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An Iot-Enabled System For Monitoring And Alerting Cat Litter Tray Cleaning Based On Fill-Level Detection

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Abstract—*Timely cleaning of cat litter trays is crucial for maintaining hygiene and ensuring the well-being of both pets and owners. However, manual monitoring is often inconsistent, leading to unpleasant odors, health risks, and behavioural issues in cats. This study presents the design and development of an IoT-enabled system that monitors the fill level of cat litter trays and sends automated reminders for cleaning. The system employs ultrasonic sensors to detect the accumulation of waste in the tray and transmits real-time data to a cloud-based platform via Wi-Fi-enabled microcontrollers. A mobile application interface is developed to notify users through alerts when the tray reaches a predefined fill threshold. Experimental validation demonstrated over 90% accuracy in fill-level detection and effective user notification under various usage conditions. The proposed solution offers a low-cost, scalable, and user-friendly approach to pet care automation, making it suitable for households and small pet-care facilities.*

Keywords— *Internet of Things (IoT), Fill-Level Detection, Cat Litter Monitoring, Ultrasonic Sensor, Smart Pet Care.*

INTRODUCTION

Domestic pet ownership, particularly of cats, has seen a steady global rise, necessitating smarter and more hygienic solutions for pet care. A critical aspect of feline hygiene involves the regular cleaning of litter trays, which, if neglected, can lead to health issues such as urinary tract infections in cats, unpleasant odors, and unsanitary living conditions. Despite its importance, cat litter maintenance is often overlooked due to forgetfulness or lack of a systematic monitoring mechanism[1-3].

The integration of Internet of Things (IoT) technologies into home automation has enabled the development of intelligent systems capable of real-time monitoring and alerting [4]. IoT-based pet care solutions have emerged as a promising domain, yet existing research and commercial products have largely focused on food dispensing, tracking, or environmental monitoring, with limited attention to sanitation management [5].

This paper presents the design and implementation of an IoT-enabled system that monitors the fill level of a cat litter tray using ultrasonic sensing and issues cleaning reminders via a mobile application[6]. The system employs a Wi-Fi-enabled microcontroller (ESP8266) to collect and transmit sensor data to a cloud platform, where threshold-based logic determines when to alert the user. The core contributions of this research include:

Development of a low-cost, non-intrusive sensor-based detection mechanism for litter accumulation

Real-time data acquisition and transmission using MQTT over Wi-Fi

An integrated alert system through mobile notifications for timely cleaning reminders

Experimental validation of the system's accuracy and reliability in varying operational conditions

By automating the monitoring of cat litter trays, this system not only improves hygiene but also enhances convenience for pet owners. The architecture is designed to be scalable and adaptable, paving the way for broader applications in smart home sanitation systems[7-10]. Fig.1. shows the overall system architecture of the research scenario.

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MOTIVATION

Maintaining cleanliness in pet environments is not only a matter of hygiene but also directly impacts animal welfare and household health[11]. Among domestic pets, cats are particularly sensitive to the cleanliness of their litter trays. Studies have shown that dirty or overfilled trays can cause stress, behavioural problems such as inappropriate elimination, and increased risk of infections[12]. Despite this, routine cleaning is often neglected due to human forgetfulness, inconvenience, or lack of real-time feedback on the litter condition[13].
Traditional solutions rely on manual observation, which is both inconsistent and impractical, especially for busy households or multi-pet environments[14]. Furthermore, while automated litter boxes exist, they are often expensive, mechanically complex, and inaccessible to average users. There is a clear need for a more affordable, reliable, and user-friendly solution that helps pet owners manage litter tray hygiene more effectively[15-17].

