



Waste Management in Smart City Using IoT

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ABSTRACT:

In many urban and rural areas, municipal garbage bins are often seen overflowing due to irregular cleaning schedules. This leads to several serious consequences, including land pollution, the spread of diseases, and the creation of unhygienic conditions, making the surroundings unpleasant and unhealthy for residents. To address this issue effectively, there is a pressing need for a system that can continuously monitor the status of garbage bins and promptly inform the municipality when a bin is full. A Smart Waste Management System can be developed using a Wireless Sensor Network (WSN) to monitor the garbage level in bins. In this system, ultrasonic sensors are installed in each bin to measure the level of waste. The data collected by the sensors is processed using a NodeMCU, a Wi-Fi-enabled microcontroller. The NodeMCU transmits the real-time status of each bin to a cloud server, such as ThingSpeak. The municipal office, equipped with a server and web interface, can monitor the status of all bins through this platform. When a bin is detected as full, an alert is generated, and the appropriate action is taken by informing the waste collection drivers. This ensures timely cleaning of garbage bins, prevents overflow, promotes environmental hygiene, and enhances the overall cleanliness and aesthetics of the area.

Keywords: Smart Waste Management , Municipal Garbage Bins , Overflow Prevention, Ultrasonic Sensor , NodeMCU , Wireless Sensor Network (WSN) , Real-Time Monitoring , ThingSpeak Cloud , Garbage Bin Status , Environmental Hygiene

I. INTRODUCTION

Waste management refers to the activities and actions required to manage waste from its initial creation to its final disposal. This includes the collection, transport, treatment, and appropriate disposal of waste, along with monitoring and regulating the entire process. Proper waste management is essential for maintaining environmental balance, safeguarding public health, and promoting sustainability. Without an effective waste management system, waste accumulation can cause severe pollution, spread diseases, and degrade the quality of life. One of the major concerns today is solid waste management, which significantly impacts the environment and human health. Solid waste, commonly referred to as municipal solid waste (MSW), constitutes the bulk of the waste generated by households, industries, and commercial activities. Addressing the management of MSW is vital, as its improper disposal can lead to land, water, and air pollution, endangering living beings and natural ecosystems.

Waste can be categorized into various types, each requiring specific handling and treatment methods. These categories include liquid waste, solid waste, organic waste, recyclable waste, and hazardous waste. Liquid waste is found in both households and industries and includes dirty water, organic liquids, wash water, waste detergents, and even rainwater. Liquid waste can be classified into two types: point source waste, which is manufactured and comes from identifiable sources like factories, and non-point source waste, which is naturally occurring, like rainwater runoff. Improper management of liquid waste can lead to contamination of water bodies and soil, posing risks to aquatic life and human health. It is, therefore, important to treat liquid waste using processes such as filtration, sedimentation, and biological treatment before releasing it into the environment.

Solid waste, on the other hand, includes a wide range of items typically discarded in households, commercial establishments, and industries. Solid waste can be broken down into subcategories like plastic waste, paper and cardboard waste, tins and metals, and ceramics and glass. Plastic waste, such as bags, containers, jars, and bottles, is particularly concerning due to its non-biodegradable nature. However, plastics can be recycled and should not be mixed with general waste. Instead, they should be sorted and placed into recycling bins. Paper and cardboard waste, including newspapers, packaging materials, and cartons, are easily recyclable and should also be separated from general waste for proper recycling. Metals like tins and scrap metal can be found throughout households and industries and should be taken to scrap yards or recycling centers for appropriate disposal. Similarly, ceramics and glass materials can be recycled, and special recycling bins or bottle banks should be used to ensure proper disposal. Managing solid waste effectively through reducing, reusing, and recycling helps minimize landfill use, conserves natural resources, and promotes a cleaner environment.

Organic waste is another major type commonly generated in households and agricultural activities. It includes food scraps, garden waste, animal manure, and spoiled meat. Over time, organic waste decomposes naturally with the help of microorganisms, producing nutrient-rich compost that can be used to improve soil fertility. Composting organic waste at the community or household level is an environmentally friendly way to manage this type of waste.

However, disposing of organic waste carelessly can lead to unpleasant odors, attract pests, and contribute to methane emissions, which significantly impact climate change. Proper segregation and composting of organic waste are crucial for maintaining environmental hygiene and promoting sustainable agricultural practices.

