESP32-WROOM-32D Pin Layout (Top View)

> **Note:**
> The pin layout of ESP32-WROOM-32U is the same as that of ESP32-WROOM-32D, except that ESP32-WROOM-32U has no keepout zone.

2.2 Pin Description

The ESP32-WROOM-32D and ESP32-WROOM-32U have 38 pins. See pin definitions in Table 3.

Table 3: Pin Definitions

Name	No.	Type	Function
GND	1	P	Ground
3V3	2	P	Power supply
EN	3	I	Module-enable signal. Active high.
SENSOR_VP	4	I	GPIO36, ADC1_CH0, RTC_GPIO0
SENSOR_VN	5	I	GPIO39, ADC1_CH3, RTC_GPIO3
IO34	6	I	GPIO34, ADC1_CH6, RTC_GPIO4
IO35	7	I	GPIO35, ADC1_CH7, RTC_GPIO5

Name	No.	Type	Function
IO32	8	I/O	GPIO32, XTAL_32K_P (32.768 kHz crystal oscillator input), ADC1_CH4, TOUCH9, RTC_GPIO9
IO33	9	I/O	GPIO33, XTAL_32K_N (32.768 kHz crystal oscillator output), ADC1_CH5, TOUCH8, RTC_GPIO8
IO25	10	I/O	GPIO25, DAC_1, ADC2_CH8, RTC_GPIO6, EMAC_RXD0
IO26	11	I/O	GPIO26, DAC_2, ADC2_CH9, RTC_GPIO7, EMAC_RXD1
IO27	12	I/O	GPIO27, ADC2_CH7, TOUCH7, RTC_GPIO17, EMAC_RX_DV
IO14	13	I/O	GPIO14, ADC2_CH6, TOUCH6, RTC_GPIO16, MTMS, HSPICLK, HS2_CLK, SD_CLK, EMAC_TXD2
IO12	14	I/O	GPIO12, ADC2_CH5, TOUCH5, RTC_GPIO15, MTDI, HSPIQ, HS2_DATA2, SD_DATA2, EMAC_TXD3
GND	15	P	Ground
IO13	16	I/O	GPIO13, ADC2_CH4, TOUCH4, RTC_GPIO14, MTCK, HSPID, HS2_DATA3, SD_DATA3, EMAC_RX_ER
SHD/SD2*	17	I/O	GPIO9, SD_DATA2, SPIHD, HS1_DATA2, U1RXD
SWP/SD3*	18	I/O	GPIO10, SD_DATA3, SPIWP, HS1_DATA3, U1TXD
SCS/CMD*	19	I/O	GPIO11, SD_CMD, SPICS0, HS1_CMD, U1RTS
SCK/CLK*	20	I/O	GPIO6, SD_CLK, SPICLK, HS1_CLK, U1CTS
SDO/SD0*	21	I/O	GPIO7, SD_DATA0, SPIQ, HS1_DATA0, U2RTS
SDI/SD1*	22	I/O	GPIO8, SD_DATA1, SPID, HS1_DATA1, U2CTS
IO15	23	I/O	GPIO15, ADC2_CH3, TOUCH3, MTDO, HSPICS0, RTC_GPIO13, HS2_CMD, SD_CMD, EMAC_RXD3
IO2	24	I/O	GPIO2, ADC2_CH2, TOUCH2, RTC_GPIO12, HSPIWP, HS2_DATA0, SD_DATA0
IO0	25	I/O	GPIO0, ADC2_CH1, TOUCH1, RTC_GPIO11, CLK_OUT1, EMAC_TX_CLK
IO4	26	I/O	GPIO4, ADC2_CH0, TOUCH0, RTC_GPIO10, HSPIHD, HS2_DATA1, SD_DATA1, EMAC_TX_ER
IO16	27	I/O	GPIO16, HS1_DATA4, U2RXD, EMAC_CLK_OUT
IO17	28	I/O	GPIO17, HS1_DATA5, U2TXD, EMAC_CLK_OUT_180
IO5	29	I/O	GPIO5, VSPICS0, HS1_DATA6, EMAC_RX_CLK
IO18	30	I/O	GPIO18, VSPICLK, HS1_DATA7
IO19	31	I/O	GPIO19, VSPIQ, U0CTS, EMAC_TXD0
NC	32	-	-
IO21	33	I/O	GPIO21, VSPIHD, EMAC_TX_EN
RXD0	34	I/O	GPIO3, U0RXD, CLK_OUT2
TXD0	35	I/O	GPIO1, U0TXD, CLK_OUT3, EMAC_RXD2
IO22	36	I/O	GPIO22, VSPIWP, U0RTS, EMAC_TXD1
IO23	37	I/O	GPIO23, VSPID, HS1_STROBE
GND	38	P	Ground

Notice:

* Pins SCK/CLK, SDO/SD0, SDI/SD1, SHD/SD2, SWP/SD3 and SCS/CMD, namely, GPIO6 to GPIO11 are connected to the integrated SPI flash integrated on the module and are not recommended for other uses.

5. Electrical Characteristics

5.1 Absolute Maximum Ratings

Stresses beyond the absolute maximum ratings listed in Table 5 below may cause permanent damage to the device. These are stress ratings only, and do not refer to the functional operation of the device that should follow the recommended operating conditions.

Table 5: Absolute Maximum Ratings

Symbol	Parameter	Min	Max	Unit
VDD33	Power supply voltage	–0.3	3.6	V
I_{output}[1]	Cumulative IO output current	-	1,100	mA
T_{store}	Storage temperature	–40	150	°C

1. The module worked properly after a 24-hour test in ambient temperature at 25 °C, and the IOs in three domains (VDD3P3_RTC, VDD3P3_CPU, VDD_SDIO) output high logic level to ground. Please note that pins occupied by flash and/or PSRAM in the VDD_SDIO power domain were excluded from the test.
2. Please see Appendix IO_MUX of *ESP32 Datasheet* for IO's power domain.

