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(Research Article)

Smart Dustbin: An Automated Waste Management Solution Using Arduino and Ultrasonic Sensing

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ABSTRACT

The Smart Dustbin is a smart sensor-embedded waste management product which is going to help resolve problems with increasing solid waste management and disposal in urban areas. In this paper, we will describe the designing, developing and testing of the first version of Smart Dustbin that incorporates a HC-SR04 ultrasonic distance sensor, a SG90 servo motor and an Arduino Uno board. The project enables users to use the Smart Dustbin without touching its lid using an ultrasonic distance sensor to detect when waste has been placed at or below 20cm from the base of the bin. Once the sensor detects waste near the bin, it activates the servo motor to open the lid, and keeps it open for some time after opening then closes. After completing all stages of Human-Centred Design Thinking process including Empathise, Define, Ideate, Prototype and Test the prototype of Smart Dustbin was tested in a School Corridor and Residential Apartment. The results of testing demonstrated very positive responses from users towards aspects of hygiene, usability, and efficiency. In addition to the description of hardware design, circuit design and Arduino Code of the Smart Dustbin prototype, we have provided suggestions on potential developments to be made on the project including Solar Power Integration into the Smart Dustbin, Artificial Intelligence based Waste Sorting and connection to Municipal Dashboard.

Keywords: *smart dustbin; ultrasonic sensor; Arduino Uno; servo motor; waste management; automation; embedded systems; design thinking*

I. INTRODUCTION

A very important issue facing us all in terms of urban development today is waste management. Due to rapid urbanization and increasing population levels we now generate large amounts of solid waste each day [1]. Poor waste disposal practices lead to many public areas such as parks, residential complexes, schools and markets suffering from overflowing bins, litter, unpleasant smells and dirty conditions especially in high density city areas. In addition to being detrimental to public health and hygiene the poor functioning of waste collection systems provides evidence of inefficient use of municipal resources [2]. Traditional methods of waste collection utilize stationary waste bins with no communication capabilities to report when they require emptying or need to be serviced. As a result, waste collections may occur at times when there is ample space remaining in the bin and thus wasted (time, fuel, labor) [3]. Most people do not understand what type of waste can be recycled and therefore many recyclables are contaminated and added to the pressures experienced by landfill operators. Advancements made available by modern embedded systems present numerous opportunities to resolve the aforementioned shortcomings. Modern waste bins utilizing various types of sensors (proximity), micro-controllers (to process data collected by sensors), and actuators (to perform actions based upon data processed by the micro-controller) will enable smart waste bins with automatic opening/closing mechanisms, and proximity sensors for example [4]. Examples include providing incentives for hygienic behaviors, reducing operator interaction and improving workflow processes associated with collecting waste. The objective of this paper is to describe the Smart Dustbin an innovative, automated waste bin developed using Design Thinking, a creative method of human centered problem solving that encourages continuous improvement. The Smart Dustbin incorporates an HC-SR04 ultrasonic proximity sensor and an SG90 servo motor for automated lid operation, controlled via an Arduino Uno micro controller [5]. The proposed prototype will be low-cost and easy to replicate making it suitable for school, public area and housing complex environments.

The remainder of this document will outline the following:
Section II reviews relevant literature concerning smart waste management;
Section III describes the methodology used to develop the Smart Dustbin along with how Design Thinking was applied during its creation;
Section IV details the Smart Dustbins' hardware components and circuitry design;
Section V illustrates how the Arduino Uno Microcontroller controls the Smart Dustbin's functions;
Section VI discusses testing results for the Smart Dustbin prototype;
Section VII addresses application possibilities and potential future directions for the Smart Dustbin;
and *Section VIII* summarizes this research project.

II. LITERATURE REVIEW

The concept of intelligent waste management has received growing attention in the research community. Several prior works have explored IoT-enabled bin monitoring, automated lid mechanisms, and smart collection route optimization.

