BinTelligence: Revolutionizing Waste Management through FPGA

Abstract ***- In this paper, we propose a smart waste management system that uses ultrasonic sensors in smart bins to monitor the fill percentage of waste, and this data is sent to Azure IoT Central through Node MCU ESP8266. The data received from various bins are again exported from Azure IoT Central to Azure IoT blob storage to store these data in an organized way. The Intel FPGA (DE10 Nano) board accesses the blob-stored data and processes it. If the fill percentage of the bin crosses a certain percentage level it sends an SMS that contains the fill percentage and its location to the respective trash collector. The higher authority can also monitor the status of each bin through a website.***

Implementing this technique can aid in trash management and the development of a sustainable city.

Keywords: Azure IoT, DE10 Nano, Blob storage, NodeMCU [ESP8266].

1. INTRODUCTION

India generates 62 million tonnes of waste every year. About 43 million tons (70%) are collected, of which about 12 million tons are treated, and 31 million tons are dumped in landfill sites. However, at least 30% of this waste is mismanaged today through open dumping or burning. Hence, managing waste is essential. A smart bin is a new high technology that integrated waste containers with smart sensors. Smart bins are an intelligent waste management system. Which allows you to track the waste management processes.

By using this proposed system, it could save time and money as the collector only goes to the filled bins to collect the trash. The collector no longer needs to stop street by street and check every dustbin if it is full or not as in the traditional situation. The operation and maintenance cost of municipalities is reduced as this system needs less manpower and fuel use by emptying full trash bins only. Not only this, the traffic congestion will be reduced as less waste collection vehicles on the roads. Indirectly, reducing air pollution due to fewer emissions of air pollutants. Furthermore, as the collectors can see which filled bins are not picked up and required to be picked, they will not miss picking up the filled bins. Hence, it keeps our surroundings clean and green as no overflowing bins and less unpleasant odour.

2. PROBLEM STATEMENT

The Global Waste Generation has increased from 635 Million Tonnes in 1965 to 1999 Million tonnes in 2015, which is more than twice. And at present it is 2.01 billion tonnes.

In India it was about 25.5 million tonnes in the year 2000. At present about 63 Million tonnes of waste is generated [i.e., as per 22 Sep 2022], from which 43 million tonnes (70%) of wastage are collected. It has also been estimated that annual waste generation will likely increase to 165 million tonnes by 2030.

In the process of collecting 43 million tons of wastage every year, the municipality vehicles travel 8 hours every day for garbage collection, a vehicle consumes an average of 28 litres of diesel. 1 litre of diesel emits 2.7 kg of Co2, which means that for making one complete round for collecting garbage, it releases approximately around 75.6 kg of Co2. According to data in 2021, there are 4041 municipalities providing waste collection services in India. Even if we consider that each municipality has only 1 vehicle, this corresponds to a total of 30.5 tons carbon emissions per day. And 1, 11,507 tons of carbon emission per year.

Due to lack of proper waste management system, municipalities are unable to collect remaining 31 million tons of wastage every year. When it comes to 2030 the wastage will be increased to 165 million tonnes, to manage these

huge wastages we need an efficient waste management system.
The traditional waste management system relies on manual monitoring, which is time-consuming, laborious, and inefficient. The bins are often emptied even when they are not full, leading to unnecessary expenses. On the other hand, the bins may overflow, causing environmental pollution and health hazards.

The main aim of this project is to overcome the Issues proposed above.

3. SOLUTION

Even if we consider that each municipality has only 1 vehicle, which travels 7 hours (reduced by one hour) every day, and it emits carbon of 94,397 tons per year.

Reducing municipality vehicle transportation by only one hour, this corresponds to a total of 17,110 tons less carbon emissions per year. Through this project we can reduce more no of travelling hours. Hence the proposed, automated waste management system that can monitor the fill level of the bins and inform the concerned authority to collect the trash when the bin is full.

As a result, it can prevent the bin from overfilling which may reduce contamination of environment such as air pollution from the odour of garbage and destroy the image of a city. Besides, it reduces the labour force in which will reduce the cost in proportional as it reduces the need for collection visits due to the result of collector is only be notified when the bin is full. In long terms, we can build a sustainable city, shaping a greater environment and future.

