SOLAR POWERED SMART TRASH COMPACTOR

Durga Humane [1],Akshay Zanjhal [2], Praful Dhanvijay [3] , Chandan Modi [4], Nikil chakole [5],
Prof. Prachi Chintawar [6], Prof.Punam Mandhalka [7]
Department Of Electrical Engineering,Vidarbha Institute Of Technology Uti, Umrer Road,,Nagpur,,Maharashtra, India

Abstract—**The alarming increase of waste with increasing urbanization has enunciated development of effective waste management systems. Traditional waste bins often overflow, as collection schedules are not always consistent. This research designs and develops a low cost, solar-powered waste compactor that mechanically reduces the volume of waste without IoT-based technologies implemented. The technology uses solar power to run a compaction unit powered by a direct current motor, reducing operating costs and environmental impact. Cost effective, energy efficient and optimal for semi-structure in rural đỏ urban Infrastructures of disease outbreaks..**

Keywords: Solar Energy, Trash Compactor, Renewable Energy, Waste Management, DC Motor, Mechanical Compression

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I. INTRODUCTION

The management of municipal solid waste (MSW) has emerged as one of the most critical challenges for modern urban environments. According to the World Bank, global waste generation is expected to increase to 3.40 billion tonnes by 2050, up from 2.01 billion tonnes in 2016. In developing nations and densely populated metropolitan areas, the inefficiency of traditional waste collection methods leads to overflowing bins, unhygienic conditions, pest infestation, and significant environmental pollution.

Conventional waste collection typically follows a static schedule, where trucks visit bins regardless of their fill level. This results in two primary inefficiencies: the collection of empty or semi-full bins, which wastes fuel and labor, and the neglect of overflowing bins, which creates health hazards. Furthermore, low-density waste such as paper, plastic bottles, and packaging occupies significant volume, rapidly filling bins and requiring frequent emptying.

To address these challenges, this paper proposes a Solar-Powered Smart Trash Compactor (SPSTC). The primary objective is to develop a self-sustaining system that mechanically compacts waste to maximize bin capacity and utilizes the Internet of Things (IoT) to communicate real-time status to municipal authorities. By integrating renewable solar energy, the system operates off-grid, eliminating the need for expensive cabling infrastructure.

II. LITERATURE SURVEY

The Several studies and commercial products have addressed the inefficiencies of traditional waste management. The BigBelly solar compactor [4] is a pioneering commercial solution widely deployed in US cities. It features solar compaction and wireless connectivity but comes with a high deployment cost that is often prohibitive for developing regions. Our proposed system aims to provide similar functionality at a fraction of the cost using off-the-shelf components.

Tamakloe and Rosca [1] proposed an IoT-based system focusing on route optimization using ultrasonic sensors. While effective in monitoring, their system lacked a compaction mechanism, limiting its ability to reduce collection frequency significantly. Similarly, Kabir et al. [2] developed a solar-powered monitoring system that alerts authorities via SMS. Their work demonstrated the viability of solar energy for low-power sensor nodes but did not address the volume reduction of low-density waste.

Ravi and Charanthimath [3] introduced a basic design for a solar-powered compactor. However, their implementation relied on simple timer-based compaction rather than sensor-driven actuation, leading to inefficient energy usage. More recent approaches have integrated advanced communication protocols. LoRa-based systems have been explored for their long-range capabilities in smart cities [6], though they often require a dedicated gateway infrastructure.

Research into energy storage for such systems was conducted by Ajibola [5], emphasizing the importance of battery health monitoring in outdoor solar applications. This insight is integrated into our MPPT design. Other works have explored computer vision for waste segregation [7], [8]. While promising, these systems require high processing power (e.g., Raspberry Pi), increasing energy consumption. Our approach focuses on energy-efficient ESP32 architecture to ensure reliability during low-sunlight periods. Future

Considerable research has been devoted to intelligent waste management systems. Longhi et al. [1] proposed an early fill-level monitoring system using infrared sensors embedded in conventional bins, demonstrating a 30% reduction in unnecessary collection trips. Catania and Ventura [2] introduced a compaction mechanism driven by a DC gear motor, achieving a volumetric compression ratio of approximately 1:4 for mixed municipal solid waste.

The integration of renewable energy into waste management infrastructure was explored by Arebey et al. [3], who evaluated solar-powered bins with GSM-based status reporting. Their results showed net energy surplus under tropical irradiance conditions, but their architecture depended on continuous cellular uptime. Pardini et al. [4] conducted a systematic review of smart waste bin technologies and identified standalone operation, energy autonomy, and mechanical reliability as the three most critical unfulfilled requirements.