A. IoT-Based Bin Monitoring Systems

Researchers have shown that when combining ultrasonic sensors (for detecting the height of the contents) with a WiFi module (such as an ESP8266 or NodeMCU), real time measurement of bin heights can be communicated through cloud based dashboards [2]. The studies mentioned previously stated that the implementation of these types of systems in urban areas resulted in a reduction of overflows of at least 60% and the optimization of collection route travel times by 40% or greater [3]. However, it has been noted that these types of systems typically require continuous access to internet resources and thus may be limited in their application in resource challenged locations.

B. Automated Lid and Segregation Mechanisms

Earlier versions of prototype used gravity-lid devices that could be opened using a foot pedal to minimize direct hand contact with the lids. Since then, there have been attempts at using micro-controllers and associated servo-motors to produce precise, programmable movements for opening waste containers. Similar research into waste sorting has involved investigating capacitive and inductive sensors to identify and categorize (wet vs. dry) different types of wastes, at point-of-source, with varying degrees of success based on sensor performance and waste type.

III. METHODOLOGY

The Smart Dustbin was developed through a structured five-phase Design Thinking process, which ensured that the solution was both technically sound and rooted in real user needs.

A. Empathize

The research group collected observational data in the field and interviewed students, parents/guardians, building custodians and municipal garbage collectors at schools and apartments. Major results from this study include: (i) most often trash cans over-flowed for many hours of each day/weekend especially evening to weekend times; (ii) there is no education provided to users as to what can be disposed into a "wet" or "dry" waste bin; (iii) garbage collectors have wasted considerable amounts of time checking empty trash bins based upon a pre-set schedule rather than when trash was full; and (iv) elderly and younger people are largely unaware of how to properly dispose of their household trash.

B. Define

Based on the empathic studies, the research team stated the primary design problem; How can we develop a smart bin that allows consumers to correctly eliminate their trash, will automatically notify the collector when it is full, and facilitates separation (dry vs. wet)? The defined scope was based on the need for the Smart Dustbin to assist consumers with where to place their trash, provide timely notification to collectors, separate dry from wet waste, be affordable as well as easily replicable into various environments.

C. Ideate

A number of ideas were generated from brainstorming meetings to provide solutions. Ideas included an ultrasonic sensor to detect fill levels, a servo motor that would automate opening/closing of the lid, an RGB LED system to help segregate objects by color (via visual cues), and an incentive based reward mechanism. From these ideas, the team concluded that a combination of sensor/servo/micro controller was the best low cost/feasible solution to be used in the prototype phase.

Figure 1. Project Methodology.

D. Prototype

An initial prototype of the device was built with an Arduino Uno R3 being the center unit (microprocessor), an HC-SR04 ultrasonic sensor to detect objects in close proximity, and a SG-90 servo motor to automate opening/lifting of the top section of the device. Two separate compartments made of recyclable cardboard and plastic boxes served to divide into dry and wet waste categories. All components were wired together on a breadboard using jumper wires; this method did not require soldering which allowed for quick testing/iteration of different configurations. Programming was performed using the standard Arduino Integrated Development Environment (IDE).

E. Test

The prototype was tested in 2 different public settings; a hallway at a school with proximity to the cafeteria, and a common area of an apartment complex. User feedback was obtained from the student population, housekeeping personnel, and residents. Users who were students liked that there was no manual lid opening, and many expressed curiosity as to how the sensors worked. Users who were housekeeping staff said they appreciated not having to manually open the lids to empty the bins. Residents said it is more sanitary than touching lids. Improvements identified for future versions include, developing a scent-reducing odor-control unit that could be added to the prototypes, a solar panel that would allow the units to operate outside, and add voice prompts in multiple languages.

