

Approaching Trash: An Autonomous IoT Mobile Bin for Nudging Waste Disposal Habits in Smart Environments

Muhammad Nabel Karima¹, Muhammad Faishal Allam², Muhammad Arfan Nurhadi³, Fahrezy Abdullah⁴, Muhammad Aqiel Wiramulya Paliwangi⁵

Abstract

The problem of littering persists to the present day, and conventional static trash cans often fail to encourage proper waste disposal. This study proposes a mobile, IoT-enabled trash bin that approaches users rather than requiring users to approach it. The prototype integrates Raspberry Pi 4 as the central controller, L298N motor drivers for movement, an ultrasonic sensor to detect obstacles, and an infrared sensor to identify users who wish to dispose of waste, enabling the lid to open and close automatically. Through a web-based interface built with Flask and Nginx, the system can record and replay movement trajectories on demand, allowing the bin to follow predefined paths autonomously. Usability testing with 20 respondents produced a mean System Usability Scale (SUS) score of 69.125, indicating that the prototype achieves an acceptable level of usability and interaction. These results suggest that the IoT-based mobile trash bin has the potential to support the development of proper waste disposal habits while demonstrating a practical and educational application of IoT in waste management.

Keywords: *IoT, Littering, Habit Formation, Smart Waste Bin, Raspberry Pi.*

Introduction

Global waste mismanagement constitutes a pressing challenge, with annual generation reaching 2.01 billion tons and projections estimating 3.4 billion tons by 2050, thereby intensifying landfill pressures, methane emissions, and public health concerns, particularly in densely populated regions such as Indonesia. Static trash bins exacerbate this issue by requiring users to seek them out, perpetuating littering due to accessibility deficits. A survey indicates that 42.9% of Indonesian respondents fail to dispose of waste consistently, attributing this primarily to insufficient bin availability (Yonatan, 2024). As observed by Razip et al. (2022) bin scarcity in certain locations leads to littering, compounded by reluctance to search for receptacles.

This pattern reveals a fundamental limitation in conventional systems, which overlook psychological principles whereby proximity and convenience enhance compliance, as evidenced by behavioral nudges in intelligent environments that increase recycling rates by 40-50% (Zhang et al., 2023). IoT addresses this through interconnected sensors, actuators, and analytics enabling autonomous operations. Defined by Abas et al. (2023) as the integration of internet connectivity and data-acquisition sensors into everyday objects, IoT facilitates transformative applications, as articulated by Diwan (2025) a mechanism for linking individuals to actionable insights that foster innovation. Systematic literature reviews substantiate these benefits in waste management, including ultrasonic-enabled obstacle avoidance and multi-parameter monitoring of fill levels for optimized operations.

Predominant IoT prototypes monitor stationary bins; however, autonomous mobile systems that approach users represent an advancement and promoting habitual engagement through interactive reciprocity (Saulitis et al., 2024). Within Indonesia's urban landscape, where littering impedes smart city initiatives, the present Raspberry Pi 4-based prototype incorporates path recording, ultrasonic obstacle

¹ SMAS IT Albinnaa Islamic Boarding School, Bekasi, Jawa Barat 17710, Indonesia, Email: muhammadnabelkarima@gmail.com, (Corresponding Author)

² SMAS IT Albinnaa Islamic Boarding School, Bekasi, Jawa Barat 17710, Indonesia.

³ SMAS IT Albinnaa Islamic Boarding School, Bekasi, Jawa Barat 17710, Indonesia

⁴ SMAS IT Albinnaa Islamic Boarding School, Bekasi, Jawa Barat 17710, Indonesia

⁵ SMAS IT Albinnaa Islamic Boarding School, Bekasi, Jawa Barat 17710, Indonesia

avoidance, and infrared-activated lid mechanisms. This configuration not only facilitates disposal but also provides practical IoT education, aligning with Sustainable Development Goals 11 (Sustainable Cities) and 12 (Responsible Consumption) by potentially yielding 18-20% emission reductions (Numa et al., 2023)

Research Questions

The investigation addresses the following research questions, grounded in identified empirical gaps:

To what extent can the proposed IoT-based medium foster consistent and appropriate waste disposal habits among users?

To what extent can the Raspberry Pi 4 effectively function as the central hub for an IoT-based waste management system?

