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Design and Build of an Automatic Cat Litter Box Cleaner Based on Internet of Things with Weight Detection

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Abstract

This research aims to design and implement an Internet of Things (IoT)-based Cat Litter Box that can automatically clean the litter box based on weight detection. The system uses an ESP8266 microcontroller as the main controller, which is connected to the Firebase Realtime Database and an Android application. A load cell sensor is used to detect the weight of the waste, while an infrared obstacle sensor functions to detect the presence of the cat. When the detected weight is ≤ 500 grams and no object is detected, a stepper motor controlled by a DRV8825 driver activates the cleaning mechanism, and an MG996R motor opens and closes the waste cover. The sensor data and system status are sent to Firebase and displayed through the Android application. Based on testing, the system worked properly. The device was able to perform automatic cleaning according to sensor conditions, display sensor data on the application, and send notifications when the detected weight exceeded 500 grams or when the infrared sensor detected an obstruction for a certain duration.

Keywords: *Cat Litter Box; ESP8266; Firebase; Infrared Obstacle; Internet of Things; Load Cell*

1. Introduction

Maintaining the hygiene of a cat litter box is crucial for the health of both the pet and the owner, as proper sanitation ensures environmental cleanliness and minimizes disease risks [1], [2]. A litter box functions as an indoor repository that aligns with a cat's instinctual behavior to bury its waste [3]. However, traditional manual cleaning is often time-consuming and inconvenient, especially for individuals with busy schedules or limited mobility [4]. Furthermore, accumulated waste and the resulting ammonia emissions can significantly reduce air quality within the living space, causing unpleasant odors and potential respiratory discomfort [2].

The advancement of Internet of Things (IoT) technology has enabled the development of intelligent pet care systems capable of automating waste management. Several studies have proposed automated litter boxes using different microcontrollers and sensors. Fadhiilah et al. [5] developed a self-cleaning litter box using PIR and ultrasonic sensors with Telegram notifications. Idlal et al. [6] automated litter cleaning and feeding using IoT, though experiencing some load cell inaccuracies. Zainal and Lee [7] utilized an ESP32 and stepper motors for litter separation, while Fahrozy and Meizar [8] implemented an IoT-based smart litter box using NodeMCU and the Blynk platform. Additionally, Waliyyu [9] constructed an automatic litter box utilizing optical and weight sensors to manage waste and sand refills.

Although previous studies have demonstrated the feasibility of automated litter boxes, several limitations remain. Many systems face mechanical challenges, such as suboptimal waste separation due to insufficient motor torque, leading to high error rates [9]. Furthermore, some systems lack robust real-time monitoring features accessible via custom mobile applications, rely heavily on complex multi-sensor setups that are difficult to maintain [5], [8], or do not implement adequate safety delays considering the pet's natural behavior [4]. Therefore, there is still a need for a reliable, IoT-integrated automated litter box with precise weight detection and a fail-safe cleaning mechanism.

This study proposes the design and implementation of an IoT-based automatic cat litter box cleaner using an ESP8266 microcontroller. The system utilizes an infrared obstacle sensor to ensure the cat's safety by detecting its presence, while a load cell monitors the accumulated waste weight in the disposal bin. The cleaning mechanism is driven by a NEMA 17 stepper motor equipped with a DRV8825 driver, and an MG996R servo motor operates the waste bin cover to contain odors. All operational data and bin status are transmitted to the Firebase Realtime Database and displayed through an Android application, enabling real-time monitoring by users.

The main contributions of this study are as follows: (1) the development of an automatic litter box cleaner equipped with an infrared safety interlock to prevent operation while the cat is present; (2) the implementation of a weight-based notification system using a load cell that halts the cleaning cycle and alerts the user when the waste bin reaches a 500 gram capacity; and (3) the integration of Firebase Realtime Database and a custom Android application for real-time remote monitoring and control.

2. Research Method

This study focuses on the design and implementation of an Internet of Things (IoT)-based automatic cat litter box cleaner using an ESP8266 microcontroller. The development process adopted the Waterfall method, which sequentially covers requirements analysis, system design, implementation, and testing. The overall methodology is illustrated through the system architecture and operational workflow presented in the following subsections.

2.1. System Architecture

The proposed system consists of a NodeMCU ESP8266 microcontroller, an infrared obstacle sensor, a load cell, motor actuators, Firebase Realtime Database, and a mobile application. The ESP8266 serves as the central controller responsible for processing sensor inputs, executing the cleaning logic, and handling cloud communication. An infrared obstacle sensor is utilized to detect the presence of the cat within the litter box. A load cell combined with an HX711 amplifier module is installed in the waste compartment to measure the accumulated waste weight. For the cleaning mechanism, a NEMA 17 stepper motor driven by a DRV8825 driver is employed to move the rake horizontally along a 33 cm lead screw, while an MG996R servo motor operates the waste bin cover. The hardware is powered by a 12V 5A DC adapter, regulated by buck converters to supply appropriate 5.2V voltages to the microcontroller and servo motor. All status and sensor data are transmitted to the Firebase Realtime Database, allowing users to monitor and control the system remotely via a dedicated Android application. As you can see in Fig. 1.