5.2 Recommended Operating Conditions

Table 6: Recommended Operating Conditions

Symbol	Parameter	Min	Typical	Max	Unit
VDD33	Power supply voltage	2.7	3.3	3.6	V
I_{VDD}	Current delivered by external power supply	0.5	-	-	A
T	Operating temperature	–40	-	85	°C

5.3 DC Characteristics (3.3 V, 25 °C)

Table 7: DC Characteristics (3.3 V, 25 °C)

Symbol	Parameter		Min	Typ	Max	Unit
C_{IN}	Pin capacitance		-	2	-	pF
V_{IH}	High-level input voltage		0.75×VDD[1]	-	VDD[1]+0.3	V
V_{IL}	Low-level input voltage		–0.3	-	0.25×VDD[1]	V
I_{IH}	High-level input current		-	-	50	nA
I_{IL}	Low-level input current		-	-	50	nA
V_{OH}	High-level output voltage		0.8×VDD[1]	-	-	V
V_{OL}	Low-level output voltage		-	-	0.1×VDD[1]	V
I_{OH}	High-level source current (VDD[1] = 3.3 V, V_{OH} >= 2.64 V, output drive strength set to the maximum)	VDD3P3_CPU power domain [1,2]	-	40	-	mA
		VDD3P3_RTC power domain [1,2]	-	40	-	mA
		VDD_SDIO power domain [1,3]	-	20	-	mA

Revision History

Date	Version	Release notes
2019.01	V1.8	Changed the RF power control range in Table 10 from –12 ~ +12 to –12 ~ +9 dBm.
2018.10	V1.7	Added notice on module custom options under Table 2; Added "Cumulative IO output current" entry to Table 5: Absolute Maximum Ratings; Added more parameters to Table 7: DC Characteristics.
2018.09	V1.6	Updated the hole diameter in the shield from 1.00 mm to 0.50 mm, in Figure 6.
2018.08	V1.5	• Added certifications and reliability test items the module has passed in Table 2: ESP32-WROOM-32D and ESP32-WROOM-32U Specifications, and removed software-specific information; • Updated section 3.4: RTC and Low-Power Management; • Changed the modules' dimensions; • Updated Figure 8 and 7: Physical Dimensions; • Updated Table 8: Wi-Fi Radio.
2018.06	V1.4	• Deleted Temperature Sensor in Table 2: ESP32-WROOM-32D & ESP32-WROOM-32U Specifications; • Updated Chapter 3: Functional Description; • Added notes to Chapter 7: Peripheral Schematics; • Added Chapter 9: Recommended PCB Land Pattern; Changes to electrical characteristics: • Updated Table 5: Absolute Maximum Ratings; • Added Table 6: Recommended Operating Conditions; • Added Table 7: DC Characteristics; • Updated the values of "Gain control step", "Adjacent channel transmit power" in Table 10: Transmitter Characteristics - BLE.
2018.04	V1.3	Updated Figure 4 ESP32-WROOM-32U Schematics and Figure 3 ESP32-WROOM-32D Schematics.
2018.02	V1.2	Update Figure 4 ESP32-WROOM-32U Schematics.
2018.02	V1.1	Updated Chapter 6 Schematics. Deleted description of low-noise amplifier. Replaced the module name ESP-WROOM-32D with ESP32-WROOM-32D. Added information about module certification in Table 2. Updated the description of eFuse bits in Section 3.1.
2017.11	V1.0	First release.

Appendix B: HC-SR04 Ultrasonic Sensor

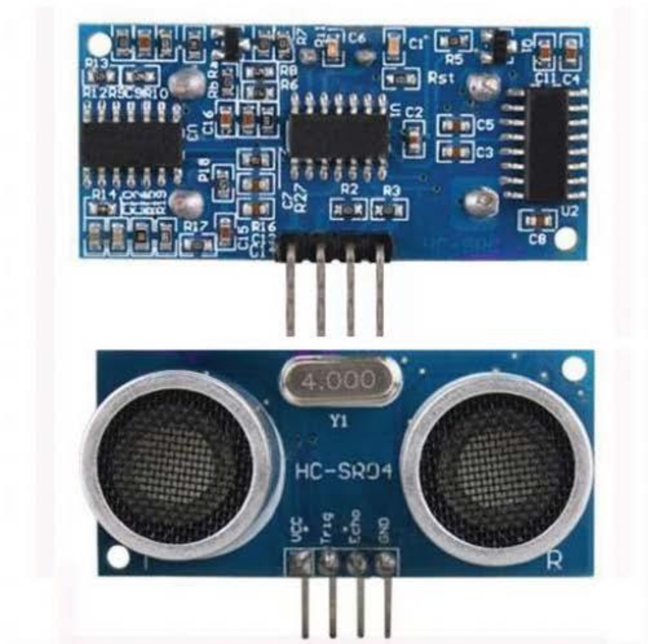
1.0 INTRODUCTION

The HC-SR04 ultrasonic sensor uses sonar to determine distance to an object like bats or dolphins do. It offers excellent non-contact range detection with high accuracy and stable readings in an easy-to-use package. From 2cm to 400 cm or 1" to 13 feet. It operation is not affected by sunlight or black material like Sharp rangefinders are (although acoustically soft materials like cloth can be difficult to detect). It comes complete with ultrasonic transmitter and receiver module.