Recyclable waste refers to materials that can be collected, processed, and re-manufactured into new products, thus conserving resources and reducing energy consumption. Common recyclable materials include paper, metal, glass, plastics, and even certain types of organic waste. Recycling plays a crucial role in waste management by minimizing landfill use, conserving raw materials, and reducing environmental pollution. Households and businesses are encouraged to segregate recyclable waste and dispose of it properly using designated recycling bins or facilities. Proper recycling practices not only benefit the environment but also help in creating new employment opportunities in the recycling and manufacturing sectors. Moreover, recycling contributes significantly to reducing the carbon footprint associated with the production of new materials.

Hazardous waste includes any type of waste that is flammable, toxic, corrosive, or reactive and poses serious threats to public health and the environment. Examples of hazardous waste include chemicals, solvents, batteries, pesticides, and medical waste. Due to their dangerous nature, hazardous wastes require special handling, storage, and disposal procedures. Improper disposal of hazardous materials can lead to soil contamination, water pollution, and air quality degradation, with long-term detrimental effects on ecosystems and human health. Specialized waste management companies are tasked with the collection and safe disposal of hazardous waste in accordance with strict regulatory guidelines to minimize risk. Public awareness and regulatory enforcement are key in ensuring that hazardous waste is properly managed and does not endanger communities or the environment.

II. LITERATURE REVIEW

Effective waste management has emerged as a critical global concern due to the rapid pace of urbanization, industrialization, and the corresponding increase in municipal solid waste generation. The improper disposal of waste not only leads to environmental pollution but also poses significant risks to public health and the sustainability of urban living. Traditional waste management systems, which rely heavily on manual monitoring and fixed schedules, often prove inefficient and result in issues like overflowing bins, increased operational costs, and ineffective resource allocation. To address these challenges, researchers and technologists have proposed various smart solutions by leveraging advancements in wireless sensor networks (WSN), cloud computing, and Internet of Things (IoT) technologies. These innovative systems aim to automate the waste collection process by enabling real-time monitoring of waste bins, optimizing collection routes, and providing timely data to municipal authorities. Sensors such as ultrasonic devices are used to detect the fill levels of bins, while microcontrollers like NodeMCU transmit the information to cloud-based platforms such as ThingSpeak. The integration of cloud computing allows for efficient data analysis, storage, and retrieval, providing city administrators with actionable insights. Consequently, smart waste management not only enhances operational efficiency but also contributes significantly to creating cleaner, healthier, and more sustainable urban environments.

1. C.K.M. Lee and T. Wu (2014) developed a waste management system for Hong Kong that focused on improving logistics and resource allocation in waste collection. Their system utilized data-driven approaches to optimize garbage truck routes, reduce operational costs, and ensure timely collection, thus improving the overall cleanliness and sustainability of the urban environment.
2. M.H.A. Wahab et al. (2014) introduced the concept of a "Smart Recycle Bin," integrating a web-based system with sensor technology. Their work emphasized real-time monitoring of bin status and immediate updates to the municipality, allowing faster response times and improved recycling efficiency. This project laid the foundation for integrating user interaction with smart waste bins.
3. S. Thakker and R. Narayanamoorthi (2015) further explored wireless waste management systems by proposing a model that combined sensor nodes with GSM modules for real-time communication. Their model effectively reduced manual monitoring and enabled authorities to take immediate action when bins reached a certain fill level, enhancing both environmental and operational benefits.
4. Ceballos and Larios (2016) discussed the role of citizen-driven smart cities in enhancing municipal services, including waste management. They proposed a model where smart systems encouraged active citizen participation, enabling communities to report waste management issues in real time. This collaborative approach strengthened the relationship between government agencies and the public.

III. METHODOLOGY OF PROPOSED SYSTEM

1.1 Components Required

1. Arduino uno

The microcontroller that powers the Arduino Uno board is based on the ATmega328P. It includes every part required to run the microcontroller. The battery can be charged by users using an AC-to-DC adapter or battery, or by connecting it via USB to a computer. It offers a simple setup procedure to get you going.