4. ALGORITHM

Step 1: Use ultrasonic sensors in smart bins to measure the fill percentage of waste.

Step 2: Send the fill percentage data from the smart bins to Azure IoT Central through Node MCU ESP8266.

Step 3: Store the data received in Azure IoT Central into Azure IoT blob storage for organized storage.

Step 4: Utilize the Intel FPGA (DE10 Nano) board to access and process the blob-stored data.

Step 5: Set a threshold fill percentage level for a bin to be considered "full."

Step 6: Continuously compare the fill percentage data with the threshold on the FPGA board.

Step 7: If the fill percentage of a bin exceeds the threshold, send an SMS to the respective trash collector with the fill percentage and location information.

Step 8: Develop a website for higher authorities to monitor the status of each bin.

Step 9: Provide real-time updates on the website to display the fill percentage and status of each bin.

Step 10: Deploy the complete system for practical implementation in a designated environment.

5. IMPLEMENTATION

This project involves the use of various technologies to achieve its objectives. The following are some of the technologies used in this project:

1. Field Programmable Gate Array (FPGA) technology: FPGA technology is used in this project to interpret the sensor data obtained from the Azure cloud. The FPGA can be programmed to analyse the sensor data and trigger notifications when the bin is full.
2. Internet of Things (IoT) technology: IoT technology is used in this project to enable the smart bin system to connect to the internet and the cloud. The system uses IoT protocols to transmit the data obtained from the sensors to the cloud.
3. Cloud computing technology: Cloud computing technology is used in this project to store and manage the data obtained from the smart bin system. The cloud can provide real-time access to the data.
4. Wireless communication technology: Wireless communication technology is used in this project to enable the smart bin system to transmit data to the cloud without the need for wired connections. The system uses

wireless protocols to transmit the data obtained from the sensors to the cloud.

USED COMPONENTS AND THEIR DESCRIPTION

1. FPGA(DE10NANO):

We are using the Intel FPGA (DE10 Nano), because Intel FPGA's are reconfigurable and provide more flexibility to the users at a lower cost. FPGA can parallelize the tasks, while the size consumption of such a system is less than the consumption of CPU and GPU with an integrated high-speed ARM-based hard processor system (HPS).

The DE10-Nano board is a popular choice among developers and researchers due to its powerful FPGA and its wide range of features.

The reason we want to use Intel FPGA in our project is that its parallel task performance. A general CPU is incapable of parallel processing, while FPGAs are capable of it even at a higher speed.

While obtaining the bin's fill level from Azure cloud, it must constantly check the condition to trigger SMS, in parallel. In addition to that, the features it has such as programmability and cost efficiency are among the top advantages of FPGAs.

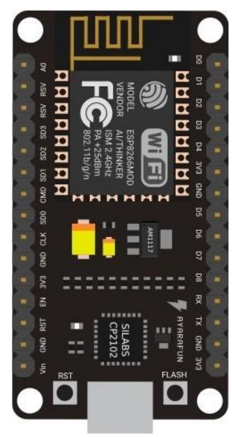
FPGAs are reprogrammable so that it provides modification feature after the circuit is designed and implemented, this feature adds adaptability feature to FPGAs. Smart Waste Containers are open for development and may require additional updates.

Since the FPGA is reprogrammable, we will not need a new processor, which will not incur any additional cost.

2. NODE MCU(ESP8266)

NodeMCU is designed to make it easy to create internet of things (IoT) devices that can connect to the internet and communicate with other devices. The purpose of node mcu in our project is to transmit the dustbin fill percent to Azure IoT central wirelessly using MQTT protocol.

The ESP8266 module at the heart of the NodeMCU board is a low-cost Wi-Fi chip with a built-in TCP/IP stack that can be programmed using Lua, a lightweight scripting language. The NodeMCU board also features a USB interface for programming and power, as well as a range of GPIO pins that can be used to connect sensors, actuators, and other components.