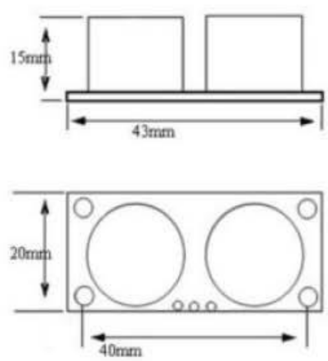
Features:

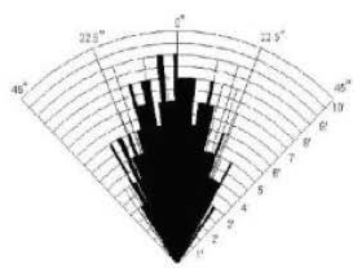
- Power Supply :+5V DC
- Quiescent Current : <2mA
- Working Currnt: 15mA
- Effectual Angle: <15°
- Ranging Distance : 2cm – 400 cm/1" - 13ft
- Resolution : 0.3 cm
- Measuring Angle: 30 degree
- Trigger Input Pulse width: 10uS
- Dimension: 45mm x 20mm x 15mm

3.0 PRODUCT LAYOUT



VCC = +5VDC
Trig = Trigger input of Sensor
Echo = Echo output of Sensor
GND = GND





Practical test of performance,
Best in 30 degree angle

4.0 PRODUCT SPECIFICATION AND LIMITATIONS

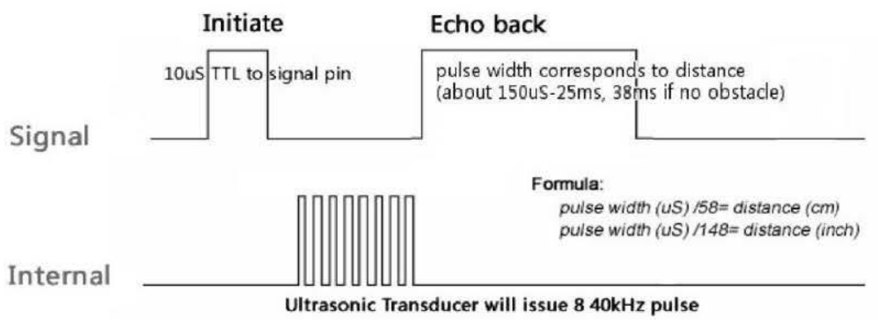
Parameter	Min	Typ.	Max	Unit
Operating Voltage	4.50	5.0	5.5	V
Quiescent Current	1.5	2	2.5	mA
Working Current	10	15	20	mA
Ultrasonic Frequency	-	40	-	kHz

5.0 OPERATION

The timing diagram of HC-SR04 is shown. To start measurement, Trig of SR04 must receive a pulse of high (5V) for at least 10us, this will initiate the sensor will transmit out 8 cycle of ultrasonic burst at 40kHz and wait for the reflected ultrasonic burst. When the sensor detected ultrasonic from receiver, it will set the Echo pin to high (5V) and delay for a period (width) which proportion to distance. To obtain the distance, measure the width (Ton) of Echo pin.

Time = Width of Echo pulse, in uS (micro second)

- Distance in centimeters = Time / 58
- Distance in inches = Time / 148
- Or you can utilize the speed of sound, which is 340m/s



Note:

- Please connect the GND pin first before supplying power to VCC.
- Please make sure the surface of object to be detect should have at least 0.5 meter^2 for better performance.

Appendix C: USB, DC & Solar Lipoly charger module

MICROCHIP

MCP73871

Stand-Alone System Load Sharing and Li-Ion / Li-Polymer Battery Charge Management Controller

Features

- Integrated System Load Sharing and Battery Charge Management
  - Simultaneously Power the System and Charge the Li-Ion Battery
  - Voltage Proportional Current Control (VPCC) ensures system load has priority over Li-Ion battery charge current
  - Low-Loss Power-Path Management with Ideal Diode Operation
- Complete Linear Charge Management Controller
  - Integrated Pass Transistors
  - Integrated Current Sense
  - Integrated Reverse Discharge Protection
  - Selectable Input Power Sources: USB Port or AC-DC Wall Adapter
- Preset High Accuracy Charge Voltage Options:
  - 4.10V, 4.20V, 4.35V or 4.40V
  - ±0.5% Regulation Tolerance
- Constant Current / Constant Voltage (CC/CV) Operation with Thermal Regulation
- Maximum 1.8A Total Input Current Control
- Resistor Programmable Fast Charge Current Control: 50 mA to 1A
- Resistor Programmable Termination Set Point
- Selectable USB Input Current Control
  - Absolute Maximum: 100 mA (L) / 500 mA (H)
- Automatic Recharge
- Automatic End-of-Charge Control
- Safety Timer With Timer Enable/Disable Control
- 0.1C Preconditioning for Deeply Depleted Cells
- Battery Cell Temperature Monitor
- Undervoltage Lockout (UVLO)
- Low Battery Status Indicator ($\overline{LBO}$)
- Power-Good Status Indicator ($\overline{PG}$)
- Charge Status and Fault Condition Indicators
- Numerous Selectable Options Available for a Variety of Applications:
  - Refer to **Section 1.0 "Electrical Characteristics"** for Selectable Options"
  - Refer to the **"Product Identification System"** for Standard Options
- Temperature Range: -40°C to +85°C
- Packaging: 20-Lead QFN (4 mm x 4 mm)

Applications

- GPSs / Navigators
- PDAs and Smart Phones
- Portable Media Players and MP3 Players
- Digital Cameras
- Bluetooth Headsets
- Portable Medical Devices
- Charge Cradles / Docking Stations
- Toys