How can a prototype of an Internet of Things (IoT)-based mobile trash bin be systematically designed and implemented so that it can navigate and move accurately along a predefined trajectory?

These inquiries target the root causes of 42.9% non-compliance rates in waste disposal practices

Objectives

This research seeks to develop interactive IoT media that reinforces waste disposal habits through user-oriented automation, integrate IoT functionalities into mobile bins for remote controllability, and construct a Raspberry Pi-centric prototype featuring path playback, sensor fusion, and web-based interfaces. Theoretically, the study contributes to IoT scholarship on behavioral interventions by building upon reviews of sensor-AI frameworks for smart cities with a novel emphasis on mobility, while practically, it facilitates deployment in educational and urban settings following validation, consistent with low-cost prototypes that diminish collection inefficiencies by 25%. Societally, anticipated litter reductions of 20-50% alleviate environmental degradation and enhance technological literacy among users.

Scope and Significance

The scope encompasses a Raspberry Pi 4 prototype utilizing ultrasonic and infrared sensors with web controllability, evaluated in an educational context in Bekasi, Indonesia, with potential for broader scalability. The significance resides in transforming passive infrastructure into proactive systems that leverage technology-psychology synergies for sustainability, offering replicable insights amid escalating global waste challenges

System Components

This device is expected to reduce littering with a trash can that can operate automatically.

Raspberry Pi 4



Figure 1 Raspberry Pi 4

Raspberry Pi is a type of miniature computer consisting of a circuit board no larger than a credit card. Designed to be affordable and accessible to a wide range of users, the Raspberry Pi has sufficient computing power to run operating systems like Linux and a wide variety of software. Despite its small size, the Raspberry Pi is equipped with a variety of input/output ports, including USB, HDMI, and GPIO (General Purpose Input/Output), allowing users to engage in creative projects and electronics experiments (Meddeb et al., 2023).

The Raspberry Pi is more than just hardware; it encompasses a large community of users who share knowledge, projects, and support. This makes the Raspberry Pi more than just a miniature computer, but also an ideal learning tool for those interested in understanding the world of programming and technology.

Flask



Figure 2 Flask

Flask is a lightweight WSGI web application framework. It is designed to make getting started quick and easy, with the ability to scale up to complex applications.

The Pigiop Library

The pigpio is a library for the Raspberry which allows control of the General Purpose Input Outputs (GPIO). Pigiop works on all versions of the Pi. The pigpio library is written in the C programming language. The pigpio daemon offers a socket and pipe interface to the underlying C library. AC library and a Python module allow control of the GPIO via the pigpio daemon.

L298N Driver

The L298N motor driver is the most widely used DC motor driver module in the electronics world, which is used to control the speed and direction of rotation of a DC motor. The L298 IC is an H-bridge type IC capable of controlling inductive loads such as relays, solenoids, DC motors, and stepper motors. The L298 IC consists of logic transistors (TTL) with NAND gates that function to facilitate determining the direction of rotation of a DC motor or stepper motor.



Figure 3 L298N Driver

HC SR-04 ultrasonic sensor

According to Monkam et al. (2023) an ultrasonic sensor is a sensor commonly used to detect an object when the object is at a certain distance in front of the sensor. Ultrasonic sensors work based on the principle of sound waves being transmitted and reflected back when they hit an object. This sensor is used to detect obstacles in front of the trash can, so this sensor signals the trash can to stop if there is an obstacle in front of it.



Figure 4 HC SR-04 ultrasonic sensor

Nginx

nginx ("engine x") is an HTTP web server, reverse proxy, content cache, load balancer, TCP/UDP proxy server, and mail proxy server. Originally written by Igor Sysoev and distributed under the 2-clause BSD License.



Figure 5 Nginx

Infrared

Infrared is electromagnetic light with wavelengths between 700 nm and 1 nm. These waves are invisible to the naked eye. Infrared radiation can be observed within the electromagnetic spectrum using a light spectroscope. This sensor is used to detect hands on the trash can lid as a command signal to open the trash can lid.



Figure 6 Infrared Sensors

Servo

A servo motor or servo motor is an electromechanical device designed using a closed-loop (servo) type control system as a driver in a circuit that produces torque and speed based on the existing electric current and voltage.

Simply put, a servo motor is a self-contained electrical device that can push and rotate objects with high precision. If you need to rotate an object at a specific angle or distance, you can use a servo motor. In this project, the servo motor is used to open and close a trash can.