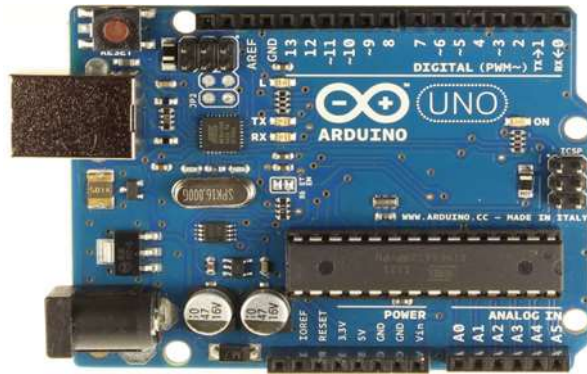


Figure 1. Arduino Uno

2. Temperature Sensor

Temperature control is a vital aspect of various industrial, commercial, and residential applications, ranging from HVAC systems to food storage and manufacturing processes. A temperature controller is an electronic device designed to maintain a desired temperature within a system by controlling heating or cooling elements. These controllers are integrated into systems to ensure that processes such as chemical reactions, environmental regulation, or machinery operation remain within an optimal temperature range. A temperature sensor is the first key component in the temperature control loop. It measures the current temperature of the system and sends the data to the controller for processing. The temperature sensor is critical for providing real-time information, ensuring that the system remains within the desired thermal limits. Various types of temperature sensors are commonly used, including thermocouples, RTDs (Resistance Temperature Detectors), and thermistors. Thermocouples are widely used in industrial applications due to their ability to measure a broad range of temperatures, consisting of two wires of different metals joined at one end, generating a voltage corresponding to the temperature difference. RTDs use the principle that the resistance of certain materials (such as platinum) increases with temperature, offering more accurate and stable readings compared to thermocouples, particularly at lower temperatures. Thermistors are temperature-sensitive resistors, with resistance varying significantly with temperature and are commonly used for precise temperature control in narrower ranges. Once the temperature sensor provides the temperature reading, this data is transmitted to a controller for analysis and decision-making.



Figure 2. Temperature Sensor

The controller processes the temperature information and determines whether action is needed to bring the temperature closer to the desired setpoint. Microcontroller-based systems, like those using Arduino, are common in many applications, allowing for customized temperature regulation. More advanced applications use PID (Proportional, Integral, Derivative) controllers, which continuously adjust the heating or cooling process to minimize any deviations from the setpoint temperature. The PID controller involves three components: Proportional (P), which adjusts the system output based on the current error (the difference between the desired and actual temperature); Integral (I), which compensates for past errors that accumulate over time; and Derivative (D), which responds to the rate of change of the error, helping to dampen overshooting and improve system stability. The actuator is the component that executes the control decisions made by the controller. It adjusts the heating or cooling system based on the controller's output. Several types of actuators can be used, including relays, solid-state relays, and variable-speed fans or pumps. Relays are commonly used in simple on/off control systems, switching the heating or cooling equipment on or off. Solid-state relays, which operate without moving parts, offer more precise control, making them suitable for industrial applications.

Variable-speed actuators, such as fans or pumps, adjust the intensity of heating or cooling, providing more gradual and efficient temperature control. The overall control of temperature can be achieved using different methods, with on/off control being the simplest and most commonly used method, especially for less complex systems. In on/off control, the heating or cooling element is turned on or off when the temperature reaches the setpoint, but this method

may lead to temperature fluctuations known as "hunting." PID control, more sophisticated than on/off control, continuously adjusts the heating or cooling element to minimize error and stabilize the temperature. PID control is particularly useful in applications requiring high accuracy and stability, such as climate control systems, chemical processing, and food preservation. Temperature control systems are essential in numerous industries and everyday applications, ensuring optimal performance, safety, and efficiency. While on/off control is suitable for basic applications, PID control is widely adopted for more demanding scenarios requiring precision. With advances in microcontroller technology and the integration of intelligent control algorithms, temperature management is becoming increasingly efficient and reliable in both industrial and consumer applications.

3. Wifi Module

Wi-Fi modules are crucial for enabling wireless communication in electronics projects. One popular option is the ESP8266, a low-cost Wi-Fi microchip with an integrated TCP/IP stack and microcontroller functionality. Key features include support for Wi-Fi 802.11 b/g/n, GPIO pins for sensor and actuator interfacing, and compatibility with communication protocols like HTTP and MQTT. It can be programmed using the Arduino IDE, making it ideal for IoT projects, home automation, and remote sensing applications. The ESP8266's versatility makes it a go-to solution for wireless connectivity in embedded systems.