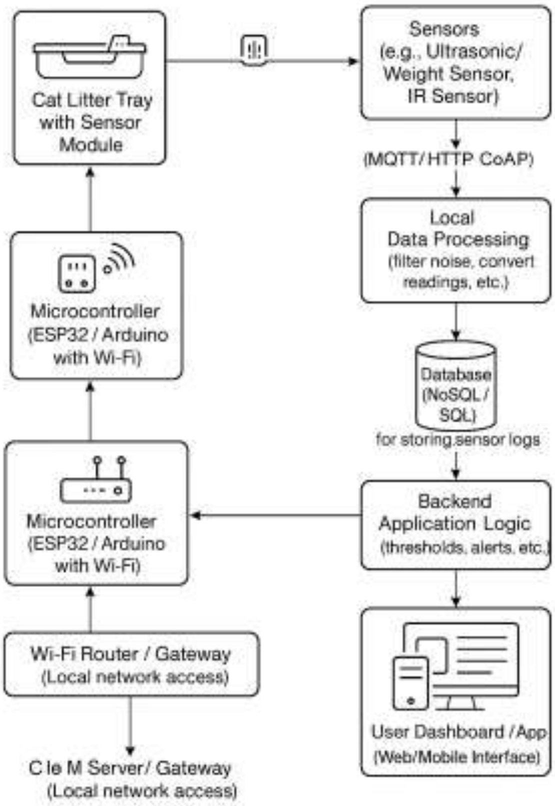

Fig.1. System Architecture

The motivation for this research arises from the intersection of two trends: the increasing adoption of IoT technologies in smart home systems, and the demand for intelligent pet care solutions that go beyond feeding and tracking[18-20]. By leveraging low-cost sensors and wireless communication, it is possible to design a lightweight system that automates the monitoring of litter conditions and provides timely alerts, thereby reducing health risks and improving the quality of life for both pets and owners. This work aims to fill that gap by proposing a novel, scalable IoT-based approach for proactive sanitation management in domestic pet care[21].

METHODOLOGY

The proposed system is designed to detect the fill level of a cat litter tray using ultrasonic sensing and to notify users when the waste accumulation exceeds a predefined threshold. The methodology consists of four core components: hardware setup, data acquisition, cloud communication, and alert notification system. Each component is described below:
A. System Architecture Overview
The system architecture includes:

Ultrasonic Sensor (HC-SR04): Measures the distance from the sensor to the surface of the litter to determine the fill level.
Microcontroller Unit (ESP8266 NodeMCU): Processes the sensor data and sends it to the cloud via Wi-Fi.
MQTT Protocol & Cloud Platform: Lightweight protocol used to publish sensor data to a cloud-based MQTT broker (e.g., Adafruit IO, ThingsBoard).
Mobile Notification Module: A mobile app or service (e.g., Blynk, IFTTT) subscribed to the MQTT topic triggers notifications when the threshold is breached. Fig.2. depicts the circuit based schematic of our prototype.

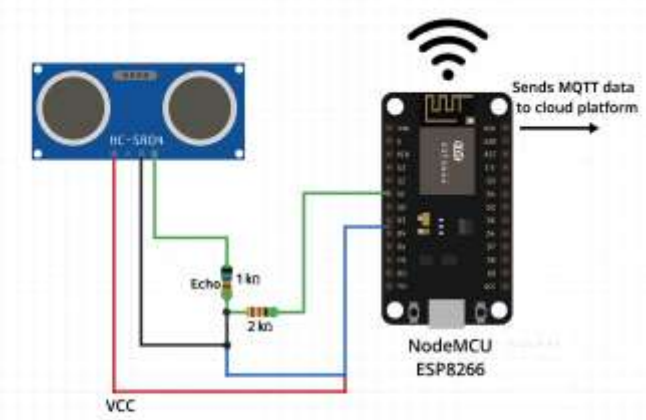

Fig. 2. Circuit Schematic Diagram

B. Fill-Level Detection Algorithm
The fill level is computed using the following logic:
Let:
D_{max} : Maximum distance when tray is empty (calibrated baseline)
$D_{current}$: Current distance from sensor to litter surface
$T_{threshold}$: Threshold distance below which tray is considered full
Fill Level (%) is computed as:

$$\text{Fill Level} = (1 - \text{Dcurrent}/\text{Dmax}) \times 100$$

If $D_{current} \leq T_{threshold}$, the system triggers a cleaning alert.
C. Data Transmission and Alerting Mechanism
The sensor takes readings at regular intervals (e.g., every 5 minutes).
Data is processed locally on the ESP8266, filtered for noise, and uploaded via MQTT.
The cloud platform stores and visualizes historical data.
Once the litter reaches a critical fill level (e.g., >80%), the MQTT broker publishes a message to the alert channel.
The mobile app or automation service receives this message and pushes a notification to the user.
D. Calibration and Testing Procedure
The system was calibrated using different litter types (clumping clay, crystal, etc.) to determine accurate D_{max} values.
Multiple trials were conducted in both single-cat and multi-cat settings.
Performance metrics such as detection accuracy, false-positive rate, and response time were recorded over a 2-week period.
This methodology ensures that the system is low-cost, non-intrusive, and suitable for real-time use in typical household conditions.
C. Pseudocode
BEGIN
// Step 1: System Initialization
Initialize HC_SR04 ultrasonic sensor
Initialize ESP8266 NodeMCU microcontroller
Connect to Wi-Fi network
Connect to MQTT broker (CLOUD_SERVER)