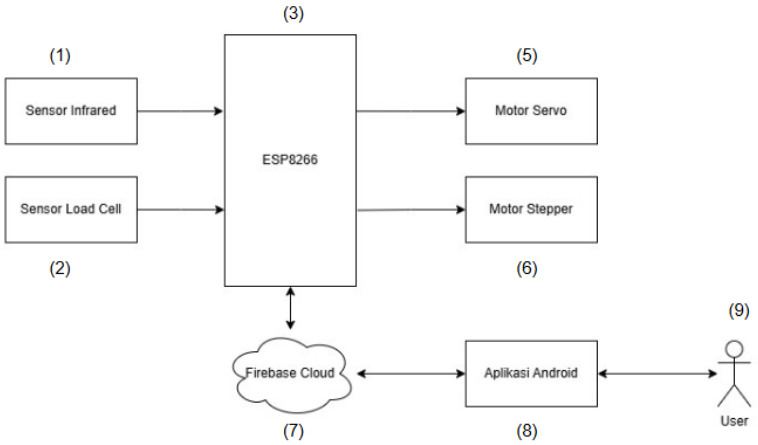

Fig. 1: Block Diagram of the proposed system

2.2. System Workflow

The operational workflow begins with the initialization of the ESP8266, sensors, and actuators. During the standby mode, the system continuously monitors the litter box using the infrared obstacle sensor. If a cat is detected, the system waits until the cat exits the box. To ensure safety and allow the waste to clump, the system imposes a 3-minute delay after the cat leaves before initiating the cleaning sequence. Before running the cleaning cycle, the system checks the waste bin's capacity using the load cell. If the accumulated weight exceeds 500 grams, the cleaning process is halted, and an automatic notification is pushed to the user's smartphone, indicating that the bin is full. If the weight is within the safe limit ($\leq$ 500 grams), the MG996R servo opens the waste bin cover, and the stepper motor drives the rake to sweep the waste into the compartment. Afterward, the servo closes the cover, the rake returns to its initial position, and the updated weight is transmitted to the Firebase Realtime Database.

