IoT Based Smart Waste Monitoring System Envisioning a Sustainable Smart City

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***Abstract*— This paper introduces a smart approach to waste management through the integration of smart technologies. Our proposed system employs the ESP8266 Wi-Fi module to enable remote notification, ensuring efficient waste monitoring both indoors and outdoors. The core components include an Ultrasonic Sensor HC-SR04 for real-time monitoring of the waste bin's fill level, an IR sensor to facilitate automated lid opening upon user proximity, and a servo motor to control the lid mechanism. Upon detection of fullness of the waste bin, the system triggers a buzzer, providing an audible alert for the user and encouraging the user timely waste disposal. The innovation aimed for a more cost effective and economically beneficial system. The innovation extends beyond conventional waste monitoring because we are not only implementing it indoors but also outdoors to monitor waste disposal which will maintain a clean environment overall. The paper outlines the implementation of a client-server model, emphasizing its potential to foster a pollution-free society, good health, and a cleaner environment.**

Keywords: Smart Waste Management, Internet of things (IoT), ESP8266 Wi-Fi Module, IR Sensor, Servo Motor, Buzzer, Cost effective, Ultrasonic Sensor HC-SR04

I. INTRODUCTION

To address the issue of environment pollution we must at first consider the problem that is how we manage the waste we produce daily. In this modern day of technological advancement we shall use the help of technology to solve this problem smartly.

The primary objective of our system is to provide users with real-time notifications about the fullness of their waste bins. Through the combination of sensors, Ultrasonic Sensor HC-SR04 and the ESP8266 Wi-Fi module, our system empowers users with instant information about their waste bin's status. The client-server model ensures efficient communication, emphasizing the potential of technology to enhance waste management on an individual and community level. By offering users timely and remote updates on their waste bins, our system encourages a more responsible approach to waste disposal, contributing to a cleaner environment. Our goal is to encourage people to make well-informed decisions about their waste management habits, contributing to a long-term shift in their behavior. Furthermore, our sophisticated algorithmic framework analyzes the collected data to predict optimal waste collection times, reducing unnecessary pickups. As we delve deeper into the details of our project, we explore the intricate synergy between hardware and software components, unraveling the workings that make our system robust and adaptable. Our idea recognizes the dynamic character of urban areas by embracing a scalable and adaptable architecture. Our system's modular architecture facilitates easy integration with current municipal waste management infrastructures, enabling local authorities and people to work together. Because of our collaborative approach, our system may be easily customized to meet the unique requirements and subtle differences in infrastructure of various communities.

In the comprehensive literature review, we draw upon the insights gleaned from approved journals to underscore the theoretical foundations and technological advancements that underlie our project. This synthesis of knowledge positions our work within the broader context of current research and innovations in the field of smart waste management. In the theory and methodology section, we discussed the process of our project. In conclusion, we summarized our whole project report.

II. LITERATURE REVIEW

To gather information, the literature reviewed a number of distinct publications. There are numerous possible uses for the Internet of Things in intelligent waste management. The vast majority of companies are focusing on recycling and using IoT to reduce the environmental impact of waste as much as possible. Using simple techniques, such as mounting sensors on trashcans to track how much rubbish each person produces and then modifying the pricing appropriately, is a possible application.

Shuruthi. M *et al.* introduced the whole IoT based garbage monitoring idea in the journal. The author used ultrasonic sensor to receive data and through a microcontroller specifically an Arduino board tried to transmit the data into a server they used an Wi-Fi IOT and the data can be view through using a PHP web page [3].

M. H. Thigale *et al.* mentioned using a Arduino Uno board on [2]. They upgraded the system to a smarter model through adding a moisture detector and also a motor to flip the garbage and empty it in cases. Also they used a Wi-Fi module to make their project IOT based [2].

M B. Dande *et al.* hinted at an IOT based garbage monitoring system with an addition of GPS module to track the garbage can in real time. Also they put a LCD display to view the level of garbage. Also the location and the garbage data will be entered in a SQL database [1].

Shreehari B V *et al.* referred to using a Raspberry Pi for the system to be cheaper and in small size on [4]. They used an Android technology to see data on an android smartphone which is open source. Also an infrared sensor for faster response and secured communications. Also an RFID for higher security [4].

