"LORAWAN-DRIVEN INTELLIGENT MEDICAL WASTE MANAGEMENT SYSTEM"

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Introduction/Background:

Medical waste management is a major challenge in healthcare facilities, as improper disposal of items like contaminated masks, syringes, gloves, and cotton can lead to serious health and environmental risks. Traditional segregation methods are manual and prone to handling errors. To overcome these issues, we have developed a LoRaWAN-driven Intelligent Medical Waste Management System that integrates AI, IoT sensors, LoRa communication, and cloud monitoring to automate waste classification and bin status tracking and monitoring.

A camera-based AI model, trained using the YOLO algorithm, identifies and categorizes various types of medical waste. Once detected, the system triggers the corresponding bin to open for disposal. Each bin is fitted with an ultrasonic sensor to measure fill levels in real time. When a bin approaches its capacity, an alert is sent via LoRa to an ESP8266 receiver, which uploads the data to the cloud for remote monitoring.

An ESP32-CAM is also used for live streaming the bin environment to monitor overflow conditions. This system enhances segregation accuracy, reduces human error, and enables real-time, data-driven decision-making for timely waste collection. By leveraging AI and IoT technologies, it provides a scalable and efficient solution for biomedical waste management in smart healthcare infrastructures.

Objectives:

- To perform efficient medical waste segregation and complience.
- To Monitor the real-time status of medical waste segregation units.
- Live Streaming of the Bins Surroundings.
- To support for Bio-hazards control.
- Use ultrasonic sensors to continuously monitor waste levels in bins and prevent overflow.
- Utilize LoRaWAN technology for efficient, long-range communication between waste bins and the central monitoring system.
- Develop a system that accurately differentiates between various types of medical waste, such as cotton, masks, and hazardous materials.

Methodology:

The proposed system integrates Artificial Intelligence, IoT, and LoRaWAN communication to create an intelligent medical waste management framework. It is structured into three primary modules: waste detection and classification, automated bin control, and real-time remote monitoring.

i.Waste Detection And Classification : The classification of waste is handled by a YOLOv8 (You Only Look Once) object detection model, trained on real images of biomedical waste such as contaminated cotton, gloves, syringes, masks, and urine bags. These are grouped into two categories: Type-1 (Infectious Waste) and Type-2 (Sharp/Liquid Waste). The trained model is executed on a laptop using Python and OpenCV through Visual Studio Code. When the system detects the type of waste via webcam input, a signal is sent to the Arduino Uno, which triggers the corresponding servo motor to open the designated bin lid.

ii. Monitoring Bins Status : Meanwhile, an ESP32-CAM module is used to provide live video streaming of the bin environment for monitoring bin surroundings and overflow status. Each bin is fitted with an ultrasonic sensor to continuously measure the waste fill level. A moisture sensor is also integrated to detect the presence of any liquid content.

iii. Transmission of data & Updation on Cloud : Sensor data from the bins is collected by the Arduino Uno, which functions as a LoRa transmitter. This data is

transmitted via LoRa SX1278 to a LoRa receiver interfaced with an ESP8266 NodeMCU module. The ESP8266, connected to the internet via Wi-Fi, pushes this data to the Blynk IoT platform, where real-time values are visualized using gauges and charts.

iv. Alerts : When a bin reaches more than 90% capacity, the system sends automated email alerts via Blynk, notifying authorities to take necessary action. This enhances timely waste clearance, reducing the chance of overflow and contamination.

Overall, the system ensures contact-minimized segregation, efficient monitoring, and timely alerts using low-power wide-area network (LoRaWAN) communication and AI-driven classification. The methodology supports scalability and sustainability, making it highly suitable for medical and hospital waste management.

Materials Used:

- **Hardware Requirements**:
    - Arduino UNO, ESP32-CAM,
    - ESP8266 Wi-Fi module, LCD 16x2 (I2C)
    - LoRa SX1278(Tx Rx), Ultrasonic Sensor (HC-SR04)
    - Servo motors, ET232 (USB to Serial converter),
    - PCB materials, and jumper wires.
- **Software Requirements:**
    - Arduino IDE for programming,
    - YOLO-trained model for waste detection
    - Blynk IoT platform for cloud-based monitoring and alerts

Block Diagram:

