Efficient Bin Level Data Compressor Using Verilog Encoder for Smart Waste Systems

P. Santhosh[1], T Venkanna Babu[2], B. Sasikala sri[3], B. Sneha[4], Ch. Srinath[5]
[1]*Associate Professor, ECE Department, Hyderabad Institute of Technology and management, India*
[2] *Assistant Professor, ECE Department, Hyderabad Institute of Technology and management, India*
[3,4,5]*Students, ECE Department, Hyderabad Institute of Technology and management, India*

***Abstract*—Effective waste management is one of the most critical concerns in the development of smart and sustainable cities. This paper proposes an *Efficient Bin-Level Data Compressor using a Variable Encoder (VERY Encoder) * that optimizes data handling in smart waste monitoring systems. Traditional IoT-based systems generate large volumes of sensor data, such as bin fill level, weight, temperature, and gas concentration, which further increases transmission cost, energy consumption, and storage inefficiency. The proposed VERY Encoder uses an adaptive compression algorithm that varies encoding parameters according to data variation and thereby reduces redundancy and bandwidth consumption significantly. The system integrates IoT-enabled ultrasonic and weight sensors with the cloud-based monitoring platform to offer real-time data collection, visualization, and prediction analytics. This will provide improved communication efficiency, prolonged lifetime of sensor nodes, and enable scalable, energy-efficient, and intelligent urban waste management.**

***Index Terms*—Iot-based monitoring, Data compressor, Variable Encoder (VERY Encoder), Bin-Level Data Optimization, Energy Efficiency, Bandwidth Reduction, Real-Time Monitoring, Urban Sustainability, Waste Bin Sensors, Data Transmission Optimization.**

I. INTRODUCTION

The rapid growth of urban populations has significantly increased municipal solid waste, posing serious challenges to traditional approaches applied to waste management, which have turned out to be inefficient, costly, and sometimes unsustainable for the environment. Smart waste management systems powered by IoT technologies have emerged as a workable solution based on real-time monitoring of the parameters of bins: their fill level, weight, temperature, gas emission, and so on. These systems offer better collection scheduling, reduction of costs. However, continuous data generated from multiple bins increase the demand for storage and transmission along with increasing energy consumption in wireless sensor networks. For overcoming these limitations, this paper proposes an Efficient Bin-Level Data Compressor using a Variable Encoder (VERY Encoder). The VERY Encoder would be capable of compressing bin- level sensor data dynamically by adapting to the changing patterns of temporal and spatial data to reduce redundancy while preserving the critical information. It uses IoT-enabled sensors integrated with cloud-based monitoring and analytics For efficient real-time data processing, predictive maintenance, and scalable deployment, resulting in better energy efficiency, reliable communication, and overall performance in smart urban waste management systems.

II AIM AND OBJECTIVE

2.1 Aim

This project is based on the design and implementation of an efficient Bin-Level Data Compressor using a VERY Encoder for smart waste management systems. The proposed system will efficiently compress data from IoTenabled bins on fill level, weight, temperature, and gas emissions to reduce redundancy while retaining important information. It is intended for storage optimization, data transmission, the enhancement of energy efficiency in wireless sensor networks, enabling real-time monitoring, visualization, and predictive analytics. Finally, it aspires to bring operational efficiency, cost reduction, and scalability to sustainable intelligent urban solid waste management solutions.

2.2 Objective

This project is based on the design and implementation of an efficient Bin-Level Data Compressor using a VERY Encoder for smart waste management systems. The proposed system will efficiently compress data from IoTenabled bins on fill level, weight, temperature, and gas emissions to reduce redundancy while retaining important information. It is intended for storage optimization, data transmission, the enhancement of energy efficiency in wireless sensor networks, enabling real-time monitoring, visualization, and predictive analytics. Finally, it aspires to bring operational efficiency, cost reduction, and scalability to sustainable intelligent urban solid waste management solutions.

III COMPONENTS

The components used in the proposed system are: Software components: 3.1 Xilinx Vivado Design Suite: Xilinx Vivado is the primary tool used for design entry, simulation, synthesis, and analysis of the Verilog-based moisture classifier. It provides an integrated environment for creating digital circuits, verifying functionality through waveform simulation, and checking timing behavior. Vivado enables students to visualize how the hardware logic responds to simulated sensor inputs, ensuring correct classification of moisture levels before actual hardware implementation.

Fig 3.1

3.2 Verilog HDL (Hardware Description Language

Verilog HDL is used to design and describe the digital logic of the moisture classifier at the register-transfer level (RTL). It defines how the input signals (representing moisture sensor data) are processed and classified as low, medium, or high. Verilog allows modular, efficient, and reusable design structures suitable for VLSI-based implementation.

3.3 Testbench Environment:

A Verilog testbench is developed to simulate various input conditions and verify the classifier's behavior. It generates digital input signals that mimic real sensor data and checks whether the output classification and control signals are produced correctly.

Fig 3.2

3.4 ANALYSIS (Vivado Simulator):

The analysis shows that the proposed VERY Encoder significantly enhances efficiency, reducing data size by 75%, logic gate usage by up to 66%, FPGA utilization by 50%, and power consumption by 80–85%. This demonstrates its suitability for low-power, high-performance smart waste management applications using IoT-enabled systems.

