Internet of Things (IoT)-Based Environmental Pollution Monitoring System

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Abstract

A healthy environment significantly benefits the well-being of living organisms, particularly humans. As intelligent and social beings, humans are obligated to conserve, maintain, and safeguard environmental cleanliness to ensure a healthy and clean habitat. For instance, the Palembang City Sanitation Office designates specific public waste disposal points where citizens should deposit their waste into provided receptacles, thereby preventing indiscriminate dumping that can lead to environmental damage or pollution. However, the existing waste collection process presents a challenge: sanitation officers often do not know when a garbage collection point is full. This lack of information results in foul odors, unsightly conditions, and residents discarding waste onto the roadside. This research, therefore, aims to develop an Internet of Things (IoT)-based system capable of automatically providing notifications and information about the garbage bin's fill level via an Android smartphone. The device is engineered to utilize an Ultrasonic sensor to provide input data to the ESP8266, which then relays the trash bin's capacity status (empty, half-full, or full). Testing of this environmental pollution monitoring tool, specifically for monitoring trash bin capacity, demonstrated the system's ability to automatically and periodically provide status notifications. This function was confirmed during the testing period from 07:00 to 16:00.

Keywords

Internet of Things (IoT), monitoring, capacity, environmental pollution

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Introduction

The Internet of Things (IoT) is a technological paradigm that integrates various electronic devices into an interconnected ecosystem via the internet. Through this concept, physical objects are embedded with sensors, processors, and communication modules, enabling them to generate, exchange, and analyze data autonomously. IoT represents a significant evolution in network communication, transforming raw environmental or operational data into meaningful and actionable information. The rapid advancement of IoT has contributed to the development of intelligent systems such as smart homes, smart buildings, and even large-scale implementations like smart cities, where environmental monitoring and automation play essential roles in improving urban management.

Environmental protection is a critical issue regulated under Law No. 23 of 1997 concerning environmental management, which defines pollution as the introduction of living organisms, substances, energy, or alterations to environmental structure caused by human activities or natural processes. Such disruptions degrade environmental quality to a level that prevents the environment from functioning according to its intended purpose. This regulatory perspective underscores the importance of effective environmental monitoring and timely intervention to prevent pollution-related degradation.

The Palembang City Environment and Sanitation Office (Dinas Lingkungan Hidup dan Kebersihan Kota Palembang) holds significant responsibility in maintaining environmental cleanliness and ensuring proper waste management within the city. The agency operates through an organizational structure consisting of three sub-sections (General and Staffing, Finance, Planning and Reporting), four divisions (Environmental Management and Capacity Building; Pollution and Environmental Damage Control; Cleaning; Hazardous and Toxic Waste Management), one Technical Implementation Unit, and a Functional Position Group. This organizational complexity illustrates the breadth of tasks carried out in environmental management, which requires continuous and reliable information flow.

In current practice, the agency deploys personnel to collect waste from predetermined disposal sites. However, the absence of real-time reporting on trash bin capacity poses recurring operational challenges. Officers are often unaware of whether a bin is full or empty, resulting in inefficient routes, unnecessary trips, or delayed waste collection. Because waste pickup is conducted only once every three days, bins frequently overflow, causing unpleasant odors and visual pollution in surrounding areas. This inefficiency reflects the need for a system capable of providing up-to-date monitoring data to support decision-making and area cleanliness.

To solve these operational shortcomings, this research proposes the development of an IoT-based monitoring system capable of detecting and reporting the fill level of trash bins in real time. By integrating sensors with online communication modules, the system allows officers to instantly determine the status of each bin. This capability supports more efficient waste-collection planning, reduces delays, and minimizes environmental disturbances caused by overflowing waste. The implementation of IoT technology is expected to enhance practicality, responsiveness, and accuracy in environmental management operations.

Based on the identified issues, the central research question of this study is: "How can an IoT-Based Environmental Pollution Monitoring System be constructed to accelerate the monitoring of waste conditions at disposal sites by leveraging Internet of Things technology to improve effectiveness, practicality, and sophistication in environmental protection?" This study aims to design, implement, and evaluate such a system to support cleaner, smarter, and more sustainable urban environmental practices.