Figure 3. Wi-Fi Module

4. Solar Panel

A 3-volt solar panel is a small and efficient power source commonly used in low-power applications, such as small electronics, embedded systems, and experimental projects. These panels provide a compact solution for powering devices that require minimal energy, making them ideal for applications where space and power consumption need to be carefully managed. Under standard test conditions, a typical 3-volt solar panel outputs around 3 volts, which is suitable for charging small batteries, powering sensors, or running microcontrollers in energy-efficient projects.

The power output of a 3V solar panel generally ranges from 0.5 to 3 watts, depending on factors such as the panel's size, design, and efficiency. Larger panels within this range are capable of generating more power, while smaller panels are suited for more energy-conscious applications. The current output typically varies between 50 and 500 mA (milliamps), based on the panel's design and the amount of sunlight it receives. The panel's dimensions are compact, usually between 2 x 2 inches for smaller versions and 5 x 5 inches for higher-power models.



Figure 4. Solar Panel

Efficiency varies depending on the type of panel. Monocrystalline 3V solar panels offer better efficiency and performance but come at a higher price point. Polycrystalline and thin-film panels are less efficient and more affordable, but they may not be suitable for all applications due to their lower energy output. Despite their limitations, 3V solar panels are an excellent choice for small, sustainable power sources in various electronic and renewable energy projects.

5. Boost Up Converter

A 3V to 12V boost converter, also known as a step-up converter, is a crucial component in many electronics projects where a lower voltage needs to be increased to a higher, more usable voltage level. These DC-DC converters are designed to efficiently convert a lower input voltage, such as 3V, to a

higher output voltage, such as 12V. This functionality is especially valuable when small power sources, such as a 3V battery or a low-voltage solar panel, are used to power devices that require a higher voltage to operate.

The input voltage range of a 3V to 12V boost converter typically spans from 2V to 5V, making it versatile for different types of low-voltage power sources. A 3V input is common and ensures compatibility with devices like single-cell lithium-ion batteries, solar panels, or other low-voltage power supplies. The output voltage is often fixed at 12V, but some models offer adjustable output voltage, allowing greater flexibility for different applications. This adjustability can be useful when a specific voltage other than 12V is required for a particular device.

One of the primary considerations when using a boost converter is the output current. The output current is determined by the input power, the efficiency of the converter, and the load placed on the system. For a 3V input stepping up to 12V, the typical current output ranges between 100 and 500 mA, depending on the converter's specifications and the demands of the connected load. This means that higher current outputs may require more efficient converters or will have to accept a trade-off in efficiency.



Figure 5. Boost Up Converter

Efficiency is an important factor in the performance of a boost converter. The typical efficiency of a 3V to 12V boost converter ranges from 80% to 90%, depending on the quality of the components used and the operating conditions. However, the efficiency of the converter can decrease as the load increases. In cases of high current demand or excessive heat generation, the converter may experience lower efficiency and waste more energy in the form of heat. Therefore, for applications where energy efficiency is critical, it is essential to select a high-quality boost converter that can handle the required load while maintaining optimal efficiency.

Boost converters are commonly used in applications such as battery-powered electronics, solar-powered systems, portable devices, and projects that require a stable and higher output voltage from a smaller power source. They are invaluable in circumstances where space is limited, and where traditional power sources are impractical. In addition to their versatility, boost converters offer a compact and cost-effective solution for voltage conversion, making them an essential tool in modern electronics design. Their ability to efficiently step up voltage, combined with their adjustable features, allows them to be used in a wide range of applications, from DIY electronics projects to more sophisticated, commercially available devices.

1.2 Block Diagram:

In response to these growing challenges, researchers, engineers, and technologists have been actively developing smarter solutions by harnessing the power of modern technologies like wireless sensor networks (WSN), cloud computing, and the Internet of Things (IoT). These technological advancements have paved the way for the creation of intelligent waste management systems that aim to automate and optimize the entire waste collection process.