The NodeMCU firmware provides a range of built-in functions for connecting to Wi-Fi networks, sending and receiving data over the internet, and interfacing with other devices using protocols such as MQTT and RESTful APIs.

It also includes support for popular IoT platforms such as AWS IoT, Google Cloud IoT, and Microsoft Azure IoT.

The NodeMCU development kit is widely used for prototyping and building a range of IoT devices, including smart home devices, weather stations, and industrial automation systems. It's low cost, ease of use, and wide range of features make it a popular choice for both hobbyists and professional developers.

Overall, NodeMCU is a powerful and flexible development platform for creating IoT devices that can connect to the internet and communicate with other devices, using the ESP8266 Wi-Fi module and the Lua scripting language.

3. ULTRASONIC SENSOR

In our project is used to measure the fill percentage of the bin. The range of ultrasonic sensor is from 2cm to 10 meters, and it gives accurate measurement.
An ultrasonic sensor is a device that uses sound waves at a frequency beyond the range of human hearing (above 20 kHz) to detect the distance of objects and measure their position. Ultrasonic sensors can be used in a wide range of applications, including automation, robotics, security systems, and automotive applications.

Ultrasonic sensors work by emitting a burst of high-frequency sound waves and then measuring the time it takes for the sound waves to bounce back after hitting an object. The sensor consists of a transmitter that emits the sound waves and a receiver that detects the reflected waves.

The distance to the object can then be calculated based on the time delay between the transmission and reception of the sound waves.

Ultrasonic sensors can operate at a range of frequencies, depending on the application. Low-frequency ultrasonic sensors are used for long-range sensing, while high-frequency sensors are used for short-range sensing and precision measurement.

Some ultrasonic sensors also feature multiple sensing elements, which can be used to detect the position and orientation of objects.

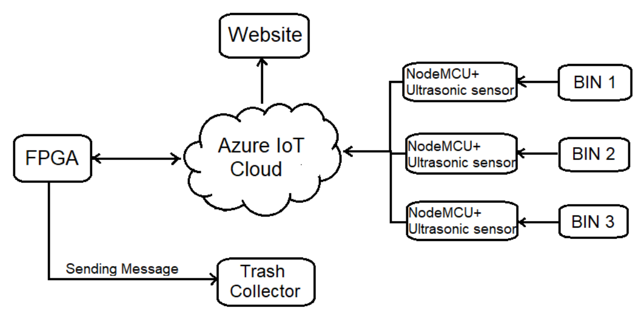
Ultrasonic sensors have a number of advantages over other types of sensors, including their ability to detect objects regardless of their shape, color, or texture, and their ability to operate in a wide range of environments, including in water and in dusty or dirty conditions. However, they can also be affected by temperature, humidity, and other environmental factors, and their performance may be limited in certain applications.

4. MICROSOFT AZURE CLOUD:

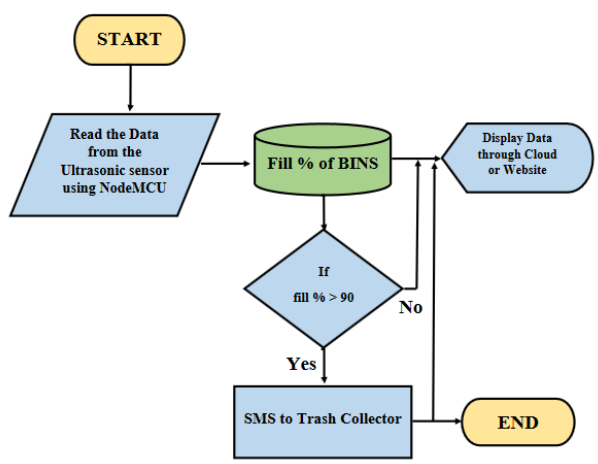
Microsoft Azure is a cloud computing platform and service offered by Microsoft. It provides a wide range of cloud-based services and solutions for businesses and developers. Azure offers infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS) options, allowing users to build, deploy, and manage applications and services through Microsoft-managed data centers.