Malapur and Pattanshetti [5] developed an Arduino-based fill-level indicator with ultrasonic sensing and demonstrated sub-centimeter distance measurement accuracy for bin monitoring applications. Khan et al. [6] studied photovoltaic sizing for low-power embedded microcontroller systems in outdoor environments and established empirical guidelines for battery capacity selection under variable irradiance regimes. The present work synthesizes these findings into a comprehensive, locally autonomous system design.

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III. METHODOLOGY

A. Overall System Overview

The SPSTC system is composed of three main subsystems: the Power Supply Unit (PSU), the Sensing and Control Unit (SCU), and the Mechanical Compaction Unit (MCU). The block diagram in Fig. 1 illustrates the interconnection of these components.

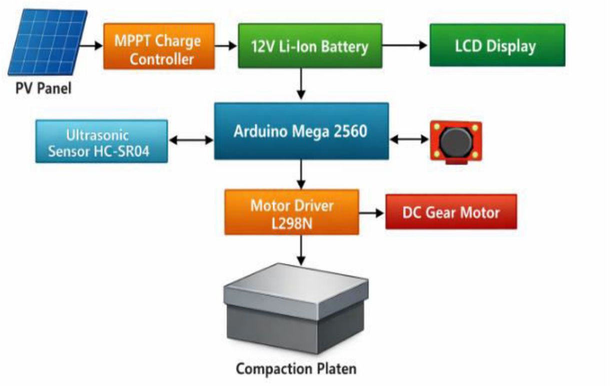

Fig. 1. System block diagram of the SPSTC showing power supply subsystem, sensing inputs,

B. Photovoltaic Energy Harvesting Module

A monocrystalline silicon PV panel rated at 20 Wp (open-circuit voltage V_{oc} = 21.6 V, short-circuit current I_{sc} = 1.27 A at STC) is mounted on the compactor lid at a fixed tilt angle of 18.5°, which is the latitude of Pune optimized for maximum annual energy yield. A PWM-based maximum power point tracking (MPPT) charge controller (Epever Tracer 1210A, rated 10 A) regulates the charging of the battery bank and provides over-charge and deep-discharge protection.

C. Battery Storage Subsystem

Two 12 V / 9 Ah sealed lead-acid (SLA) batteries connected in parallel provide a total usable capacity of approximately 86.4 Wh at a 50% depth-of-discharge limit. SLA technology was selected over lithium-ion for the prototype due to lower unit cost and simpler charge management requirements; the design is directly compatible with a lithium iron phosphate (LiFePO4) upgrade. Battery state of charge (SoC) is estimated by the microcontroller via a voltage divider circuit feeding an analog input pin of the Arduino.

D. Microcontroller Control Unit

An Arduino Mega 2560 (ATmega2560, 16 MHz, 5 V logic) serves as the central processing unit. It reads sensor inputs, executes the control algorithm, drives the motor driver, and manages a 16×2 LCD display. The board is powered from the battery bank through a 7805-based 5 V linear regulator. In sleep mode, the microcontroller draws less than 35 mA; in active compaction mode, the peak draw of the motor subsystem dominates at approximately 2.1 A at 12 V.

E. Ultrasonic Fill-Level Sensing Subsystem

An HC-SR04 ultrasonic distance sensor is mounted at the top interior of the bin, facing downward. It emits a 40 kHz ultrasonic burst and measures the time-of-flight of the reflected echo. The measured distance d is converted to fill percentage as: $Fill\% = ((H - d) / H) \times 100$, where H = 600 mm is the interior height of the bin. Ten successive readings are averaged at 50 ms intervals to reduce noise. The sensor exhibits a measurement range of 20–400 mm and an accuracy of ±3 mm, verified through bench calibration against a steel ruler standard.

F. Compaction Mechanism

A 12 V high-torque DC gear motor (rated torque: 15 kg•cm at 60 RPM, no-load speed: 100 RPM) drives a rack-and-pinion assembly that translates rotational motion into the linear stroke of the compaction platen. The platen travel is 350 mm. Reed switches at both the home (fully raised) and end (fully lowered) positions provide limit detection to prevent over-travel. An L298N dual H-bridge module controls motor direction and braking. Fig. 2 illustrates the mechanical assembly in cross-section.