Description

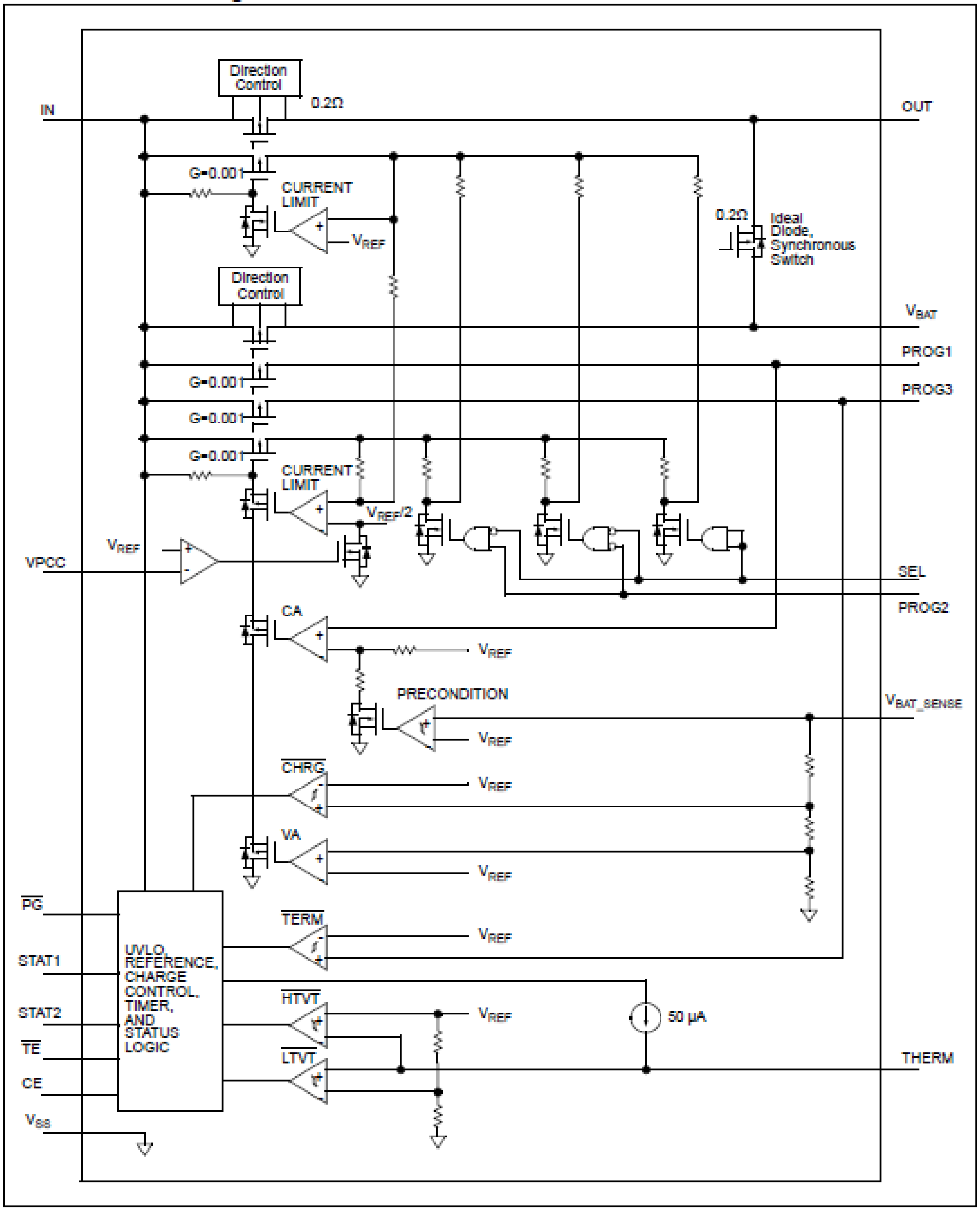
The MCP73871 device is a fully integrated linear solution for system load sharing and Li-Ion / Li-Polymer battery charge management with ac-dc wall adapter and USB port power sources selection. It's also capable of autonomous power source selection between input or battery. Along with its small physical size, the low number of required external components makes the device ideally suited for portable applications.

The MCP73871 device automatically obtains power for the system load from a single-cell Li-Ion battery or an input power source (ac-dc wall adapter or USB port). The MCP73871 device specifically adheres to the current drawn limits governed by the USB specification. With an ac-dc wall adapter providing power to the system, an external resistor sets the magnitude of 1A maximum charge current while supports up to 1.8A total current for system load and battery charge current.

The MCP73871 device employs a constant current / constant voltage (CC/CV) charge algorithm with selectable charge termination point. The constant voltage regulation is fixed with four available options: 4.10V, 4.20V, 4.35V, or 4.40V to accommodate new, emerging battery charging requirements. The MCP73871 device also limits the charge current based on die temperature during high power or high ambient conditions. This thermal regulation optimizes the charge cycle time while maintaining device reliability.

The MCP73871 device includes a low battery indicator, a power-good indicator and two charge status indicators that allows for outputs with LEDs or communication with host microcontrollers. The MCP73871 device is fully specified over the ambient temperature range of -40°C to +85°C.

Functional Block Diagram



4.0 DEVICE OVERVIEW

The MCP73871 device is a simple, but fully integrated linear charge management controllers with system load sharing feature. Figure 4-1 depicts the operational flow algorithm.