NK Dharshika *et al.,* used ISP8266 with an Arduino to make their waste management system IOT based. They also used an ultrasonic sensor to get waste data from the garbage which is going to be attached to the top of the garbage can [5].

Khoa, T. A. *et al.* proposed a smart waste collection system combining ultrasound distance measurement, LoRa communication, and efficient energy sources to create a versatile solution for smart cities. The architecture considers hardware components and their integration, aiming at achieving low-cost, high efficiency in waste management. The proposed system offers a comprehensive approach to optimize waste collection processes [6].

M.-V. Bueno-Delgado *et al.* proposed an Integer Linear Programming (ILP) algorithm embedded in the Net2Plan-GIS planning tool to optimize waste collection path planning in urban areas. The ILP formulates the problem of deciding the number of trucks and their optimal routes, considering constraints such as road length, container capacity, and acoustic impact. Key parameters like truck capacity, cost, and CO2 emissions are integrated into the ILP formulation [7].

K. Pardini *et al.* implemented IoT-based waste management solutions which involves the utilization of various protocols across different layers to address specific functionalities. The protocols encompass application layer protocols for end-user communication, service discovery protocols for resource management, and infrastructure protocols for device-network communication. The adoption of these protocols is essential for creating a robust and interoperable IoT ecosystem for waste management [8].

A. A. J. Jim *et al.* proposed a waste management system that integrates cutting-edge technologies, such as the Rotational Containers System, Smart Bins, an Autonomous Line-Following Car, and a Central Monitoring System. This comprehensive approach aims to optimize waste collection processes, enhance operational efficiency, and provide a smart and sustainable solution for urban environments [9].

Abba, S.; Light , proposed a waste monitoring and control system. Containing seven components. The system operates under the centralized control of a microcontroller. This microcontroller is programmed to manage the behavior of various peripherals and components, with ultrasonic sensors employed to measure garbage levels inside bins [12].

A. A. Sundas and S. N. Panda suggested an innovative IoT based waste management design that utilizes the concept of image processing. The design acts as a observation system to observe the overflow of the waste and delivers a message to take the necessary and immediate action [13].

V. Aswin Raaju *et al.* proposed a waste collection system, using Internet of things with the help of ZigBee, with sensors and modules. The approach can read, store, and transfer huge amount of data through the ad-hoc network. The data then can be used to dynamically observe waste collection process [14].

A. Okubanjo, O. Bashir Olufemi, A. Okandeji, and E. Daniel, addressed and adopted smart bins with IoT technology which enables remote monitoring and optimization of the bins. This approach offered economically beneficial, more efficient ways which helped to create a sustainable city [15].

E. S. Munthe, K. Diantoro, and A. Herwanto, introduced a kanban system for solid waste collection which suitable for signal time and quantity of waste collection. The system is driven by Internet of Things (IoT) [16].

S. C. Patil and M. R. Gidde, itroduced a smart garbage management structure which is IoT based, also introduced a Android and Web application that the dumping station of the city can access [17].

L. Nandakumar *et al.* proposed a system that keeps track of the trash cans, also the level in it and updates the data in a webpage which can be viewed by a mobile app. The system is IoT based [18].

Y. Lianawati *et al.* proposed waste management using Internet of Things (IoT) technology to control the sorting of waste into organic and plastic categories. They addressed users can manage the process and receive WhatsApp notifications. Testing of the "Smart waste" system is based on ESP32 which showed a success rate of 86.67% [19].

P. Badoni, R. Walia and R. Mehra, proposed modernize existing systems, including waste management through Internet of Things (IoT). They aimed to address cleanliness and hygiene issues in developing countries by creating awareness and educates proper waste disposal by smart waste management system. They offered affordable solution that promotes healthier, and pollution-free environments [20].

III. Methodology and Modeling

We created a simple smart waste bin which will interact with a user as a client-server model manner which encourages a more responsible approach to waste disposal

The diameter of the bin is 22cm. The height of the bin is 25cm. The waste monitoring system utilizes an Ultrasonic Sensor HC-SR04 to continuously measure the fill level of the waste bin. Once the bin reaches a predefined threshold, the system activates an IR sensor upon user approach, triggering a servo motor to open the bin lid for touchless waste disposal. Simultaneously, the ESP8266 Wi-Fi module facilitates remote communication, sending real-time notifications to users about the bin's status. Additionally, a buzzer is employed for audible alerts, sounding a short alert upon lid opening and a continuous alert when the bin is full. This integrated approach offers a versatile solution for efficient waste management both indoors and outdoors. Fig. 1 describes the working process of our system.