Methodology

This study employs Action Research, which falls under the scope of applied research and integrates knowledge, research, and action. Action research shares commonalities with participatory research, collaborative inquiry, emancipatory research, action learning, and contextual action research. Simply put, it is "learning by doing" applied within a professional context, where the practitioner continuously generates new ideas implemented as actions to improve work processes and outcomes.

The Action Research method, a collaborative approach for systematic investigation and problem-solving, consists of several sequential stages: Diagnosing, Action Planning, Action Taking, Evaluating, and Learning. (See Figure 1: Action Research Method).

Figure 1. Research Method

Requierements Analysis

The initial step in system development is to define and articulate the system requirements. The preliminary analysis of the problem identifies the following hardware and software needs:

1) Hardware Requirements

- Computer/Laptop with a Core i5 2.8 GHz Processor
- Ultrasonic Sensor Component
- NodeMCU ESP8266 Component

- Other Electronic Components

2) Software Requirements

- Windows 10 Professional (Operating System)
- XAMPP (including Apache, MySQL, and phpMyAdmin)
- Adobe Dreamweaver CS6
- Arduino Uno Editor
- Mozilla Firefox and Google Chrome (Browsers)

System Input Design

The monitoring system's conceptual design, specifically for the ultrasonic/distance sensor input, is illustrated in the block diagram. See Figure 2: Block Diagram of the Trash Bin Sensor System :

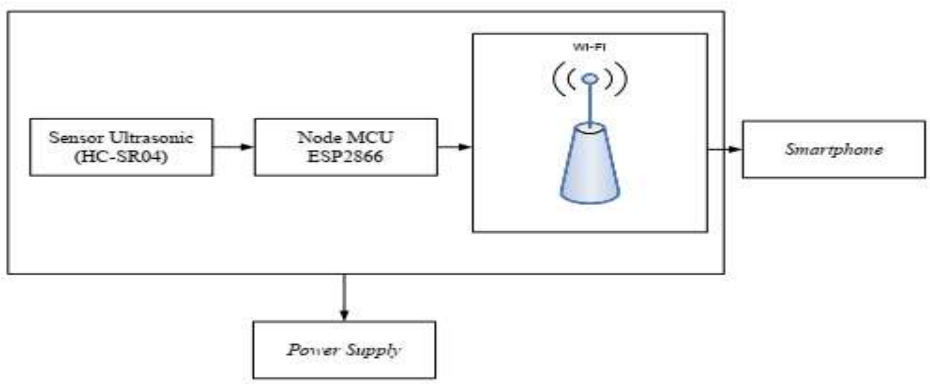

Figure 2. Block Diagram of the Trash Can Sensor System

1. Ultrasonic/Distance Sensor (HC-SR04): The HC-SR04 sensor is triggered by a pulse signal of at least 10mu S applied to the Trigger pin. It then transmits eight ultrasonic pulses at 40 KHz48. This 8-pulse pattern acts as a marker to differentiate the transmitted signal from ambient ultrasonic noise. The ultrasonic pulses travel outward to the object. Simultaneously, the Echo pin goes HIGH to mark the beginning of the echo signal.

   - If no signal is reflected or received within a 38 mS timeout (meaning no object is present), the Echo signal returns to LOW
   - If a reflected signal is received, the Echo signal immediately changes to LOW.
   - The duration of the HIGH state on the Echo signal is used to calculate the distance between the sensor and the object. This distance data is then processed for serial-to-Wi-Fi transmission

2. NodeMCU ESP8266: The ESP8266 module features a TTL (Transistor-Transistor Logic) serial output, equipped with GPIO (General Purpose Input/Output), allowing it to function standalone or with an additional microcontroller. TTL output logic is defined by LOW 0 volts and HIGH 1 at 3.3 or 5 volts. Data received from

the DHT11 sensor (an apparent error, should likely be HC-SR04 based on context) is processed digitally and then transmitted via Wi-Fi for display on the Android smartphone.

- Smartphone: An Android smartphone is required to display the monitoring application, which shows graphical representations and the changing fill condition of the trash bin.
- Power Supply: The power supply delivers the necessary voltage to the entire circuit.

System Flow

The system flow for the environmental pollution monitoring is outlined in the flowchart (See Figure 3).