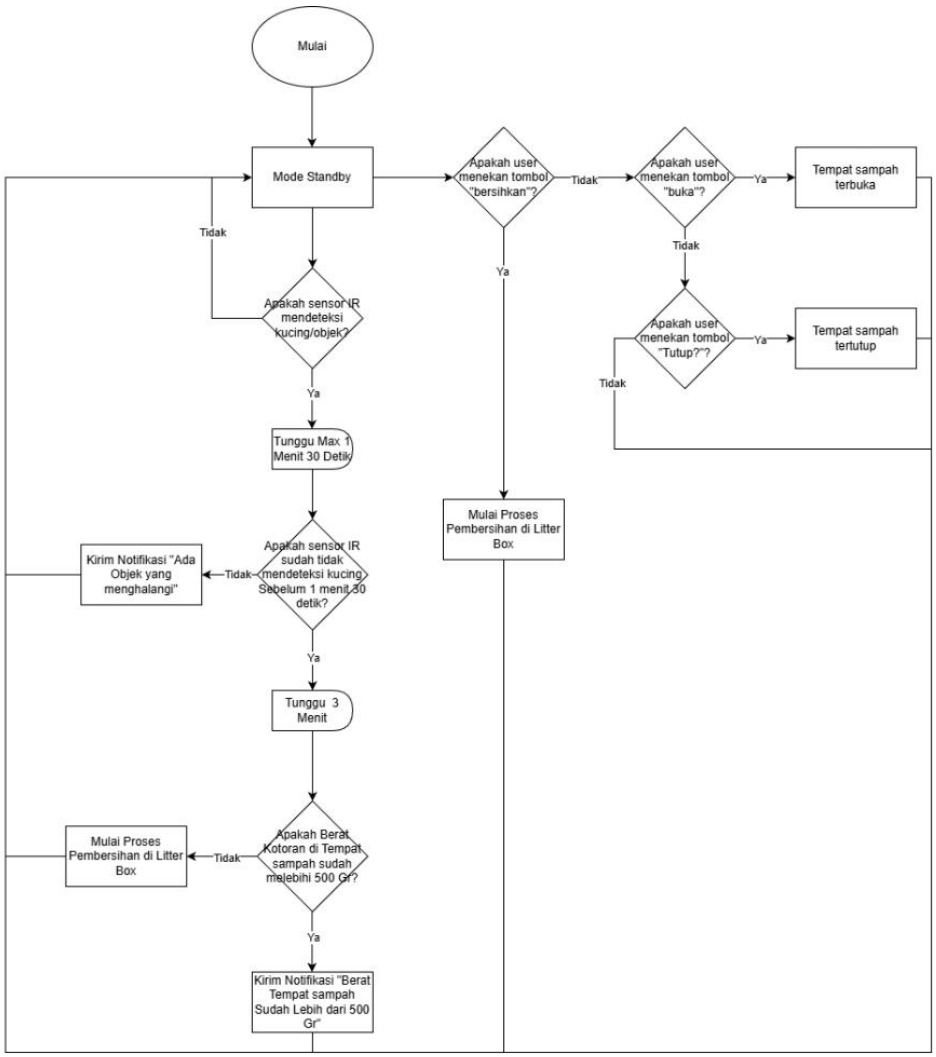

Fig. 2: Workflow of the proposed system

3. Result and Discussion

3.1. Prototype Implementation

The proposed automatic cat litter box was successfully developed by integrating the ESP8266 microcontroller, an infrared obstacle sensor, a load cell, a NEMA 17 stepper motor, an MG996R servo motor, Firebase Realtime Database, and a custom Android application. The ESP8266 serves as the central controller responsible for processing sensor data, executing cleaning logic, controlling motor movements, and transmitting information to the cloud database. The hardware implementation was assembled within a custom wooden structure coated with High-Pressure Laminate (HPL) for durability against moisture. The mechanical cleaning system relies on a stepper motor driving a rake along a 33 cm lead screw, while the servo motor operates the waste bin cover. The infrared sensor is positioned at the front to detect the cat's presence, and the load cell is placed beneath the waste bin to measure the accumulated weight. The final physical assembly of the hardware prototype is depicted in Figure 3.

Fig. 3*:* The physical prototype of the automated cat litter box cleaner

Furthermore, a mobile monitoring application, "SmartCatLitterBox," was developed and connected to the Firebase Realtime Database. The application enables users to monitor the accumulated waste weight, cat detection status, and device operational status in real-time, as well as providing manual control options (Clean, Open, Close). The user interface of the application, displaying real-time data integration, is illustrated in Fig. 4. The successful integration of hardware and software components demonstrates the feasibility of implementing an IoT-based automatic litter box cleaner.

Fig. 4: The user interface of the SmartCatLitterBox Android application

3.2. Load Cell Sensor Testing

The load cell sensor, coupled with the HX711 module, was evaluated to determine its accuracy in measuring the weight of the accumulated waste in the bin. The measured values were compared with the actual weights to assess the sensor's performance. The system is programmed to halt operation if the detected weight reaches or exceeds the 500 gram threshold.

Table 1: Load Cell Sensor Testing Result

No	Actual Weight	Detected Weight	Device Status
1	259 g	270 g	Active
2	237 g	244 g	Active
3	630 g	633 g	Nonactive (Overload)
4	87 g	0 g	Active
5	26 g	30 g	Active
6	1200 g	1186 g	Nonactive (Overload)
7	2486 g	2450 g	Nonactive (Overload)
8	355 g	350 g	Active
9	470 g	468 g	Active
10	100 g	0 g	Active

The testing results indicate that the load cell provides reasonably accurate weight measurements, with slight deviations from the actual weights, which is expected in electronic measurement systems. Notably, the sensor successfully triggered the system to halt operation (Nonactive) when the weight exceeded the 500 gram limit, demonstrating effective capacity management. Out of 10 trials, 8 measurements accurately reflected the system's operational logic, yielding a 90% success rate. The discrepancies observed at lower weights (e.g., 87g and 100g reading as 0g) suggest a minor calibration offset or structural interference, yet the overall system safety threshold remained intact.

3.3. Infrared Obstacle Sensor Testing

The infrared obstacle sensor was tested to determine its effective detection range for various objects. The sensor must reliably detect the presence of a cat to prevent the cleaning mechanism from operating while the litter box is in use.