Smart waste management systems integrate real-time monitoring of waste levels in bins through sensor deployment. This real-time data is then transmitted to centralized cloud platforms, enabling municipal authorities to make informed decisions about collection schedules and routes. By optimizing waste collection routes and timings, these systems significantly reduce operational costs, save fuel, and contribute to a cleaner environment. Additionally, timely data analytics help in identifying patterns and trends in waste generation, assisting city planners in developing more sustainable urban policies.

1. Solar Panel: Captures sunlight and converts it into electrical energy (DC) to power the system.
2. Boost-Up Converter: Increases the low voltage from the solar panel to a higher voltage needed to charge the battery.
3. Battery: Stores the electrical energy generated by the solar panel for continuous operation even during low sunlight conditions.
4. Inverter: Converts stored DC battery power into AC to power standard output loads when needed.
5. Arduino Uno: Acts as the brain of the system, processing sensor data and controlling operations like switching the pump.
6. Temperature Controller: Monitors the temperature and provides data to Arduino for environment-related decisions or safety precautions.
7. Relay: Acts as an electrically operated switch, allowing Arduino to control high-current devices like the water pump safely.

8. Pump:Pumps water based on the control signal received from Arduino through the relay.
9. Wi-Fi Module:Provides wireless connectivity to the system, allowing remote monitoring and control through a mobile app or web platform.
10. Ultrasonic Sensors (Sensor 1 & Sensor 2):Measure distance to monitor the water level in tanks or reservoirs.
11. Mobile:Acts as the user interface for monitoring system status and manually controlling operations remotely.

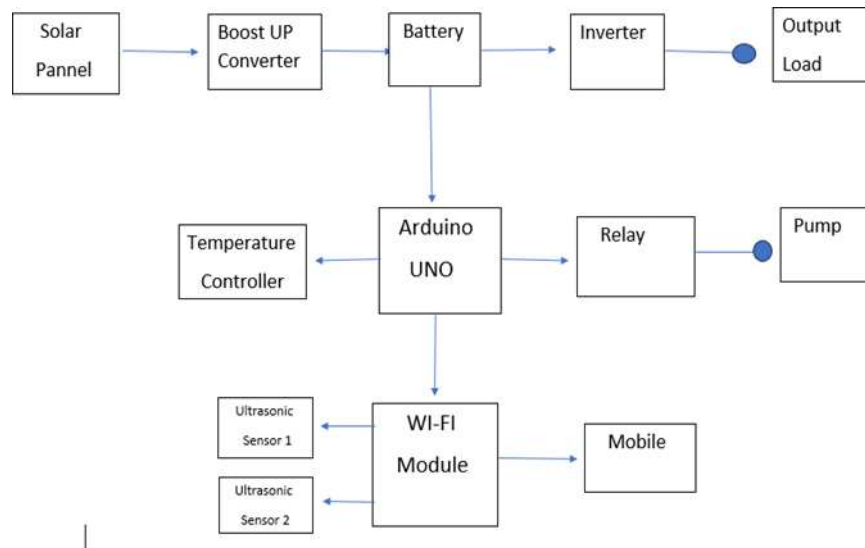


Figure 6. Block Diagram of proposed system

IV. APPLICATIONS & ADVANTAGES

Applications:

- 1) Municipal Solid Waste Management.
- 2) Smart Cities Development.
- 3) Hospitals and Healthcare Centers.
- 4) Universities and Educational Institutions.

Advantages:

- 1) Real-Time Monitoring.
- 2) Timely Waste Collection.
- 3) Resource Optimization.
- 4) Environmental Benefits.

V. EXPERIMENTAL RESULTS



Figure 7. Results

VI. CONCLUSION AND FUTURE WORK

The novel cloud-based system for waste collection in smart cities offers an advanced and efficient solution to manage urban waste. This system maintains an improved and updated database that records the garbage collection schedule, the quantity of waste collected, and the specific location details. By implementing this innovative approach, the common problem of garbage overflowing from bins in residential areas can be significantly reduced. Traditionally, waste collection relied heavily on manual efforts or basic loaders with little coordination, often resulting in delays and unhygienic conditions. This smart system ensures timely collection and enhances operational efficiency. Additionally, the project focuses on developing dedicated applications for city administrations and municipal staff, allowing real-time monitoring, route optimization, and better planning of waste management activities.

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