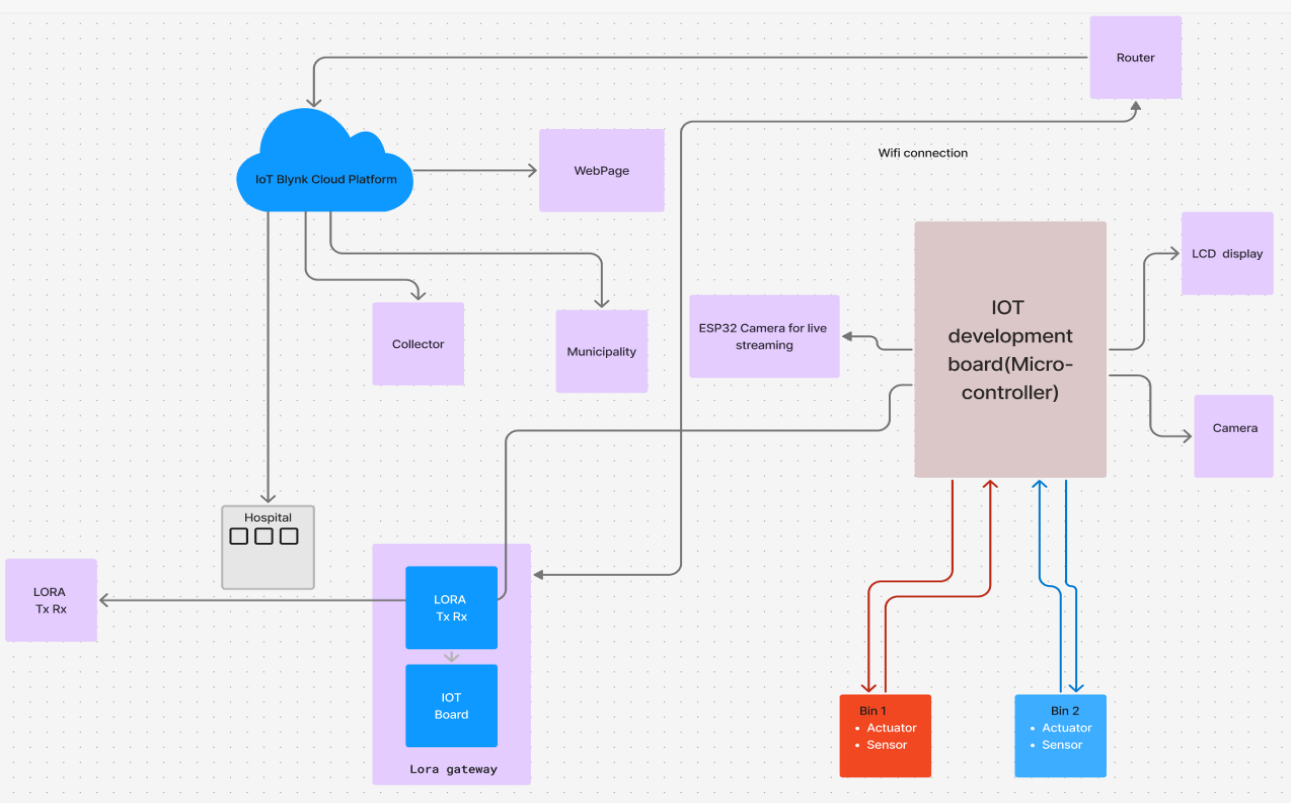

Figure 1: Lorawan Management System Block Diagram

Results And Conclusions:

Result

- The LoRaWAN-based communication system successfully enabled long-range, low-power data transmission between the waste bins and the central monitoring system.
- The system effectively monitored biomedical waste levels using ultrasonic sensors and transmitted the data wirelessly.
- The cloud-based platform displayed the bin status remotely, allowing healthcare authorities to track waste levels efficiently.
- The sensors provided accurate readings of waste bin fill levels, preventing overflow and ensuring timely disposal.
- The system provided real-time access to waste data for hospitals, municipalities, and sanitation authorities.
- Monitoring the Surroundings of the bin

Conclusion

The LoRaWAN-Driven Intelligent Medical Waste Management System successfully achieved its objectives by establishing reliable communication, ensuring accurate waste monitoring, enabling cloud storage, and providing real-time access to stakeholders. This system presents a scalable, cost-effective, and efficient solution for biomedical waste management in healthcare facilities.

Project Outcome & Industry Relevence:

1. Addresses a Critical Healthcare Challenge
    - Biomedical waste mismanagement can lead to serious health and environmental hazards. This project directly tackles that issue with smart technology.
2. Supports Government & WHO Guidelines
    - Aligns with government regulations and WHO protocols for safe biomedical waste handling and tracking.
3. Smart Healthcare Infrastructure Integration
    - Complements the Digital Health Mission and Smart Hospital initiatives, making it relevant for modern healthcare systems.
4. IoT & Cloud in Waste Management Sector
    - Leverages IoT and cloud technologies, which are in high demand across industries, making the system relevant for smart city and health-tech startups.
5. Potential for Commercial Deployment
    - With further development, this prototype can be commercialized and deployed in hospitals, municipalities, and industrial healthcare parks.
6. Sustainability & Green Technology
    - Promotes eco-friendly practices, supporting industries focused on sustainability, waste tech, and clean environment solutions.

Working Model Vs. Simulation:

Our LoRaWAN-Driven Intelligent Medical Waste Management System is a fully functional working model, not just a simulation. While some components, such as the AI-based waste identification, use trained models, the overall system is physically implemented and operates in real-world conditions.

Projects Outcomes And Learnings:

- Integration of LoRaWAN for Long-Range, Low-Power Communication
- Smart Waste Segregation and Monitoring.
- Cloud-Based Data Storage and Access.
- Automated Alerts & Notifications for Efficient Waste Disposal.
- Cost-Effective and Scalable Solution
- Simple, flexible and robust design of identification, segregation and monitoring and alert system

Future Scope:

- Integration of AI and Machine Learning for Waste Classification.
- GPS-Based Waste Bin Tracking.
- Develop solar-powered waste bins to enhance system sustainability and reduce dependence on external power sources.
- Mobile Application for Real-Time Monitoring and Alerts.
- Implement blockchain technology to securely store and track biomedical waste disposal records.
- Expansion to Other Waste Management Sectors.
- Collaborate with government agencies and healthcare organizations to implement the system on a larger scale.
- Use big data analytics to analyze trends in biomedical waste generation.
- Integrating ESP32 Camera to indentify and segregate Waste
- Automatic Segregation by using robotic arms.