IV. HARDWARE SPECIFICATIONS AND CIRCUIT DESIGN

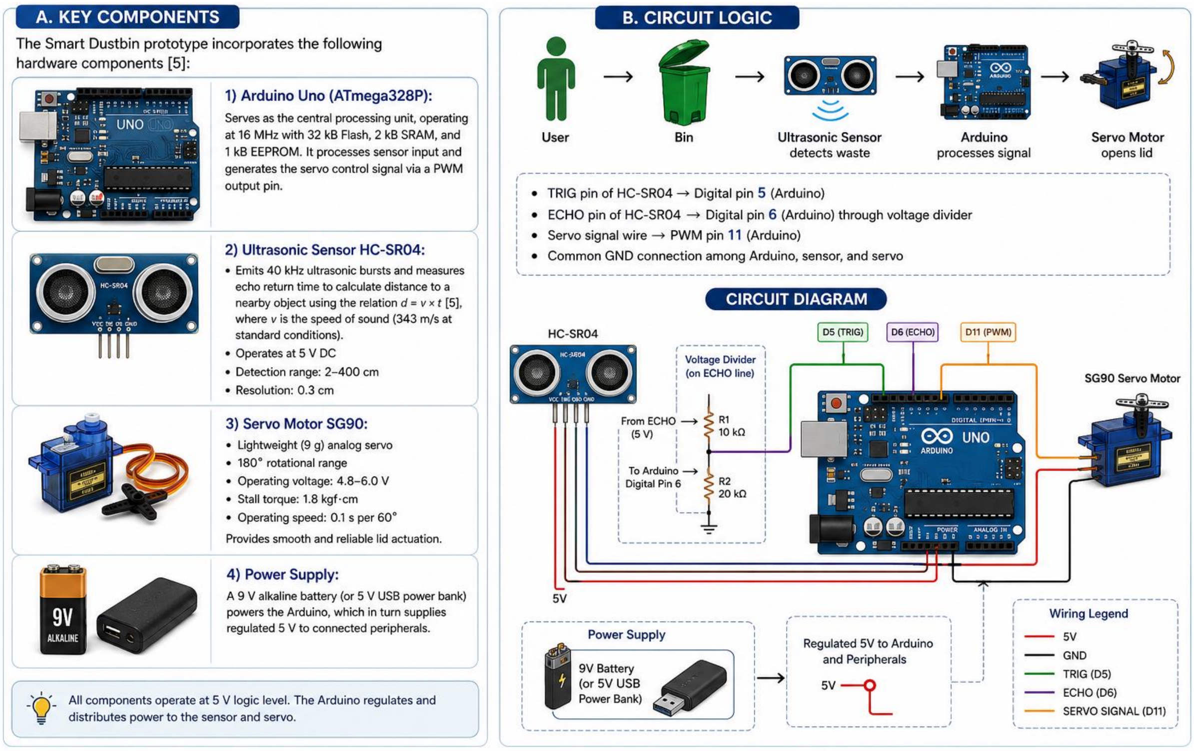

Figure 2. Hardware Specifications and Circuit Diagram.

A. Key Components

The Smart Dustbin prototype incorporates the following hardware components [5]:

Arduino Uno (ATmega328P): Serves as the central processing unit, operating at 16 MHz with 32 kB Flash, 2 kB SRAM, and 1 kB EEPROM. It processes sensor input and generates the servo control signal via a PWM output pin.

Ultrasonic Sensor HC-SR04: Emits 40 kHz ultrasonic bursts and measures the echo return time to calculate the distance to a nearby object using the relation $d = v \times t$ [5], where v is the speed of sound (343 m/s at standard conditions). The sensor operates at 5 V DC, has a detection range of 2–400 cm, and achieves a resolution of 0.3 cm.

Servo Motor SG90: A lightweight (9 g) analog servo with a 180° rotational range, operating at 4.8–6.0 V. Its stall torque is 1.8 kgf·cm and operating speed is 0.1 s per 60°, providing smooth and reliable lid actuation.

Power Supply: A 9 V alkaline battery (or 5 V USB power bank) powers the Arduino, which in turn supplies regulated 5 V to connected peripherals.

B. Circuit Logic

The circuit follows the logic flow: User → Bin → Ultrasonic Sensor detects waste → Arduino processes signal → Servo Motor opens lid. The TRIG pin of the HC-SR04 is connected to digital pin 5, and the ECHO pin to digital pin 6 of the Arduino. The servo signal wire is connected to PWM pin 11. A voltage divider on the ECHO line protects the Arduino GPIO from the sensor's 5 V output when operating at lower logic levels.