Figure 7 Servo

Habit

According to Sabrina Dachmiati (2015:10), habits are behaviors that are consistently displayed and relatively stable as a result of experience and repeated learning. Habits are closely related to attitudes, because attitudes can be formed from habits, and vice versa, habits can influence attitudes. Attitudes that are consistently displayed or repeatedly displayed become stable over time, then these attitudes become habits.

Flowchart

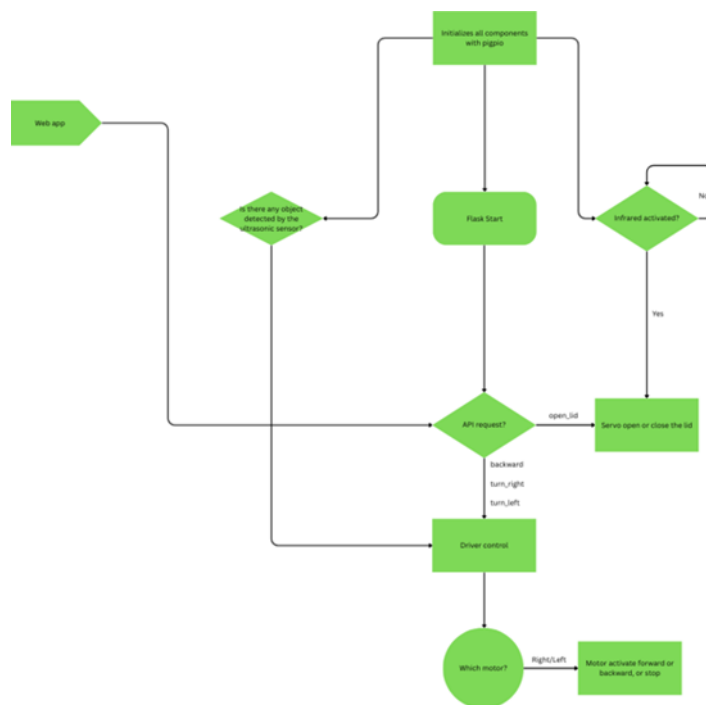


Figure 10 Flowchart

Analysis

SUS (System Usability Scale) Table

The SUS is one of the most popular usability testing tools. Developed by John Brooke in 1986, the SUS is a reliable, popular, effective, and inexpensive utility scale. The SUS has 10 questions and 5 response options. Response options range from strongly disagree to strongly agree. The SUS has a minimum score of 0 and a maximum score of 100.

Black box

Black box testing is the testing of an application's functionality or usability. Black box testing is essential for finding bugs or problems in a tool or application.

Results and Discussion

Tools and Materials

Tools: Laptop/Mobile Phone, WI-FI connection, scissors, glue gun, soldering iron, cutter.

Materials: 3.7 volt battery, L298N Motor Driver, 12V Motor, XI-602 Stepper, Raspberry Pi 4, Ultrasonic Sensor, Infrared Sensor, SG90 Servo, Omnidirectional Wheel, 8.5cm Plastic Wheel, cardboard.

How It Works

The device is expected to work properly after the following steps:

First, it must be made sure that the Raspberry Pi and the user's device have a shared connection and are connected to the network.

Second, all the components are surely connected to the correct pins accordingly. Third, it is to be made sure that the python program is coded correctly with all the pins set accordingly and Nginx is serving the frontend web app while proxying every API request to the Flask API.

Fourth, it is to be made sure that the device is given stable power from a reliable power source.

Finally, the device should be controllable through the web app by accessing its IP address relative to the shared network between the Raspberry Pi and the user's device. The web app should post user commands through the API and the device should run the commands accordingly. If the user were to

prompt to record the commands, the device would do so and playback the recording when the user prompted to do so if recording has stopped. The ultrasonic sensor would stop any movement of the device if it were to detect an obstacle blocking its path. The lid could be opened by triggering the infrared sensor module or by controlling it via the web app.

Module Simulation

1. Prepare the power supply to the trash (battery)



Figure 11 Power supply (battery)

2. Turn on the switch on the trash can



Figure 12 Power switch

3. Input the route using the application that has been created on the Mobile Phone/Laptop



Figure 13 Smart Bin Apps

4. The inputted trajectory will be recorded, and the trash will operate using the recorded results.
5. A person who wants to throw away rubbish approaches the rubbish bin and brings the rubbish close to the lid of the rubbish bin.