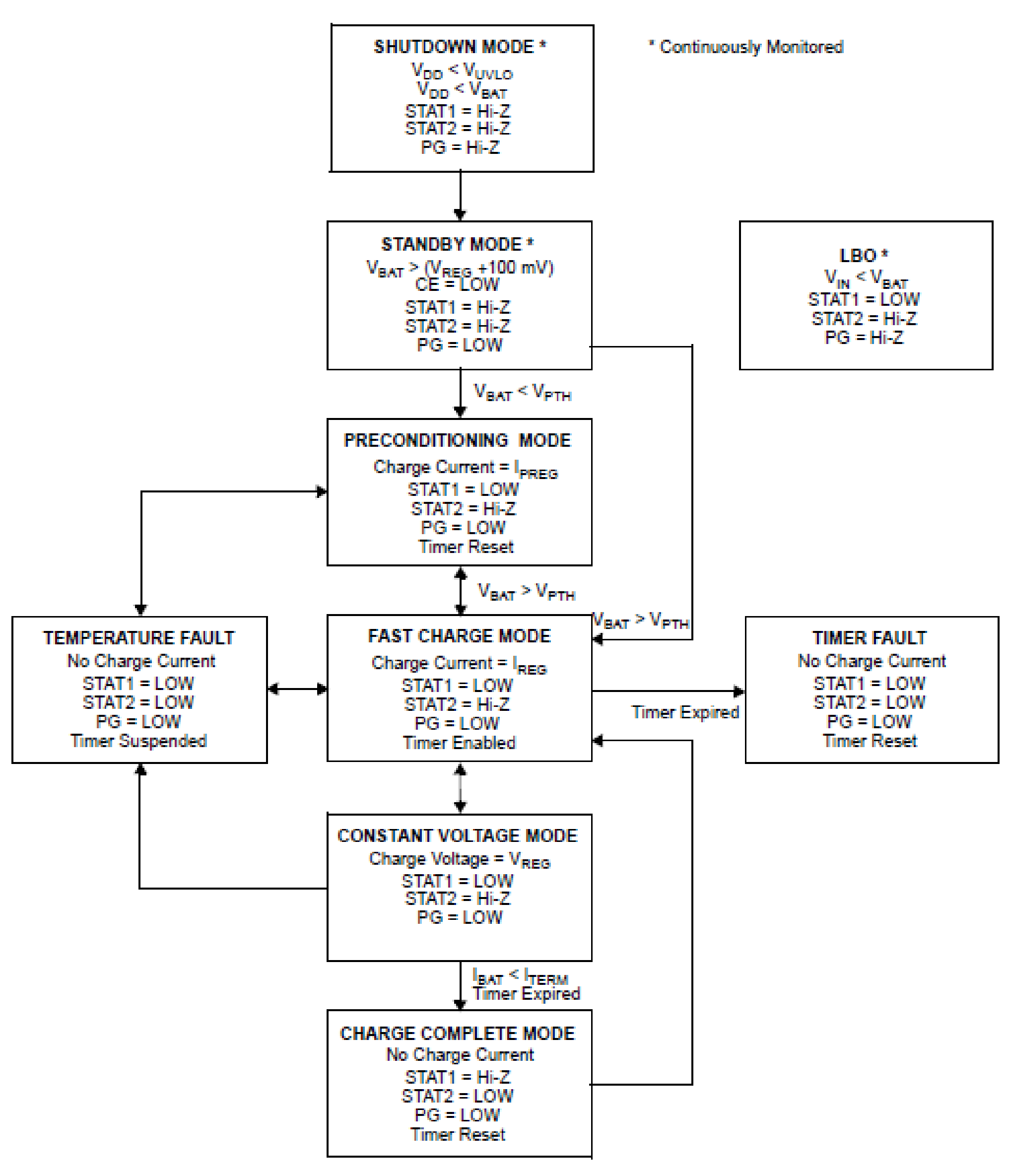


FIGURE 4-1: MCP73871 Device Flow Chart.

Appendix D: Li-Polymer 2000 mAh Battery

SHENZHEN PKCELL BATTERY CO., LTD

PKCELL

Li-Polymer Battery Technology Specification

Model: Li-Polymer 803860 2000mAh 3.7V with PCM

Customer confirmation	Corporate name	
	Checked	
	Approved	
	Corporate seal	

Signed： ______________

Drafted by: ______________

Approved by：______________

Document No.： QA.S.0228 Edit：**A**

SHENZHEN PKCELL BATTERY CO., LTD
Company address: E2 Building,Guangming Technology Park,No.24 Zhonghua Road,Longhua New Area,Shenzhen Guangdong, China.
（Tel）：+86-755-86670672 （Fax）：+86-755-86670609
E-mail：pkcell@pkcell.net Website：http://www.pkcell.net

(If manufacturer want to modify the product technology specification, we won't inform you additionally)

1 Scope

This document describes the performance characteristics and testing methods for Li-polymer battery produced by SHENZHEN PKCELL BATTERY CO., LTD.

2 Product type and model number

2.1 Product type

Lithium-polymer battery

2.2 Model number

LP-803860 3.7V 2000mAh with PCM

3 Rated performance

Form 1: Battery rated performance

No	Item	Rated performance	Remark
1	Capacity	Nominal 2000mAh Minimum 1900mAh	Standard discharge after standard charge
2	Nominal voltage	3.7V	Mean operation voltage during standard discharge after standard charge
3	Voltage at end of discharge	3.0V	Discharge cut-off voltage
4	Charging voltage	4.2V	
5	Standard charge	Constant current 0.2C_5A Constant voltage 4.2V Cut-off current 0.01C_5A	
6	Quick charge	Constant current 1C_5A Constant voltage 4.2V Cut-off current 0.01C_5A	
7	Standard discharge	Constant current 0.2 C_5A End voltage 3.0V	
8	Maximum continuous discharge current	1 C_5A	Text
9	Operation temperature range	Charge: 0~45℃	60±25%R.H
		Discharge:-20~60℃	
10	Cycle life	>300cycles	Charging/discharging in the below condition: Charge: standard charge Discharge:0.2C_5A to 3.0V Rest time between charge/discharge:30min Until the discharge capacity <60% of NC
11	Storage temperature	During 1 month: -5 ~ 35℃	60±25%R.H
		During 6 months: -20 ~ 45℃	

4 Electrical performances

Form 2: Battery electrical performances

No	Items	Test procedure	Requirements
1	Nominal voltage	The average value of the working voltage during the whole discharge process.	3.7V
2	Discharge performance	The discharge capacity of the battery, measured with $0.2C_5A$ down to 3.0V within 1 hour after a standard charge	Discharge ≥Minimum capacity
3	Capacity retention	After 28 days storage at 25±5℃, after having been standard charged and discharged at $0.2C_5A$ to 3.0V (the residual capacity is above 80% of nominal capacity)	Discharge time≥4h
4	Cycle life	Charging/discharging in the below condition: Charge: standard charge Discharge:$0.2C_5A$ to 3.0V Rest time between charge/discharge:30min Until the discharge capacity <60% of NC	>300cycles

5 Standard test conditions

Test should be conducted with new batteries within one week after shipment from our factory and the batteries shall not be cycled more than five times before the test. Unless otherwise defined, test and measurement shall be done under temperature of 20±5℃ and relative humidity of 45~85%. If it is judged that the test results are not affected by such conditions, the tests may be conducted at temperature 15~30℃ and humidity 25~85%RH.

6 Cautions in use

To ensure proper use of the battery please read the manual carefully before using it.