We used this Azure cloud for storing the large amount of data in an organized way. It is more reliable and offers more features when compared to other clouds such as firebase, ThingSpeak, Ubibots…

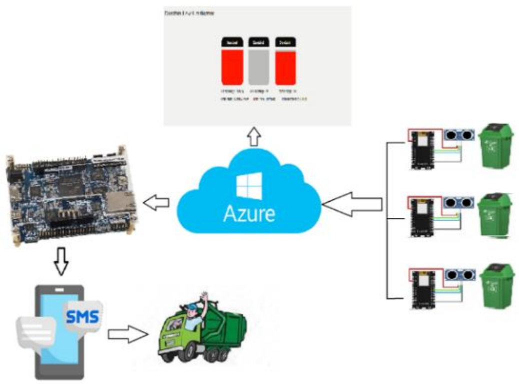
BLOCK DIAGRAM



FLOW CHART



CIRCUIT / SCHEMATIC DIAGRAM



IMPLEMENTATION ANALYSIS

The implementation of a smart waste management system involves several technical and operational considerations, including:

- **Sensor selection:** The choice of sensors is crucial for accurate monitoring of the fill level of smart bins. Ultrasonic sensors are commonly used due to their non-contact measurement capability and ability to work reliably in various weather conditions.
- **Network integration:** The data from the sensors is transmitted to a cloud-based platform, such as Azure IoT Central, through a microcontroller board, such as Nodemcu ESP8266, which connects to the internet and sends the sensor data to the cloud platform.
- **Software development:**

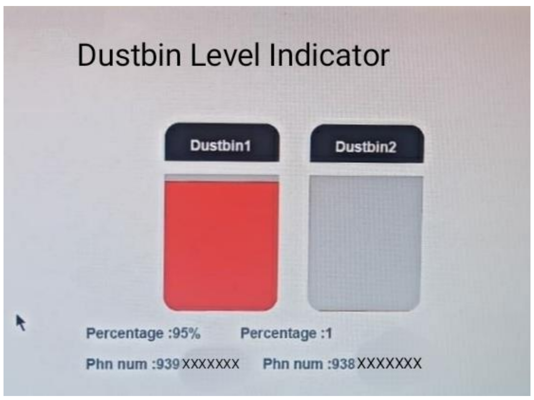
The software development for the system involves programming the FPGA board, configuring the cloud platform, and developing a website or web-based dashboard for higher authorities to monitor the smart bins. The FPGA board is programmed to process the sensor data, monitor the fill percentage, and trigger notifications when the threshold is crossed. The cloud platform is configured to receive and store the sensor data, and to trigger events or notifications based on predefined rules. The website or web-based dashboard is developed to display real-time data on the fill levels of the smart bins.

- **Scalability and maintenance:** The smart waste management system should be designed to be scalable and maintainable. As the number of smart bins and the volume of data increases, the system should be able to handle the growing demands. Regular maintenance activities such as sensor calibration, firmware updates, and system backups should be performed to ensure smooth operation of the system.
- **Notification system:** One of the key features of the proposed system is its ability to send notifications to the respective trash collectors when the fill percentage of a smart bin crosses a certain threshold. This is achieved by programming the FPGA to monitor the fill percentage data and trigger notifications, such as SMS notifications, to the designated collector's mobile number when the threshold is crossed. The notifications contain information such as the fill percentage and the location of the bin, enabling efficient and timely waste collection.
- **Website or web-based dashboard:** The system also includes a website or a web-based dashboard that allows higher authorities to monitor the status of each smart bin. This provides real-time visibility into the fill levels of all the smart bins in the network, allowing for better planning and management of waste collection routes and schedules.
- **Optimization of waste collection operations:** The data collected from the smart bins, along with data analysis techniques, can be used to optimize waste collection operations. For example, by knowing the fill levels of the bins in real-time, the system can optimize collection routes to avoid unnecessary trips to partially filled bins, reducing costs and minimizing carbon emissions from municipal vehicles.
- **Sustainability and environmental benefits:** The implementation of a smart waste management system can have several sustainability and environmental benefits. It can prevent smart bins from overflowing, reducing pollution of the environment and eliminating unpleasant odors associated with