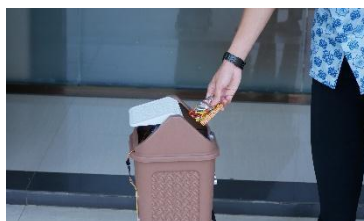


Figure 14 Simulation

6. The trash will open & close automatically and return to its original path.

- The trash will stop automatically if there is an object in front of it ±15cm from the trash can.

SUS Table

In this research, the device has been tested by 20 respondents. As shown in the SUS table below, every respondent gave a score with average score of 69.125 which is included in Acceptable category.

NO	RESPONDENT	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	AMNT	SCR
1	Respondent 1	1	2	3	0	3	2	2	3	3	0	19	47.5
2	Respondent 2	3	2	2	0	3	2	2	2	3	0	19	47.5
3	Respondent 3	4	3	4	2	3	3	3	3	3	0	28	70
4	Respondent 4	2	2	3	2	3	2	1	3	3	1	22	55
5	Respondent 5	3	4	4	2	3	2	3	3	3	2	29	72.5
6	Respondent 6	3	3	3	2	3	2	2	3	2	1	24	60
7	Respondent 7	3	2	3	2	3	3	2	2	4	2	26	65
8	Respondent 8	4	2	4	0	4	3	4	2	2	0	25	62.5
9	Respondent 9	4	4	4	4	3	2	3	3	3	3	33	82.5
10	Respondent 10	4	3	4	4	3	2	4	4	4	0	32	80
11	Respondent 11	2	3	2	0	3	1	2	4	4	0	21	52.5
12	Respondent 12	4	3	3	2	3	3	3	3	3	2	29	72.5
13	Respondent 13	4	4	3	2	2	2	3	3	4	3	30	75
14	Respondent 14	3	0	3	0	2	2	3	4	3	0	20	50
15	Respondent 15	4	2	3	1	3	3	4	3	3	2	28	70
16	Respondent 16	4	3	3	4	3	3	4	4	3	1	32	80
17	Respondent 17	4	4	4	4	4	4	2	4	3	4	37	92.5
18	Respondent 18	3	3	3	3	3	2	3	4	4	4	32	80
19	Respondent 19	3	4	4	4	4	4	2	4	3	2	34	85
20	Respondent 20	3	2	4	4	1	3	4	4	4	4	33	82.5
TOTAL SCORE												1382.5	
AVERAGE SCORE												69,125	

V.5. Black Box

No	Testing	Test case	Expected Results	Result
1.	L289N Motor Driver	Can the driver control both motors' speed and direction?	The driver can control both motors' speed and direction.	Valid
2.	Infrared Sensor Module	Can the Infrared Sensor Module detect objects obscuring its vision and return a high voltage input?	The Infrared Sensor Module can detect objects obscuring its vision and return a high voltage input.	Valid
3.	HC-SR04 Ultrasonic Sensor	Can the Ultrasonic HC-SR04 Sensor trigger and echo ultrasonic sound waves to determine obstacle distance in front of it?	The Ultrasonic HC-4.SR04 Sensor can trigger and echo ultrasonic sound waves to determine obstacle distance in front of it.	Valid

4.	SG90 Servo Motor	Can the SG90 Servo Motor be controlled to open or close the lid mechanism?	The SG90 Servo Motor can be controlled to open or close the lid mechanism.	Valid
5.	Pigpio Daemon	Can the pigpio Daemon launch the pigpio library as a daemon to provide control for all components?	The pigpio Daemon can launch the pigpio library as a daemon to provide control for all components.	Valid
6.	Flask Framework	Can the Flask Framework accept API calls and communicate with the pigpio Daemon to control all components based on the API calls?	The Flask Framework can accept API calls and communicate with the pigpio Daemon to control all components based on the API calls.	valid
7.	.Nginx Server	Can the Nginx Server serve the frontend web app to the user while proxy reversing API calls to the Flask backend?	The Nginx Server can serve the frontend web app to the user while proxy reversing API calls to the Flask backend.	valid

Conclusions

The implementation of IoT technology in the mobile trash bin prototype demonstrates that an interactive, mobile medium can encourage users to dispose of waste more easily and more routinely in the appropriate receptacle, indicating that this type of media has potential to support the formation of proper waste disposal habits. The Raspberry Pi 4 successfully operated as the central control unit of the system by coordinating the ultrasonic and infrared sensors, the motor driver and its DC motors, and the IoT communication modules, thereby validating its suitability as a compact hub for IoT-based waste management applications. Furthermore, a functional mobile trash bin prototype was realized by integrating an ultrasonic sensor for obstacle detection, a DC motor for wheel actuation, and a Raspberry Pi 4 as the main controller, with testing confirming that the device was able to follow a predetermined path and perform its core functions reliably.