Table 2: Infrared Obstacle Sensor Testing Result

No	Test Distance (cm)	Cat Detection	Hand Detection	Paper Detection
1	2 cm	Detected	Detected	Detected
2	4 cm	Detected	Detected	Detected
3	6 cm	Detected	Detected	Detected
4	8 cm	Detected	Detected	Detected
5	10 cm	Not Detected	Detected	Detected
6	12 cm	Not Detected	Not Detected	Detected
7	15 cm	Not Detected	Not Detected	Detected
8	20 cm	Not Detected	Not Detected	Not Detected

The results show that the sensor consistently detects all object types within a close range of 2 to 8 cm. However, at a distance of 10 cm, the sensor failed to detect the cat (fur), while still detecting the hand and paper. This variation confirms that the effective range of the infrared sensor is highly dependent on the surface properties of the object. Paper, being smooth and reflective, provided the strongest return

signal (up to 15 cm), whereas cat fur tended to absorb or scatter the infrared light, resulting in a weaker reflection and a shorter effective detection range (2-8 cm). Despite this limitation, the sensor placement ensures reliable detection when the cat enters the litter box.

3.4. Actuator Performance Testing

The NEMA 17 stepper motor and the MG996R servo motor were tested to verify their accuracy and responsiveness in executing the cleaning mechanism. The stepper motor drives the rake, while the servo operates the waste bin cover.

Table 3: Stepper Motor Testing Result

No	Commanded Distance (cm)	Actual Distance Traveled (cm)
1	10 cm	10 cm
2	20 cm	20 cm
3	25 cm	25 cm
4	33 cm	33 cm

As shown in Table 3, the NEMA 17 stepper motor, controlled by the DRV8825 driver, demonstrated excellent precision. The actual distance traveled by the rake matched the commanded distance exactly in all trials, indicating that the motor control system operates flawlessly without missing steps.

Table 4: Servo Motor Testing Result

No	Commanded Angle (°)	Waste Bin Cover Condition
1	0	Closed
2	90	Half Open
3	150	Fully Open

The servo motor testing (Table 4) confirms that the MG996R successfully opens and closes the waste bin cover according to the commanded angles. The servo responded quickly and accurately, whether controlled manually via the Android app or automatically during the cleaning cycle. Although occasional minor resistance was noted due to the weight of the cover material, the functional operation remained robust.

3.5. System Integration and Firebase Communication Testing

The overall system integration testing evaluated the seamless operation of sensors, actuators, Firebase Realtime Database, and the Android application. The testing ensured that data transmission and automated responses occurred correctly under various scenarios.

Table 5: Overall System Integration Testing Result

No	Device Condition	IR Detection	Detected Weight (g)	Stepper Response	Servo Response	App Notification
1	No Cat Present	False	26	No Movement	No Movement	None
2	Cat Enters Box	TRUE	26	No Movement	No Movement	None
3	Cat Exits, Weight ≤ 500 g	False	26	Moves to Clean	Opens & Closes Cover	None
4	Weight > 500 g	False	633	No Movement	No Movement	"Litter Box Deactivated – Weight exceeded 500 g."
5	Object Blocks IR > 1m 30s	TRUE	45	No Movement	No Movement	"Warning: Cat is idle in litter box for > 1m 30s."
6	"Clean" button pressed in app	False	120	Moves to Clean	Opens & Closes Cover	None
7	"Open" button pressed in app	False	44	No Movement	Opens Cover	None
8	"Close" button pressed in app	False	245	No Movement	Closes Cover	None

The integration testing confirms that the system operates exactly as designed. The safety interlock successfully prevents the cleaning mechanism from engaging when a cat is present (Test 2) or if the sensor is blocked for an extended period, triggering an appropriate notification (Test 5). The 3-minute delay mechanism functions correctly after the cat exits, followed by the automated cleaning cycle (Test 3). Furthermore, the load cell effectively halts the system and alerts the user when the bin is full (Test 4). Manual overrides via the Android app (Tests 6, 7, 8) were executed promptly, demonstrating reliable bidirectional communication through the Firebase Realtime Database with an average response time of less than two seconds.

4. Conclusion

The development and implementation of the IoT-based automatic cat litter box cleaner have been successfully realized. The integration of the ESP8266 microcontroller with the HX711 load cell, infrared obstacle sensor, and motor actuators demonstrated reliable operational performance. The system effectively executed the automated cleaning mechanism while strictly adhering to the safety interlocks when a cat was detected. Furthermore, the 500-gram weight threshold accurately halted the system and triggered real-time notifications through the Firebase-integrated Android application, proving the system's capability in safely managing waste capacity and maintaining hygiene.

Although the system met its primary objectives, further improvements can be explored for future iterations. Enhancing the mechanical design with higher-torque motors and a lighter waste bin cover would optimize the cleaning and sealing processes. Additionally, replacing the infrared obstacle sensor with a PIR or ultrasonic sensor could provide more accurate pet detection, as it would be less affected by the light-absorbing properties of various cat fur types. Finally, the mobile application could be upgraded to include data visualization, such as weight-tracking graphs and cleaning history logs, to offer users more comprehensive monitoring capabilities.

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