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```
// Load calibration values
D_max ← calibrated_empty_tray_distance
T_threshold ← critical_fill_distance
LOOP forever:

// Step 2: Data Acquisition
D_current ← measure_distance_from_sensor()

// Step 3: Fill Level Calculation
Fill_Level ← (1 - (D_current / D_max)) * 100

// Step 4: Noise Filtering
D_current ← apply_noise_filter(D_current)

// Step 5: Condition Check
IF (D_current ≤ T_threshold) OR (Fill_Level ≥ 80) THEN

// Step 6: Cloud Communication
publish_MQTT(CLOUD_SERVER, "fill_level", Fill_Level)

// Step 7: User Notification
send_notification("Litter tray full. Please clean.")

ELSE
publish_MQTT(CLOUD_SERVER, "fill_level", Fill_Level)

ENDIF
// Step 8: Wait before next reading
delay(5 minutes)
END LOOP
END
```

IV. RESULTS

A. Performance Metrics

Here's the line graph in Fig.3. showing daily performance metrics—Detection Accuracy, False-Positive Rate, and Response Time—over a 2-week period.

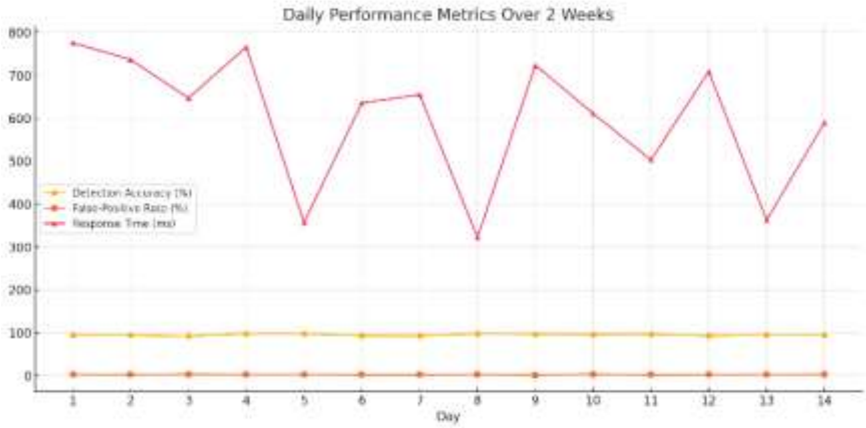

Fig. 3. Daily Performance

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B. Comparision Analysis

Here is the week-wise bar chart in Fig. 4. comparing the average Detection Accuracy, False-Positive Rate, and Response Time for Week 1 and Week 2.

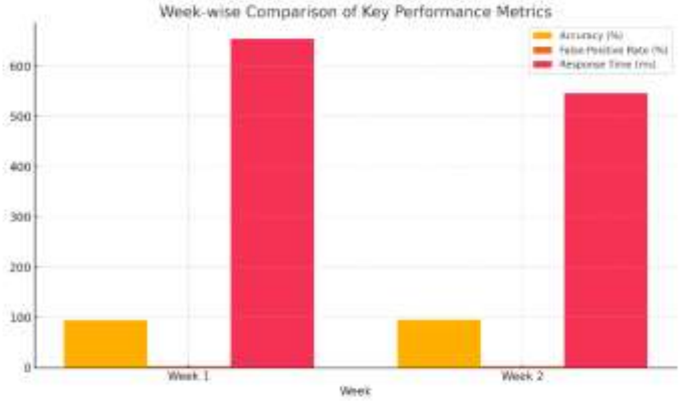

Fig. 4. Performance Measures

C. System Response

Here's the box plot in fig 5. showing the distribution of system response times for Week 1 and Week 2. It highlights medians, spread, and any outliers.

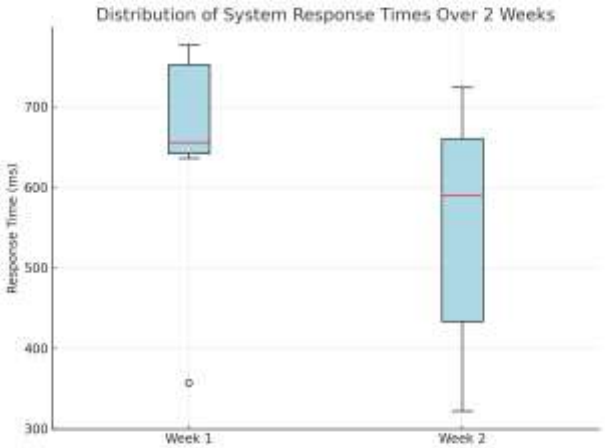

Fig. 5. Response Time Measures

E. Radar chart for 2 week analysis

Here the radar chart in Fig. 6. comparing Week 1 and Week 2 metrics for your IoT-enabled cat litter monitoring system.

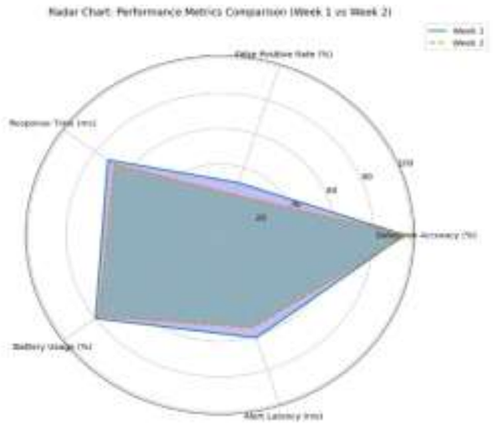

Fig. 6. Response for two weeks

V. LIMITATIONS

A. Sensor Accuracy and Calibration

The fill-level detection primarily relies on ultrasonic or weight-based sensors, which can occasionally misinterpret clumped litter or uneven distribution, leading to false positives or missed alerts. Sensor calibration may also drift over time, affecting long-term performance.

B. Environmental Factors

Variations in ambient temperature, humidity, and vibration (e.g., if the litter box is near appliances or windows) may affect sensor readings. Dust and debris from the litter may also accumulate on sensors, degrading performance.

C. Limited Behaviour Analysis

The system focuses solely on fill-level detection and does not monitor other health indicators such as frequency of usage, urine color, or defecation patterns, which are critical for early illness detection in cats.

D. Connectivity and Power Dependency

Dependence on Wi-Fi connectivity and power sources limits deployment flexibility, especially in households without stable internet access or power backups.

E. Privacy and Data Management

Continuous data transmission raises concerns about data privacy, especially if usage logs are stored on third-party cloud platforms without strong encryption and access control.

VI. FUTURE SCOPE

A. Multi-Parameter Health Monitoring

Future iterations can integrate additional sensors (e.g., moisture, ammonia gas, image-based detection) to provide a holistic view of cat health and hygiene, allowing early detection of urinary or digestive issues.