Suggestions

Subsequent development of this prototype is recommended to employ two separate power supplies, one dedicated to the motors and another to the Raspberry Pi 4, to achieve a more stable current and reduce the risk of system resets or voltage drops. It is also advisable to select motors with a lower rotational speed so that the torque is less aggressive and the movement of the bin is smoother and safer, and to utilize batteries with a larger capacity to support longer operating times. Considering the positive effects observed in user interaction with the device, further enhancement of the prototype is encouraged, and the broader application of IoT technology in other everyday objects is suggested, as there remains substantial potential for innovation and impact in this domain

Acknowledgement

The authors would like to express sincere gratitude to their parents for continuous encouragement, to Ust. Azhar Faturohman Ahidin, S.Si., Ust. Alif Rezky, M.Pd., Ust. Panji Asmara, S.Pd., and Ust. Rayis Syamlan, S.T. for their invaluable guidance and supervision, and to Albinnaa Islamic Boarding School and all parties who provided facilities and support for this research

References

- [1] Agnes Z. Yonatan. (2024). Survei GoodStats: Benarkah Kesadaran Masyarakat Akan Isu Sampah Masih Rendah? Goodstats. <https://goodstats.id/article/survei-goodstats-benarkah-kesadaran-masyarakat-akan-isu-sampah-masih-rendah-U7WXA>
- [2] Diwan, S. A. (2025). Optimizing guest experience in smart hospitality: Integrated fuzzy-AHP and machine learning for centralized hotel operations with IoT. *Alexandria Engineering Journal*, 116, 535–547. <https://doi.org/10.1016/j.aej.2024.11.051>
- [3] Meddeb, H., Abdellaoui, Z., & Houaidi, F. (2023). Development of surveillance robot based on face recognition using Raspberry-PI and IOT. *Microprocessors and Microsystems*, 96. <https://doi.org/10.1016/j.micpro.2022.104728>
- [4] Monkam, P., Lu, W., Jin, S., Shan, W., Wu, J., Zhou, X., Tang, B., Zhao, H., Zhang, H., Ding, X., Chen, H., & Su, L. (2023). US-Net: A lightweight network for simultaneous speckle suppression and texture enhancement in ultrasound images. *Computers in Biology and Medicine*, 152, 106385. <https://doi.org/10.1016/J.COMPBIOMED.2022.106385>
- [5] Numa, I. A. N., Wolf, K. E., & Pastore, G. M. (2023). FoodTech startups: Technological solutions to achieve SDGs. *Food and Humanity*, 1, 358–369. <https://doi.org/10.1016/j.foohum.2023.06.011>
- [6] Razip, M. M., Savita, K. S., Kalid, K. S., Ahmad, M. N., Zaffar, M., Abdul Rahim, E. E., Baleanu, D., & Ahmadian, A. (2022). The development of sustainable IoT E-waste management guideline for households. *Chemosphere*, 303. <https://doi.org/10.1016/j.chemosphere.2022.134767>
- [7] Saulītis, A., Silkāne, V., & Gaile, G. A. (2024). Nudging pro-environmental behaviour in a subsidized waste recycling system: A field experimental study. *Journal of Environmental Psychology*, 99. <https://doi.org/10.1016/j.jenvp.2024.102416>
- [8] Upahm Abas, S., Duran, F., & Tekerek, A. (2023). A Raspberry Pi based blockchain application on IoT security. *Expert Systems with Applications*, 229. <https://doi.org/10.1016/j.eswa.2023.120486>
- [9] Zhang, J., Huang, Y., Zhu, J., & Zhao, L. (2023). A meta-analysis on the effectiveness of food-waste reducing nudges. *Food Policy*, 120. <https://doi.org/10.1016/j.foodpol.2023.102480>