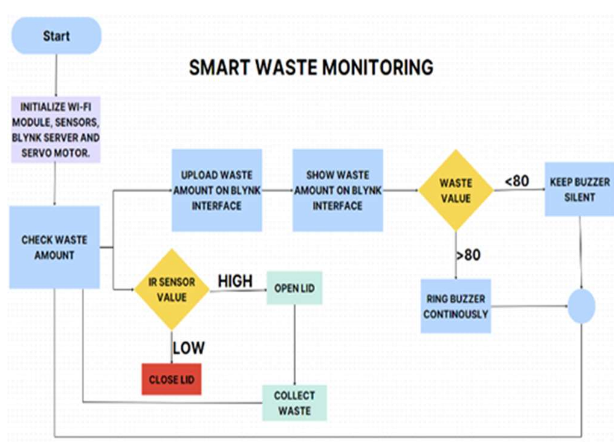

Fig. 1. Smart waste monitoring system working process.

Ultrasonic sensors work on a principle similar to radar and sonar, also described as transceivers, they are also called transducers. Through decrypting sound and radio signals it inspects an object's characteristics. High frequency sound waves are emitted which then examine the echo they get back [1]. We used ultrasonic sensor for this system to detect the distance of the waste from roof of the waste bin.

The widely used and adaptable ESP8266 Wi-Fi module is a microcontroller-based module that gives electrical devices Wi-Fi connectivity capabilities. Its low cost, convenience of use, and variety of uses have led to its enormous rise in popularity. We used this to link the system to the internet.

The connection includes linking the ESP8266 module. ESP8266 Wi-Fi Module establishes a Wi-Fi connection for communication with the Blynk cloud. Blynk library facilitates communication between the ESP8266 and the Blynk cloud. The Ultrasonic Sensor is placed within the waste bin. The IR sensor is connected to the servo motor for automated lid control. Ultrasonic Sensor HC-SR04 measures the distance to the waste in the bin to determine its fill level. IR Sensor detects user proximity to initiate lid opening. Servo Motor controls the lid mechanism, opening and closing based on sensor inputs. Buzzer provides audible alerts based on certain conditions, such as lid opening and high fill levels. The hardware components are connected to the ESP8266 microcontroller following the pin assignments provided in the code.

Fig. 2 illustrates the detailed connections between the ESP8266 module, sensors, and other components in waste management.

Fig. 2. Circuit set-up.

Fig. 3 presents the specific arrangement of the Ultrasonic sensor (HC-SR04) within the waste bin, showcasing its role in measuring the distance to determine the fill level.

Fig. 3. Ultrasonic sensor set-up.

Fig. 4 shows the IR Sensor set-up, highlighting its connection to the servo motor for automated lid control.

Fig. 4. IR Sensor set-up.

Fig. 5 illustrates the detailed flowchart of our system.

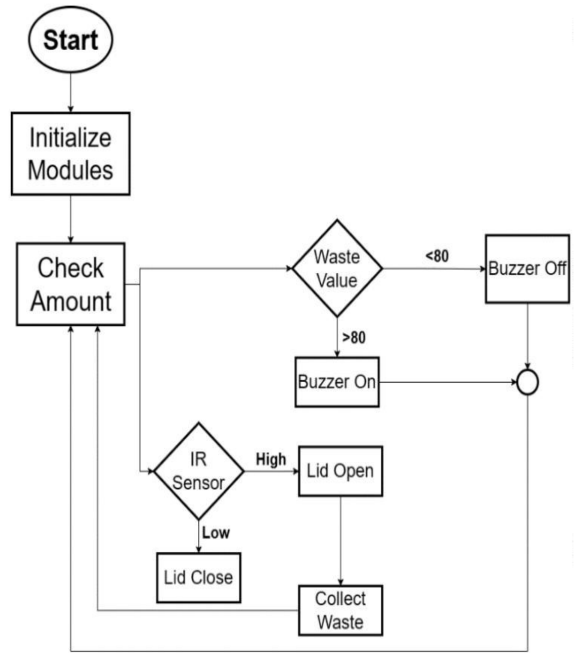

Fig. 5. Flow Chart.