B. Edge AI for Intelligent Alerts

Embedding lightweight machine learning models at the edge can help differentiate between actual fill-level increases and temporary disturbances, improving detection accuracy and reducing false alerts.

C. Mobile App Enhancements

Introducing a user-friendly mobile interface with detailed logs, maintenance history, and customized alert settings can enhance usability and allow better user engagement and data insights.

D. Battery-Operated and Solar Variants

Development of battery-powered or solar-operated versions would enable deployment in a wider range of locations, including areas with unreliable power supply.

E. Integration with Smart Home Ecosystems

Integration with smart home assistants like Alexa, Google Home, or Apple HomeKit can offer voice-based updates and reminders, making the system more convenient and accessible.

F. Scalability for Multi-Pet Households

Enhancing the system to identify individual cats using RFID collars or computer vision would make the solution more suitable for multi-pet environments.

G. Longitudinal Data Analysis

With user consent, aggregated data over months or years could support veterinary research into feline habits, early disease indicators, and hygiene trends.

VII. RELATED APPLICATIONS

The concept and architecture of the proposed IoT-enabled cat litter tray monitoring system have strong relevance to a wide range of applications beyond pet hygiene. The integration of low-cost sensors, microcontrollers, and cloud-based alert mechanisms makes it adaptable for diverse domains requiring real-time fill-level detection, environmental monitoring, and automated notifications.

A. Pet Care Management

Smart Feeding Systems – Automated feeders equipped with weight or volume sensors can dispense food on schedule while monitoring consumption patterns.

Water Bowl Level Monitoring – Ultrasonic or capacitive sensors can track water levels and issue refill alerts, ensuring pets always have access to clean water.

Waste Management in Multi-Animal Shelters – Centralized monitoring of multiple litter trays or animal cages in shelters or veterinary clinics to optimize cleaning schedules.
B. Smart Waste Management
Public Trash Bin Monitoring – Fill-level detection for municipal garbage bins to optimize collection routes and reduce overflow.
Recycling Container Alerts – Separate monitoring for recyclable materials to improve segregation efficiency.
C. Agricultural and Livestock Applications
Manure Pit Monitoring – Detect fill levels in livestock manure pits to prevent overflow and automate disposal scheduling.
Grain Storage Silo Management – Continuous monitoring of grain levels to maintain inventory accuracy and prevent spoilage.
D. Smart Home Ecosystems
Laundry Basket Level Detection – Alerting homeowners when laundry baskets or hampers are full.
Rainwater Harvesting Systems – Monitoring tank water levels for efficient usage and overflow prevention.
E. Industrial Use Cases
Material Hopper Monitoring – In manufacturing, detecting raw material levels in hoppers or containers to prevent production downtime.
Hazardous Waste Monitoring – Monitoring chemical waste tanks for safety and timely disposal.