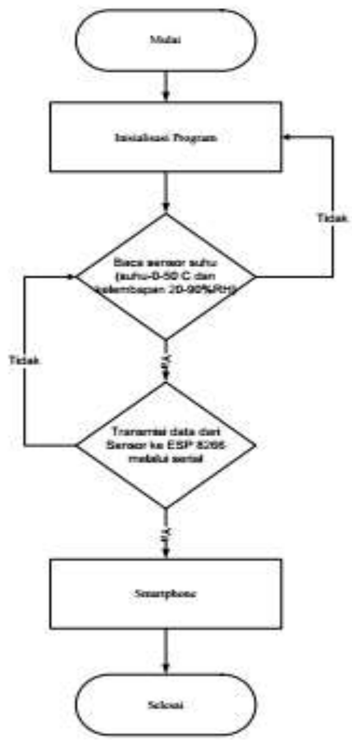

Figure 3. Flowchart of environmental pollution monitoring system

Based on the system flow illustrated in Figure 3, the process begins when the user presses the "Start" button to activate the device, initiating the program responsible for controlling all components. Subsequently, the HC-SR04 ultrasonic sensor reads the surrounding distance. If no data is detected, the system returns to the initialization phase; otherwise, the sensor data is transmitted to the NodeMCU ESP8266 microcontroller. The data is then sent via a Wi-Fi signal connected to an internet-enabled device, which ultimately interfaces with a smartphone.

The smartphone used must operate on the Android platform, as it is required to run the monitoring application. This monitoring application is Android-based and functions to control the Arduino microcontroller remotely via the internet. Upon launching the application, a real-time distance display appears, continuously updating according to the condition of the waste bin. The process concludes when the user exits or closes the application.

Figure 4. Internet network connection configuration via Wi-Fi on Arduino IDE

Node MCU ESP-8266

NodeMCU is a microcontroller board based on the ESP8266 Wi-Fi module, making it well-suited for applications in the Internet of Things (IoT), smart home control, and other wireless automation systems. As an open-source IoT platform, NodeMCU includes firmware designed to operate the ESP8266 Wi-Fi system-on-chip (SoC). It serves as both a firmware and development kit that facilitates rapid prototyping of IoT products using a few lines of Lua script.

NodeMCU employs Lua as its scripting language, built upon the eLua project and developed using the ESP8266 SDK version 1.4. It integrates various open-source projects, such as lua-cjson, and encompasses firmware that runs on the ESP8266 Wi-Fi SoC, along with hardware based on the ESP-12 module.

Figure 5. ESP8266 MCU Node

Ultrasonic Sensor HCSR04

The HC-SR04 sensor is a low-cost version of the ultrasonic PING sensor developed by Parallax. The primary difference lies in the number of pins used: the HC-SR04 utilizes four pins, whereas the Parallax PING sensor operates with three pins. The HC-SR04 is a ready-to-use ultrasonic sensor that integrates transmitting, receiving, and controlling functions for ultrasonic waves within a single device. It is capable of measuring object distances ranging from 2 cm to 4 meters, with an accuracy of approximately 3 mm. Therefore, when calculating distances with a maximum range of 4 meters, the measurement formula must be adjusted or recalibrated to ensure unit consistency and precision.

Figure 6. HC-SR04 Ultrasonic Sensor

Breadboards

A breadboard, also referred to as a working board, is used to assemble simple electronic circuits without the need for soldering. This solderless configuration allows for flexible modifications to the wiring scheme without risking damage to the board itself. Commonly known as a project board, the breadboard serves as the foundational platform for constructing electronic circuits and is widely utilized as a prototyping tool in circuit design.

Figure 7. Breadboard

Jumper Cables

Jumper wires, also referred to as Dupont cables, are electrical connectors equipped at both ends with terminals that facilitate easy connection to other components. These cables are primarily used to transmit electrical energy and consist of two main parts: an insulator and a conductor. The insulator, typically made of plastic or rubber, serves as the protective outer layer, while the conductor—commonly composed of copper—functions as the medium for electrical flow. Jumper wires are essential in prototyping electronic devices, acting as interconnects between components. Their flexible and reusable nature makes them ideal for assembling and modifying circuit designs without permanent soldering.

Figure 8. Jumper Cable

Results

The IoT-based environmental monitoring system, using NodeMCU ESP8266 and the HC-SR04 Ultrasonic Sensor on an Android platform, successfully monitors and detects the capacity status of the trash bin.