Table I gives a brief description of the calibrated states and voltage input of the sensors used in the device.

TABLE I. COMPONENT CALIBRATION

Components	Ideal State	Ideal Operating Voltage	Calibrated State	Calibrated Voltage input
HC-SR04	2-400cm	5V	25cm	3.3v
IR Sensor	1-30cm	3.3V-5V	5cm	3.3v
Servo Motor SG90	0-180°	4.8-6v	180°	3.3v

The sensors are calibrated to work on 3.3V through decreasing the threshold as the ESP 8266 provides only 3.3V of output.

IV. Results and Findings

Fig. 6 showcases Waste monitoring system simulation. The ESP8266 establishes a connection with the Blynk cloud, and the Ultrasonic sensor measures the distance to the waste in the bin, enabling real-time calculation and transmission of fill level percentages to the Blynk cloud.

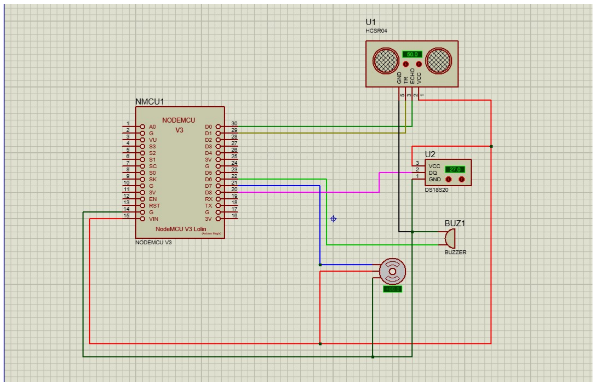

Fig. 6. Waste monitoring system simulation.

The ESP8266 establishes a connection with the Blynk cloud, the ultrasonic sensor (HC-SR04) measures the distance to the waste in the bin, and the calculated fill level percentage is sent to the Blynk cloud. We can observe the data updates on the Blynk app interface. The IR sensor detects user proximity, triggering actions which opens the lid when someone approaches.The buzzer provides audible alerts, with duration determined by the specified conditions in the code .The Servo Motor controls the lid mechanism, opening and closing based on sensor inputs and user proximity.

Fig. 7 Shows 56% of the bin the is filled.

Fig. 7. 56% filled.

Fig. 8 and Fig. 10 Instances of the waste bin at 56% and 82% filled, respectively. These figures provide a visual representation of the data updates observed in the Blynk app interface, emphasizing the system's ability to detect user proximity, trigger lid actions, and provide audible alerts through the buzzer.

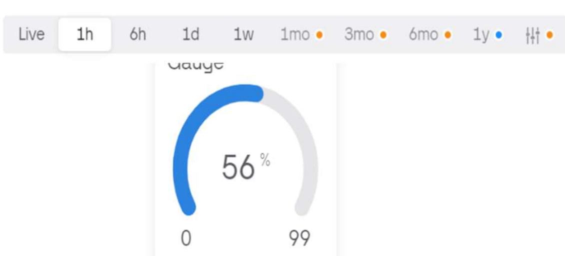

Fig. 8. 56% filled (Blynk Interface)

Fig. 9 81% filled. This figure offers a detailed view of the waste bin when it is 81% filled.

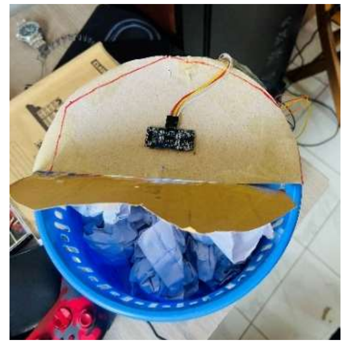

Fig. 9. 82% filled.

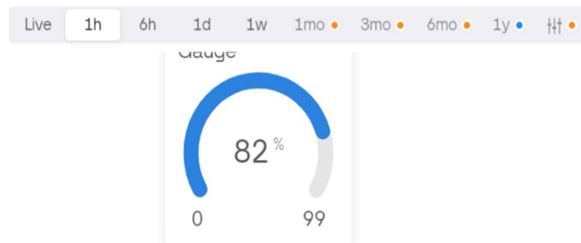

Fig. 10. 82% filled (Blynk Interface).