6.1 Handling

Do not expose to, dispose of the battery in fire.
Do not put the battery in a charger or equipment with wrong terminals connected.
Avoid shorting the battery.
Avoid excessive physical shock or vibration.
Do not disassemble or deform the battery.
Do not immerse in water.
Do not use the battery mixed with other different make, type, or model batteries.
Keep out of the reach of children.

6.2 charge and discharge

Battery must be charged in appropriate charger only.
Never use a modified or damaged charger.
Do not leave battery in charge over 24 hours.

6.3 storage

Store the battery in a cool, dry and well-ventilated area.

6.4 disposal

Regulations vary for different countries, Dispose of in accordance with local regulations.

7 Battery operation instruction

7.1 Charging

Charging current Cannot surpass the biggest charging current which in this specification book stipulated. Charging voltage :Does not have to surpass the highest amount which in this specification book stipulated to decide the voltage.

Charge temperature : The battery must carry on the charge in the ambient temperature scope which this specification book stipulated.Uses the constant electric current and the constant voltage way charge, the prohibition reverse charges. If the battery positive electrode and the cathode meet instead, can damage the battery.

7.2 Discharging current

The discharging current does not have to surpass this specification book stipulation the biggest discharging current, the oversized electric current electric discharge can cause the battery capacity play to reduce and to cause the battery heat.

7.3 Electric discharge temperature

The battery discharge must carry on in the ambient temperature scope which this specification book stipulated.

7.4 Over-discharges

After the short time excessively discharges charges immediately cannot affect the use, but the long time excessively disharges can cause the battery the performance, battery function losing. The battery long-term has not used, has the possibility to be able to be at because of its automatic flashover characteristic certain excessively discharges the condition, or prevented excessively discharges the occurrence, the battery should maintain the certain electric quantity.

7.5 Storing the batteries

The battery should store in the product specification book stipulation temperature range. If has surpasses above for six months the long time storage, suggested you should carry on additional charge to the battery.

8 Period of warranty

The period of warranty is half year from the date of shipment. Pkcell guarantees to give a replacement in caseof batteries with defects proven due to manufacturing process instead of the customers abuse and misuse.

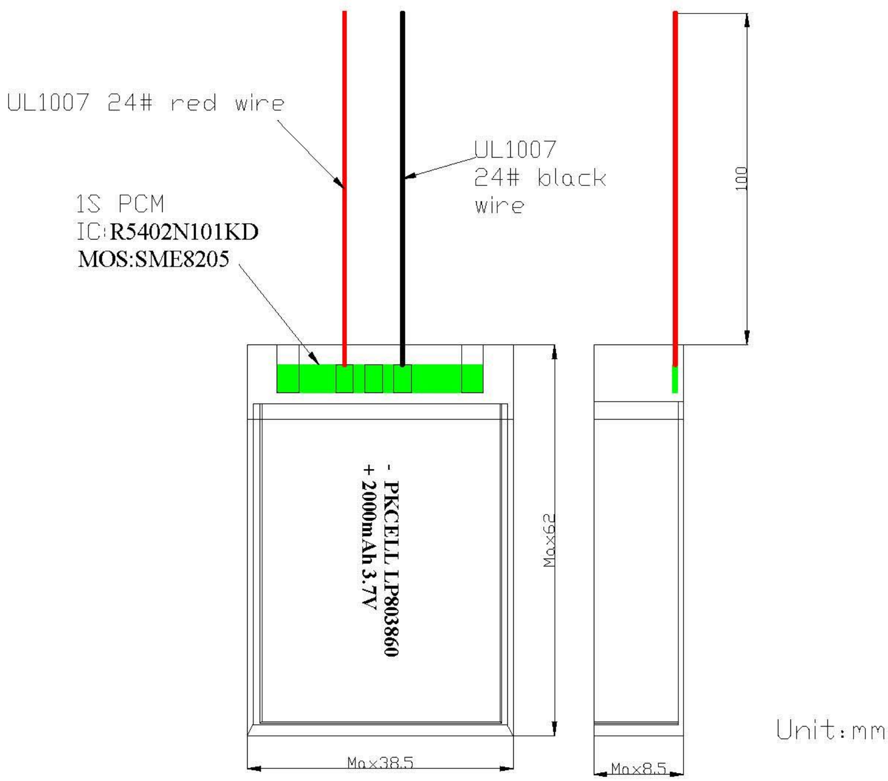
9 Other the chemical reaction

Because batteries utilize a chemical reaction, battery performance will deteriorate over time even if stored for a long period of time without being used. In addition, if the various usage conditions such as charge, discharge, ambient temperature, etc. are not maintained within the specified ranges the life expectancy of the battery may be shortened or the device in which the battery is used may be damaged by electrolyte leakage. If the batteries cannot maintain a charge for long periods of time, even when they are charged correctly, this may indicate it is time to change the battery.

10 Note

Any other items which are not covered in this specification shall be agreed by both parties.

11 Battery pack drawings



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Appendix E: CEM-1203 magnetic buzzer

For more information, please visit the product page.