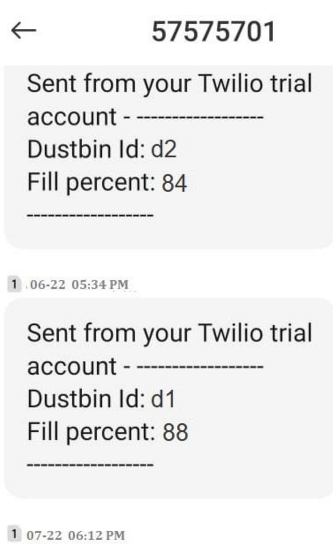
garbage. It can optimize the labor force involved in waste collection, reducing the need for frequent collection visits to partially filled bins and resulting in cost savings in terms of labor and vehicle maintenance.

- **Integration with Existing Waste Management Infrastructure:** The smart waste management system should be integrated with the existing waste management infrastructure in the urban area. This may involve coordination with local waste management authorities, municipal corporations, or other relevant stakeholders to ensure smooth integration of the system into the existing waste collection and disposal processes.

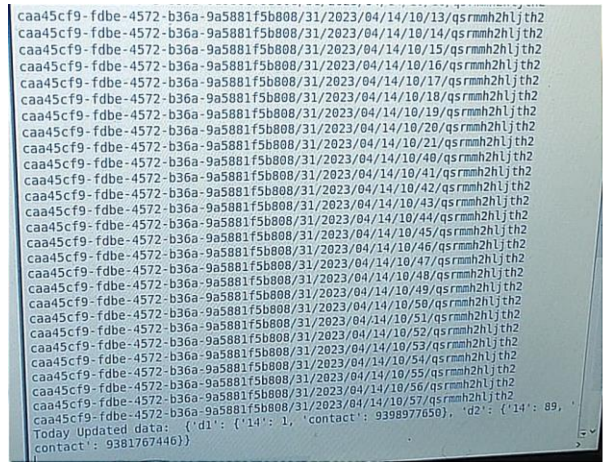
6. RESULTS



The user-friendly website interface displaying real-time fill percentage and status of smart bins for efficient waste management.



An SMS notification containing the fill percentage and bin id, sent to the respective trash collector for prompt waste collection.



Showcasing Python code running on an FPGA, processing and analyzing the fill percentage data from smart bins in real-time for efficient waste management.

Features:

- Unlimited bins monitoring.
- Works without any limitations in range of connectivity.
- Relatively less hardware components. MQTT protocol makes transmission easier.
- Automatic message sending to trash collector
- Time to Time monitoring through website by authorities.

Advantages:

- Reduce Labour Force.
- Reduce Fuel Consumption.
- Reduce CO2 Emission Rate.
- Saves Time and Efficient collection of waste.
- Protects form various Health Hazards.

7. FUTURE SCOPE AND IMPROVISATIONS

- ✓ Decreasing cost per bin by building a PCB including Ultrasonic sensor and MCU unit with Wi-Fi module.
- ✓ Adding features like automatic opening of lid of the bin
- ✓ Introducing reliable battery

- ✓ Making it efficient of climatic conditions
- ✓ Sending alert when the bin is dropped
- ✓ Keeping wet and dry dustbins
- ✓ After collecting the waste we could also make new dustbins from the plastic waste we collected.

8. CONCLUSION

The implementation of a smart waste management system using ultrasonic sensors, Azure IoT Central, Azure IoT blob storage, and an Intel FPGA board can offer numerous benefits in optimizing waste collection, reducing costs, and improving sustainability in urban areas facing increasing waste generation. However, careful consideration of technical and operational aspects such as sensor selection, network integration, software development, data analysis, security and privacy, scalability, integration with existing waste management infrastructure, training and capacity building, user engagement and education, regulatory compliance, and testing and piloting is crucial to ensure successful implementation and operation of the system. With proper planning, implementation, and monitoring, a smart waste management system can contribute to a cleaner and greener city, promoting a sustainable and environmentally conscious approach to waste management.