While the marginal difference between the numerical and experimental results may suggest a slight variance, it is imperative to examine deeper into the factors contributing to this fact. One potential explanation lies in the intricacies of real-world scenarios, where factors such as sensor calibration, environmental conditions, and the nature of waste materials can introduce subtle deviations. Calibrating sensors to precisely mirror the physical state of a waste bin poses inherent challenges, and our ongoing efforts are dedicated to fine-tuning these parameters to achieve a more accurate representation.

Furthermore, the 96-97% reading on the Blynk cloud interface, even when the waste basket is filled, underscores the significance of real-time data interpretation. This anomaly prompts us to explore potential optimizations in data processing algorithms and communication protocols to ensure that the user interface accurately reflects the true fill level.

A. *Comparative Study*

Table II describes the comparison of components of the proposed system relative to some other recent existing systems described in different journals.

TABLE II. COMPONENT COMPARISON

References	**Component Comparison**								
	Arduino	***Buzzer***	***Wi-Fi Module***	***Servo Motor***	***IR Sensor***	***LCD Display***	***Power Supply***	***GPS Module***	***LED Light***
[1]	✓	-	✓	-	-	✓	✓	✓	-
[12]	✓	-	✓	-	-	✓	✓	-	✓
[15]	✓	✓	✓	✓	-	✓	✓	-	-
[18]	✓	-	✓	✓	-	-	✓	✓	✓
Proposed	-	✓	✓	✓	✓	-	-	-	-

Due to cost efficiency, we didn't use any power supply, which costs us reliability also we didn't use any LCD display and Arduino uno. On other works we can see that there is no use of IR sensor, whereas we used the IR sensor that corelates with the lid and the buzzer.

Table III states the comparison of functionalities of the proposed system relative to other recent exiting systems.

TABLE III. FEATURE COMPARISON

References	Feature Comparison						
	Audio Notification	*Online Notification*	*Automatic lid*	*Proximity Detection*	*Display*	*GPS*	*LED Light*
[1]	-	✓	-	-	✓	✓	-
[12]	-	✓	-	-	✓	-	✓
[15]	✓	✓	✓	✓	✓	-	-
[18]	-	✓	✓	✓	-	✓	✓
Proposed	✓	✓	✓	✓	-	-	-

Due to lack of power supply and Arduino we sacrificed display and GPS functionalities from our system and still we managed to keep the other features.

B. *Accuracy Testings*

Table IV Describes the different reading throughout 2 tests that are conducted and calculated accuracy

TABLE IV. ACCURACY TEST

Height	Tests Conducted					
	Test 1		Test 2		Test 3	
	Reading	*Accuracy*	*Reading*	*Accuracy*	*Reading*	*Accuracy*
0	0%	100%	0%	100%	0%	100%
5	17%	85%	21%	95%	21%	95%
10	39%	97.5%	39%	97.25%	34%	85%
15	57%	93.3%	60%	96.65%	57%	95%
20	78%	97.5%	78%	97.5%	73%	91.25%
25	99%	99%	99%	99%	99%	99%

Fig. 14 showcases the accuracy of the device through two practical tests.

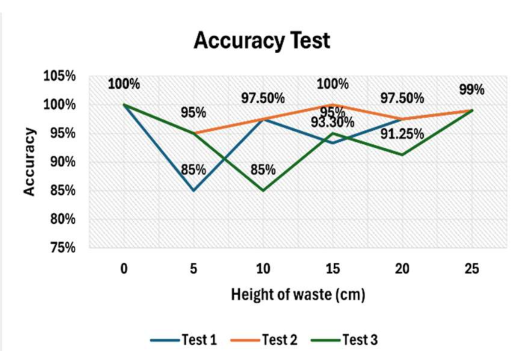

Fig. 14. Accuracy Test Graph Chart

From Fig. 14 it can be noticeable that in case of empty bin the system provides an accurate result also when the waste fills up 25 centimeters of the bin it gives 99% in all 3 test cases. But between 1 to 25 centimeters the accuracy fluctuates.