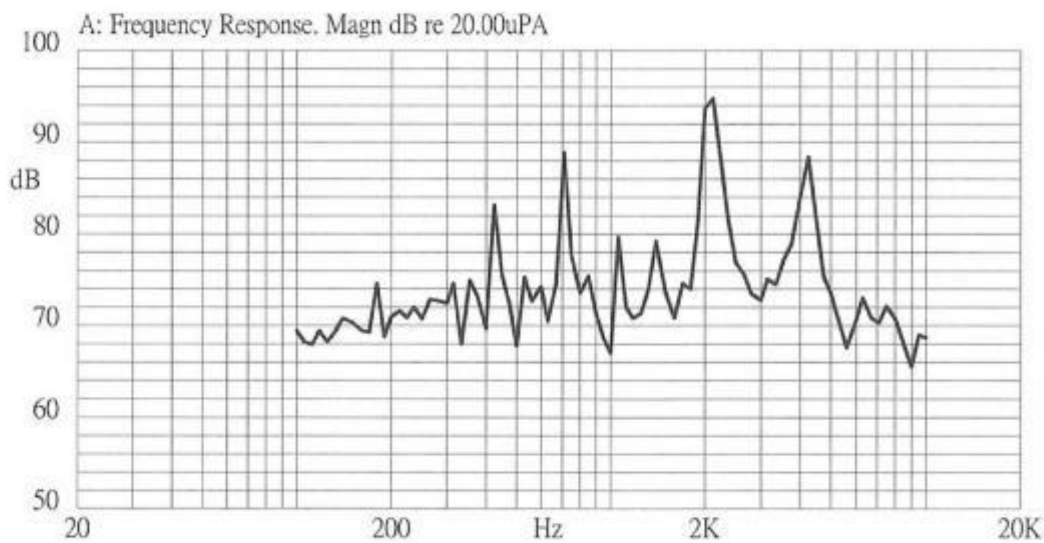
CUI INC	Part No: CEM-1203(42) Description: magnetic buzzer	Date: 8/11/2006 Unit: mm Page No: 1 of 5

RoHS

Specifications

Rated voltage	3.5 Vo-p	
Operating voltage	3.0 - 5.0 Vo-p	
Mean current	35 mA max.	Applying rated voltage, 2048 Hz square wave, ½ duty
Coil resistance	42 ±6.3 Ω	
Sound output	Min. 85 (Typical 95) dBA	Distance at 10cm (A-weight free air). Applying rated voltage of 2048 Hz, square wave, 1/2 duty.
Rated frequency	2,048 Hz	
Operating temperature	-20 ~ +60° C	
Storage temperature	-30 ~ +70° C	
Dimensions	ø12.0 x H8.5 mm	See attached drawing
Weight	1.4 g	
Material	PPO (Black)	
Terminal	Pin type (AU Plating)	See attached drawing
RoHS	yes	

Frequency Response Curve



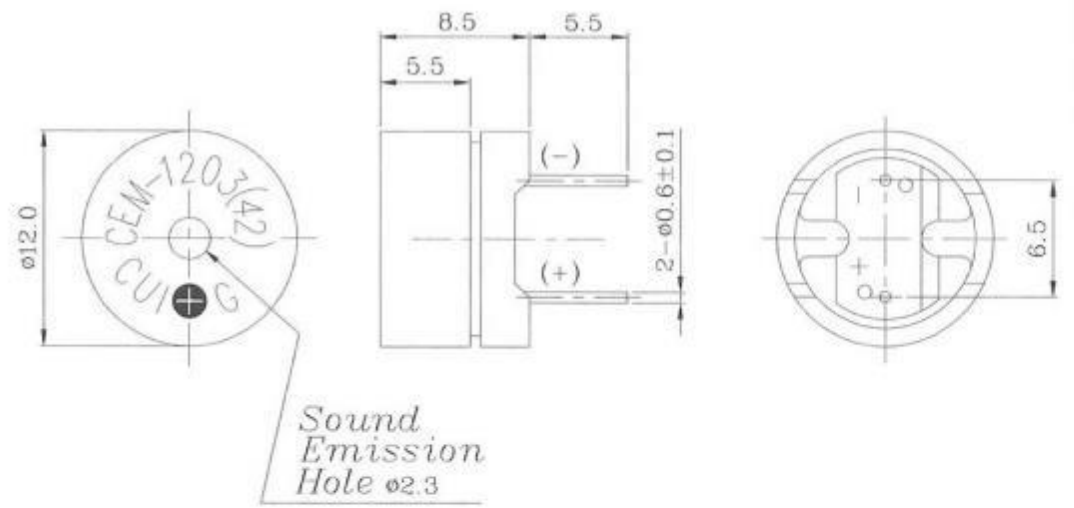
Phone: 800.275.4899 Fax: 503.612.2381 www.cui.com 20050 SW 112th Ave. Tualatin, OR 97062

For more information, please visit the product page.

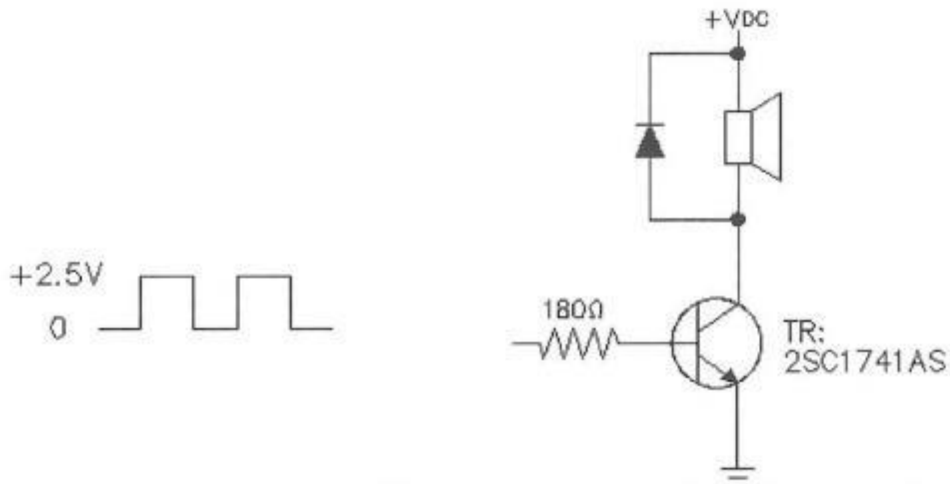
CUI INC	Part No: CEM-1203(42)	Date: 8/11/2006
	Description: magnetic buzzer	Unit: mm
		Page No: 2 of 5