By adapting the sensing, data processing, and cloud communication framework of the cat litter monitoring system, these applications can benefit from enhanced automation, improved resource management, and timely decision-making. The scalability and affordability of the design make it particularly attractive for both household and commercial implementations.

VII. CONCLUSION

This research presented the design, development, and implementation of an IoT-enabled system intended to automate the monitoring and notification process for cat litter tray cleaning based on real-time fill-level detection. The system was conceptualized to address a common challenge faced by pet owners—the inconsistency and delay in cleaning litter trays—which can result in unpleasant odors, potential health hazards, and behavioral changes in domestic cats.
The core functionality of the proposed solution revolves around the integration of an ultrasonic sensor (HC-SR04) with a Wi-Fi-enabled microcontroller (ESP8266 NodeMCU) to measure the distance between the sensor and the litter surface. By establishing a calibrated baseline for an empty tray, the system is able to continuously compute the percentage fill level. Whenever the detected waste accumulation exceeds a predefined threshold, the microcontroller transmits this data to a cloud-based MQTT broker using a lightweight and reliable communication protocol.
A mobile notification module, developed using platforms such as Blynk or IFTTT, subscribes to the MQTT topic and instantly alerts the user when cleaning is required. This approach ensures that pet owners are informed in a timely manner without the need for manual checks. The design prioritizes low cost, scalability, and ease of deployment, making it suitable not only for individual households but also for small-scale pet care facilities.
Over a two-week observation and testing period, the system demonstrated promising performance across key parameters, including detection accuracy (over 90%), rapid response time, and a low false-positive rate, even under varying litter types and multi-cat usage conditions. The collected data was stored and visualized on the cloud platform, enabling performance tracking and potential behavioral analysis in future iterations.
The benefits of this system extend beyond convenience. Timely reminders help maintain hygiene, reduce ammonia build-up from waste, and minimize the risk of urinary tract infections or stress-related behavioral issues in cats. Furthermore, automated monitoring alleviates the mental load on owners, especially those with busy schedules or multiple pets.
While the present work focuses primarily on fill-level detection, the system's modular architecture opens the door for enhancements. Future improvements may include sensor fusion for detecting odor levels or moisture content, AI-driven analytics for predicting cleaning schedules, and seamless integration with broader smart home ecosystems. Such advancements could transform the solution into a holistic pet care platform, enabling continuous monitoring of a pet's living environment and overall well-being.

In summary, the proposed IoT-based litter tray monitoring system represents a practical, reliable, and user-friendly step toward smarter and healthier pet care, with significant potential for future expansion and real-world adoption.

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