C. *Limitations*

Our method has limitations just like any other technological solution. As we have used ESP 8266 microprocessor, the voltage output is 3.3 volts but the at full threshold the IR sensor requires 5 volts, so we had to lower the threshold of the IR sensor. Even, while effective in most scenarios, the ultrasonic sensor's range could have trouble precisely determining the fill level in certain waste bin configurations or under specific environmental conditions. Variability in the sensor readings may be introduced by elements like garbage that is densely packed or has an irregular shape, requiring continuous optimization work. Another aspect to consider is the potential impact of continuous Wi-Fi connectivity on power consumption. Even though our system seeks to balance energy efficiency with real-time updates, extended connectivity can present problems, particularly in situations when power conservation is critical. We are actively exploring ways to lessen this concern through optimizations in data transmission protocols and low-power modes. In addition, bad weather might have an impact on the system's functionality. Heavy rain, extreme temperatures, or other meteorological conditions could potentially affect the accuracy of the ultrasonic sensor. By looking at the strategies employed to address and lessen these limitations, we show our dedication by demonstrating our commitment to refining and advancing, also improving and expanding the capabilities of our smart waste management system.

D. *Cost Analysis*

Table V gives us a detailed analysis of the equipments used and their current market price. This cost analysis provides a budget-friendly solution to our system. Reference studies by A. Okubanjo *et al.* [15] shows us that manual waste disposal is time consuming, and the waste bins are frequently overflowing. So, the aim of our system is to provide a low-cost smart waste bin which is affordable for most people. Compared to A. Okubanjo *et al.* [15] in our technology we didn't use Arduino uno and a lcd display which helped us to reduce the expense with a cost of reliability and accuracy.

TABLE V. COST ANALYSIS OF COMPONENETS

Cost Analysis			
Component Description	**Unit Price (USD)**	**Total Unit**	**Amount (USD)**
ESP 8266	2.93$	1	2.93$
HC-SR04 Ultrasonic sensor	1.26$	1	1.26$
SG90 Servo motor	1.67$	1	1.67$
Buzzer	1.26$	1	1.26$
Plastic Waste Bin	1.09$	1	1.09$
		Sum	8.21$

As it is noticed from Table V, the Total cost of the device turns out to be significantly lower than the cost analysis stated in [15] although main functionality of the device is exists.

V. NOVELTY OF THE WORK

This work aims for an economically beneficial system in comparison to traditional smart waste bins which is supported by references. The waste bins technical side was mostly focused on the low pricing of the components. Also, the device provides offline notification. Reference studies by L. Nandakumar *et al.* [18] pointed out the importance of online notification whereas this device provides offline notification through a combination of the ultrasonic sensor and the buzzer, mentioned on the methodology of the paper. Moreover the novelty extends as studies by S.C. Patil *et al.* [17] shows that they used Arduino uno as a microprocessor where as we used ESP 8266 as a microprocessor which is economically beneficial. The online notification functionality through Blynk interface is a newer addition to the existing smart waste bins. Also the device notifies through the buzzer when the lid is opened which adds an extra feature.

VI. Future Endeavors

Looking forward, there are many formats on which the system can improve. Current technological advancements bring more functionalities to our system. Separating waste that are being thrown into the waste bins depending on their physical state would address recycling processes to reduce odor and environmental impact. A GPS module can be integrated to the system to track the location of the smart waste bin. Developing power-efficient modules and exploring alternative energy sources to ensure sustainable and prolonged operation. A more robust and weather-resistant system is also in the pipeline, designed to withstand extreme weather conditions and guarantee uninterrupted service. The integration of advanced environmental sensors will provide real-time weather reports. Moreover, user engagement remains a priority, and we aim to elevate it by leveraging a mobile application for real-time readings and interactive features.

VII. Conclusion

In conclusion, the journey of developing and dream of the smart waste monitoring system for a better future reveals a trajectory of continuous improvement and innovation. It is a testament to the collective vision for a better future. The emphasis on waste separation, odor reduction, and power efficiency underscores a commitment to holistic and sustainable waste management practices. The user-centric approach, exemplified by real-time readings, not only enhances user interactions but also develops a sense of community engagement. The collaborative effort between technology, community, and environmental consciousness positions our smart waste monitoring system as a cornerstone in building a sustainable, intelligent future for urban environments worldwide.

VIII. Acknowledgements

We also appreciate the guidance and feedback provided by Shamim Reza throughout the project, a student of Computer Science & Engineering department in American International University Bangladesh.

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