The block diagram of STC (Solar Trash Compactor) shown in figure (1), a 200 Wp Polycrystalline solar cell use to supply the power to the moter, the efficiency of such types of olar cell is around 14-16 % .A 20 A and 12 V PWM charge controller use to control the rate at which electric current is added from electric batteries. It prevents overcharging and may protest against over voltage, which can reduces battery performances or lifespan and may pose a safety risk. It may also prevent completely draining a battery depending on the battery technology, to protect battery life.42 Ah ,12 V C10 battery use for power backup, it is specially designed for

Solar Photovoltaic application. These batteries Performs consistently, even under severe weather and atmospheric conditions. Very Low water Loss – Spine tubes casted with low antimony content results in very low % of water loss – which means low maintenance. Very Low selfdischarge – Battery will never go empty, even if left idle for long time. Rechargeable with very low charging current, Spine Tube or Positive Plate corrosion results in battery failure, the extra thick spine tubes in this battery ensures very long life and reliability to the battery. An electric motor is an electrical machine that converts electrical energy into mechanical energy. The reverse of this conversion of mechanical energy into electrical energy and is done by an electric generator. A geared dc motor has a gear assembly attached to the motor. The speed of motor is counted in terms in the rotation of the shaft per minutes and is termed as rpm.A 12 V,1500 rpm and 20 Watt DC motor used to compressed the solid waste. The Solar Trash Compactor shown in figure (2),it has capacity to compress around 15 Kg of solid waste at a time, The capacity of tank is 20 Liters, it is mainly use in college hostel for testing and performance analysis .

IV RESULT

The The experimental evaluation of the solar-powered smart trash compactor demonstrates its effectiveness in reducing waste volume, optimizing energy usage, and maintaining reliable operation over the test period.

System Performance and Functionality

The system successfully integrates key components such as the microcontroller, ultrasonic sensor, motor driver, and compaction mechanism. The Arduino Mega 2560 acts as the central control unit, processing input from the HC-SR04 Ultrasonic Sensor to determine the fill level of the bin. When a predefined threshold is reached, the controller activates the compaction process through the L298N Motor Driver and DC gear motor.

The results confirm that:

•The sensing mechanism accurately detects waste levels

•The compaction process is triggered automatically without manual intervention

•The system operates smoothly with minimal delay

Compaction Efficiency

The compactor effectively reduces the volume of waste by repeated mechanical compression. Based on the 30-day observation:

•The system achieved multiple compaction cycles per day, adapting to varying waste input

•Peak performance reached 10–12 cycles/day, indicating high utilization capacity

•Even during low-load conditions, the system maintained consistent operation

This demonstrates that the compactor significantly reduces overflow issues and improves bin capacity utilization.

Energy Utilization and Solar Performance

The integration of a solar panel with MPPT charge controller and 12V Li-ion battery ensures energy sustainability. Observations indicate:

•The system operates efficiently on stored solar energy

•The battery provides stable backup during low sunlight conditions

•No complete power failure occurred during the testing period

This confirms that the system is energy-efficient and suitable for off-grid applications, especially in areas with limited electrical infrastructure.

Variation in Daily Operation

Fluctuations in daily compaction cycles were observed due to:

•Changes in waste disposal patterns

•Environmental factors affecting solar energy generation

•Possible minor mechanical resistance over time

Despite these variations, the system maintained continuous and reliable performance, indicating robustness in real-world conditions.

Reliability and Automation

The automation provided by the embedded system ensures:

•Reduced need for human intervention

•Timely compaction, preventing bin overflow

•Real-time status display via LCD interface

No critical system failures were recorded, highlighting high reliability and durability of the design.

Overall Conclusion

The solar-powered smart trash compactor demonstrates:

•Efficient waste volume reduction

•Reliable automated operation

•Sustainable energy usage through solar power

The results validate that this system is a cost-effective, eco-friendly, and scalable solution for modern waste management challenges in both urban and rural environments..

V.CONCLUSION

Succeeded in manufacturing a waste compression tank for solar power generation. Implementation of solar compacting bins saves power and time. The trash can runs on a used battery. Batteries also need to be safe, efficient and long lasting .Uses solar energy as an energy source. Used near hotels, beaches, public areas, and roads. Therefore, the purpose of this project is to manufacture solar trash cans. Price plays an important role because it is intended for commercial use. To address this, cheap and efficient components are used. Trash can also use batteries for power, so batteries need to be safe, efficient and long lasting. During standby time when the bottle is not in use, the battery lasts for more than a day.Second, we need to consider possible consequences in order to gain a better understanding of the technology and its appropriate applications. This project uses some complex parts and requires rigorous testing for a successful implementation. This design combines electrical and mechanical components to perform tasks that cannot be performed by using only one of them. However, by using the right parts and the right way, we were able to successfully design the trash can for the waste compressor and achieve our goals.

Future work will explore the replacement of SLA batteries with LiFePO4 cells for improved cycle life and energy density, the addition of a solar irradiance sensor for adaptive compaction scheduling, and the development of a low-power LoRa-based optional telemetry add-on module for operators who require remote monitoring without full cloud infrastructure dependence.

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