Appearance Drawing

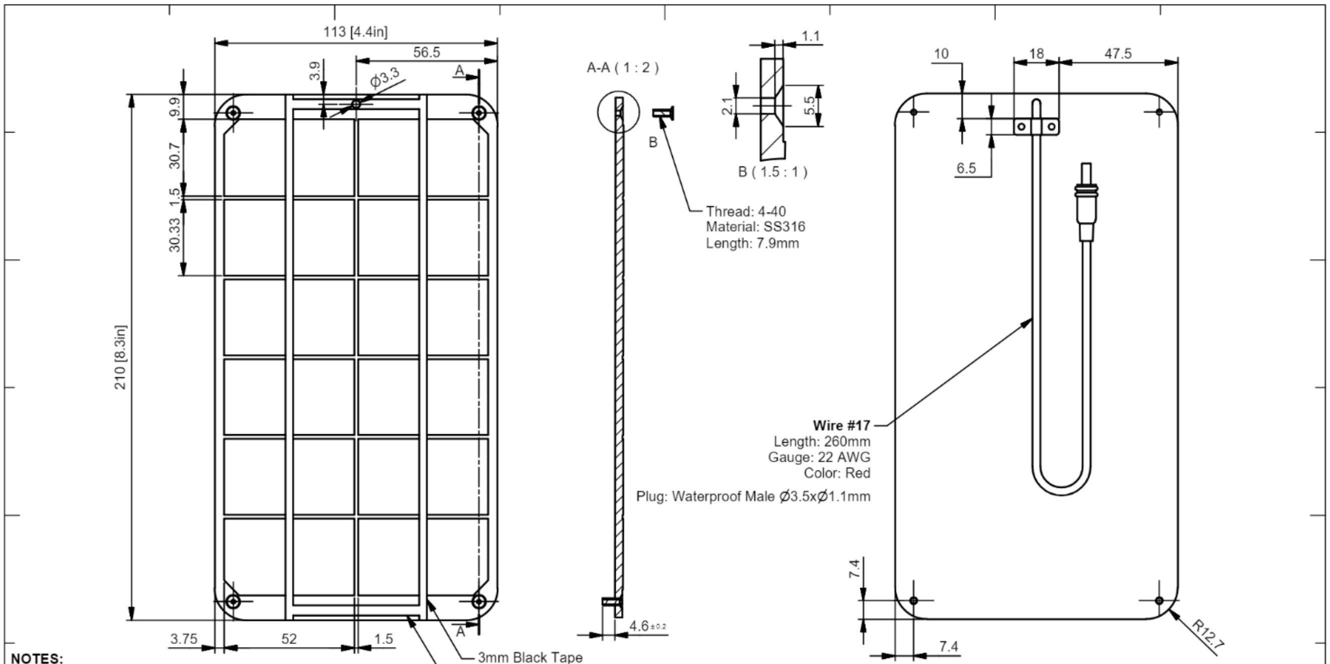
Tolerance: ±0.5



Measurement Method



Appendix F: Voltaic Systems 3.5W 6V



NOTES:

1. Total Panel Thickness (not including screws): 4.8mm ± 0.2mm
2. Weight: 155.9g [5.5oz]
3. Waterproof Rating: IP67
4. All materials RoHS compliant
5. Tape over all electrical connections

FILE DETAILS	SUBSTRATE	HARDWARE	POWER
PRODUCT NAME: **3.5W 6V 113x210mm**	SIZE: 113x210mm	WIRE: Male 3.5x1.1mm 260mm	Spec. Tolerance: ±10% (Vp,Ip)
DWG. NO. 3.5_6_113x210_R1	MATERIAL: 3.0mm AL-Plastic Composite	WIRE COLOR: Red	Cell Supplier: Solar World
DWG. TYPE: Production	COLOR: Silver / Charcoal / Orange	WIRE NO. Wire 17	Cell: Efficell M C4 3BB 4.59W
SCALE: 1:2 UNITS: MM TOLERANCE: ±0.1mm SHEET: 1/1	COATING: Urethane	STRAIN RELIEF: Metal	Cell Efficiency: +19.1%
CREATED BY: TK DATE: 2017/7/6	TAPE: 3mm + 4mm Black	SCREWS: C-MPSCRS028X0079-KM#	
REV. 1 CHANGE: DATE: CHK'D BY: SM	TEMP. RANGE: -40*C - 85*C [-40*F - 185*F]	NUTS: None	

MC	12	pcs
Voc	7.7	V
Vp	6.5	V
mAsc	590	mA
mAp	550	mA
Wp	3.5	W

Voltaic

VITA

DARACK NANTO

Education:

High School Diploma, Morning Glory International School, Bingerville, Côte d'Ivoire 2012

B.S. Manufacturing Engineering Technology, East Tennessee State University, Johnson City, Tennessee 2016

M.S. Engineering Technology, East Tennessee State University, Johnson City, Tennessee 2019

Cert. Business Administration, East Tennessee State University, Johnson City, Tennessee 2019

Professional Experience:

Founder, Eco-Smart Can, Johnson City, Tennessee, April 2015 - Present

Graduate Assistant, East Tennessee State University, Department of Engineering, Engineering Technology, and Surveying, Johnson City, Tennessee, August 2018 - May 2019

Personal Trainer, East Tennessee State University, Department of Campus Recreation, Johnson City, Tennessee, May 2018 - August 2018

Facility Assistant, East Tennessee State University, Department of Campus Recreation, Johnson City, Tennessee, May 2018 - August 2018

Standardized Patient, East Tennessee State University, Quillen College of Medicine, Johnson City, Tennessee, May 2018 - August 2018

Resident Director (RD), East Tennessee State University, Department of Housing and Residence Life, Johnson City, Tennessee, May 2016 - May 2018

Resident Advisor (RA), East Tennessee State University, Department of Housing and Residence Life, Johnson City, Tennessee, August 2014 - May 2016

Publications:

Nanto, Darack B., "The Eco-Smart Can" (2016). Undergraduate Honors Theses. Paper 363. https://dc.etsu.edu/honors/363

Honors and Awards:

Awarded 1st place at the Innovative Buccaneers Competition
Awarded 1st place at the Appalachian Research Forum
Project was featured several times in the local news
Award green project of my campus
TVA outstanding project award
Campus Sustainability Fee Award
Student-Faculty Collaborative Grants
Honors in Discipline