Discussion

Hardware Configuration

The combined hardware components are configured into a circuit to detect the trash bin's capacity (See Figure 9: Hardware Circuit).

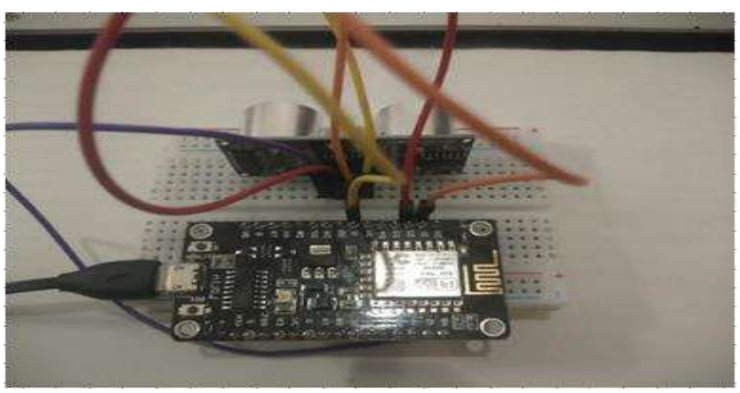

Figure 9. Hardware Circuit

This circuit was subsequently mounted onto a standard plastic trash bin, which served as the testing medium (See Figure 10: Hardware Circuit on the Trash Bin Medium).

Figure 10. Hardware Circuit to Trash Can Media

Trash Bin Capacity

The combined hardware components are configured into a circuit to detect the trash bin's capacity (See Figure 9: Hardware Circuit). This circuit was subsequently mounted onto a standard plastic trash bin, which served as the testing medium (See Figure 10: Hardware Circuit on the Trash Bin Medium).

$$\text{Capacity} = \frac{\text{Output Sensor}}{24} \times 100 \ (1)$$

Where:

- Capacity : Capacity value
- Output Sensor : Value generated by the sensor
- 24 : Maximum sensor value

The results from the experiment are summarized in Table 1:

No.	Jam	Kapasitas (%)
1	07.00	00.00%
2	10.00	25.00%
3	11.00	55.00%
4	13.00	66.00%
5	14.00	78.00%
6	15.00	85.00%
7	16.00	90.00%

Based on the collected data, the trash bin capacity conditions were categorized as follows:07:00 – 10:00: Capacity is below 50%, categorized as empty. For instance, a recorded capacity of 15% (See Figure 11).11:00 – 14:00: Capacity is above 50%, categorized as half-full. For instance, a recorded capacity of 65% (See Figure 11)15:00 – 16:00: Capacity reaches approximately 95%, categorized as full. For instance, a recorded capacity of 98% (See Figure 11).

Figure 11. Monitoring the trash can while it is still empty until it reaches its condition

The compiled data confirms that the designed trash bin monitoring system can automatically provide capacity information that accurately reflects the condition of the sensor-equipped bin. The logic for obtaining the capacity value is implemented in the Arduino IDE (See Figure 12: Arduino IDE for trash bin capacity data acquisition).

Figure 12. Arduino IDE for collecting trash bin capacity data

Conclusion and Recommendations

The results of the monitoring system implementation and testing yielded several strengths, weaknesses, and constraints. Strengths, the hardware successfully monitors the trash bin's condition in real-time and transmits this data to a database server. The software provides information on the trash bin's condition in real-time through graphical illustrations and percentage values. The software is accessible via an Android mobile device using an internet connection. The software is capable of providing notifications when the trash bin is full.

Weaknesses, the hardware must be continuously connected to a 5V battery power source. Field deployment requires careful consideration of the necessary battery capacity to maintain operation for a specified period. The hardware cannot transmit data in real-time without an internet connection. Field implementation requires a solution for reliable internet connectivity.

Constraints, the hardware must not be exposed to water. Field deployment in rainy conditions necessitates ensuring the device's complete waterproof security. The system is vulnerable to inaccuracies if the sensor is obstructed or interfered with by objects placed directly on it.

Recommendation, due to the current limitations, future research should focus on further development. A key recommendation is to expand the project's platform compatibility beyond Android to include other operating systems, such as iOS or Raspberry

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