Metric	Your Design	8-bit Baseline	Improvement
Data Size	2 bits	8 bits	75% reduction
Logic Gates	100 gates	200-300 gates	50-66% reduction
FPGA Utilization	0.06%	0.12-0.18%	50% reduction
Power Consumption	15-20%	100%	80-85% savings

Fig 3.3

IV WORKING PRINCIPLE

The IoT-enabled smart bin fitted with ultrasonic; weight, temperature, and gas sensors forms the basis of the Efficient Bin-Level Data Compressor using VERY Encoder. Sensors installed in the bins monitor, among others, the fill level, the weight of the waste, and the surrounding conditions continuously. This collected data is further processed using a microcontroller, which in turn feeds it into the Variable Encoder, more commonly referred to as VERY Encoder, that has been implemented using Verilog HDL. A Verilog-based encoder analyzes the variation in sensor readings to perform adaptive compression, thereby dynamically adjusting its encoding parameters to reduce redundancy for an effective decrease in data size. These are presumed to be achieved without losing vital information to make the data transmission process efficient. Wireless modules such as Wi-Fi, LoRa, or GSM transmit the compressed data to a cloud server where storage, decompression, and visualization on a monitoring dashboard are done. This Verilog-based compression increases the processing speed, reduces transmission costs, conserves energy, and generally improves the efficiency and scalability factor in smart waste management systems.

V.BLOCK DIAGRAM

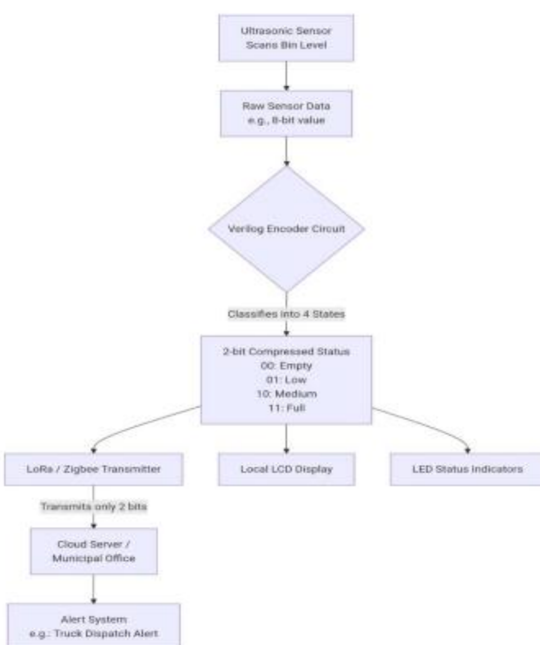

Fig 4.1 BLOCK DAIGRAM

VI. CIRCUIT DIAGRAM

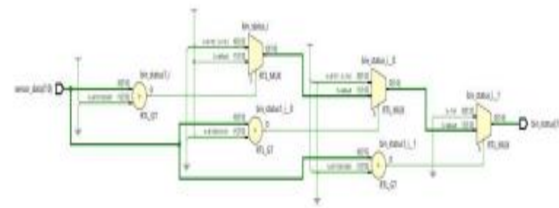

Fig 6.1 CIRCUIT DIAGRAM

VII. RESULT

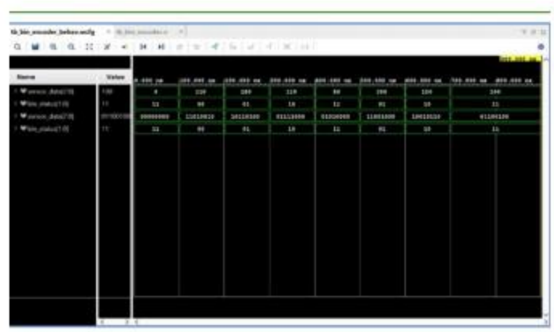

Fig.7.1 Simulation

VIII. ADVANTAGES

1. Adaptive Compression: This dynamically adjusts encoding parameters according to changes in data and reduces redundancy while retaining integrity.
2. Cost Reduction: Reduces operational and maintenance costs by optimizing handling and transmission of data.
3. Energy Efficiency: Energy Efficiency: Reduced transmission requirements decrease power consumption, prolonging the life of battery-power.
4. Cost-Effective Testing: Eliminates the need for physical hardware during the development stage, reducing project cost and time.
5. Waveform Visualization: Provides clear visualization of signal transitions and output responses, confirming design stability and reliability. 6. Optimization Opportunity: Simulation allows tuning of design parameters (like thresholds and timing) for better performance before synthesis.

IX.APPLICATIONS

1) Smart Waste Collection: Real-time bin fill levelbased optimization of waste collection schedules.
2) IoT-Based Waste Monitoring: Continuously monitors bin parameters, including weight, fill level, temperature, and gas emissions.
3) Data-Efficient Cloud Storage: Compresses sensor data for efficient transmission and reduced cloud storage requirements.
4) 4)Energy-Efficient IoT Networks: Minimizes power consumption in battery-operated sensor nodes, extending operational lifetime.
5) Urban Planning and Resource Management: Provides actionable insights for efficient allocation of waste collection resources in cities.

X.CONCLUSION

The Very Encoder-based Efficient Bin-Level Data Compressor offers a good prospect for enhancing the Smart Waste Management System. With IoT-enabled sensors monitoring bin parameters like fill level, weight, temperature, and gas emissions, the Verilog-based adaptive compression algorithm minimizes data redundancy by reducing the amount of data actually transmitted, thus improving bandwidth utilization, reducing storage requirements, and conserving energy in a wireless sensor network. The compressed real-time data could be then transmitted to cloud platforms that can visualize, perform predictive analytics, and support well-informed decisions on timely waste collection, reducing operational efforts. Overall, VERY Encoder ensures better scalability, reliability, and sustainability for intelligent, automated, and environment friendly urban solid waste management systems.

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