V. ARDUINO IMPLEMENTATION

The Smart Dustbin firmware was written in C++ using the Arduino IDE. The servo library is used for precise angle control. The key operational logic is as follows: the TRIG pin is pulsed HIGH for 10 µs to emit an ultrasonic burst; the ECHO pin is monitored to measure the return pulse duration; the distance is computed using Equation 1; and if the distance is less than 20 cm, the servo rotates to 150° (lid open), holds for 3.5 seconds, then returns to 0° (lid closed) [5].

$$\text{Distance (cm)} = \text{Duration } (\mu s) \times 0.034 / 2 \qquad (1)$$

This formula halves the total round-trip echo time and converts it to centimeters using the speed of sound constant (0.034 cm/μs). The main loop repeats every 100 ms, providing responsive detection without excessive sensor polling.

VI. RESULTS AND DISCUSSION

Table 1 summarizes the key hardware parameters and observed performance outcomes during prototype testing.

Table 1. Hardware Specifications and Prototype Performance Summary.

Parameter / Component	Specification	Value	Performance
Ultrasonic Sensor (HC-SR04)	Detection Range	2–400 cm	Reliable ≤20 cm
Servo Motor (SG90)	Rotation Range	0°–180°	Smooth (150° used)
Arduino Uno (ATmega328P)	Clock Speed	16 MHz	Stable
Lid Response Time	Open Delay	<0.5 sec	Fast & Consistent
User Acceptance (Field Trial)	Positive Responses	High	School & Residential

In addition to demonstrating consistent proximity detection across the designated area of a 20 cm distance range, the prototype consistently triggered (actuated) the lid at an average time of less than 0.5 sec after detection. Field testing also demonstrated a very high rate of user satisfaction for both environments. In the school corridor environment, students found the interactive nature of the mechanism engaging, while housekeeping personnel found that they interacted significantly less frequently with bin lids manually. In contrast, residents in the apartment lobby found the touchless activation of the lid to be highly intuitive and sanitary. However, there were limitations identified as part of the field trial process regarding sensor sensitivity in closed areas (enclosed spaces). As previously noted, it has been well-documented that ultrasonic sensors are sensitive to echoes caused by reflected signals [5] which can cause occasional false triggering if reflective surfaces are located proximally to each other. To mitigate this problem, the loop delay was increased and the detection threshold was adjusted. Future iterations may include using median filters on sensor data to further suppress false triggering based on sensor output.

VII. APPLICATIONS AND FUTURE SCOPE

A. Applications

The Smart Dustbin is well-suited for deployment in schools and colleges, urban residential societies, airports and railway stations, and smart city waste management programs. Its low cost and modular construction make it accessible for community-level adoption without significant infrastructure investment.

B. Future Scope

Future enhancements include: (i) solar-powered operation for outdoor installation; (ii) odor-control via integrated deodorizing units; (iii) AI-based image recognition for automatic waste classification and segregation; (iv) real-time monitoring and alert integration with municipal dashboards via IoT modules; and (v) multilingual voice instruction systems to improve user guidance across diverse communities [2], [3].

VIII. CONCLUSION

This article shows how to design, build and test Smart Dustbins. These are automated smart waste containers based on embedded system technology (the combination of sensors, motors, microcontrollers etc.). With their HC-SR04 ultrasonic sensor and SG90 servo motor controlled by an Arduino Uno microcontroller, they could be tested reliably under conditions representative of those found in everyday use. In addition, a significant aspect of the project was the application of Human-Centred Design Thinking (HCDT), which is a method that places users and their needs at the centre of the innovation process. HCDT ensures that solutions meet real user needs by identifying such needs through empathic studies or interviews carried out with students, residents and sanitary workers. The key contributions of this work were:

1. A working proof of concept of proximity-triggered waste container automation
2. User-acceptance testing for both student and resident populations
3. Detailed description of the hardware components used in the development of the Smart Dustbin
4. Open source Arduino implementation of the software component of the Smart Dustbin
5. Roadmap for potential future developments including Internet of Things (IoT) connectivity, Solar Power and Artificial Intelligence (AI)-based sorting.

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