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Decentralized Bio-Waste Liquefaction: An Automated Approach to on-site Fertilizer generation for Urban Agriculture.

[1]Mrs. Kouser Taj, [2]Mr.Mohamed Shafiulla S

[1]Assistant professor, Department of Robotics & Artificial Intelligence, Sri Siddhartha Institute of Technology, SSAHE, Tumkur, Karnataka

[2]Assistant professor, Department of Electronics & communication Engineering, Channabasaveshwara Institute of Technology, Gubbi Karnataka, India

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Abstract:

Dealing with kitchen waste is one of the biggest headaches in urban living. Usually, it just ends up in a landfill, which is a massive waste of nutrients that could be put back into the earth. To fix this, we've developed a compact, automated system designed specifically for homes and restaurants that turns food scraps into plant food instantly. Most composting takes forever and requires a lot of manual labor. Our system skips the wait by using a dual-motor setup to handle everything: The Grinder: A high-torque motor shreds various types of wet waste into smooth, consistent slurry. The Distributor: A second motor pumps that nutrient-rich liquid directly into garden soil or planters.

By automating the process from "scraps to soil," we've removed the mess and the need for large compost bins. It's a "set it and forget it" approach to recycling. Our initial tests show that this system successfully closes the loop, turning a household chore into a direct benefit for urban gardening. It proves that we can manage waste right where it's created, using low energy to transform raw scraps into immediate nourishment for the environment.

Keywords: Automated Waste Management, Wet Waste Crusher, Nutrient Recovery, Urban Farming, Bio-slurry, and Decentralized Recycling

I. INTRODUCTION

In India about 60 million tonnes of waste is being generated every year. Ten million tonnes of garbage is generated in metropolitan cities .The landfills of most of these cities are overflowing with no space for fresh garbage waste. The philosophy of "waste management hierarchy" has been adopted by most nations as the step for developing municipal solid waste (MSW) management strategies. According to a sanitation survey called "Swachh Survekshan-2016" conducted by the ministry of urban development under the swachh bharath mission, it was found that about 50% people in India face the problem of improper waste collection and management. According to centre of science and environment, innovative disposal and recycling methods must be introduced instead of landfill sites. Thus, we have proposed a cost effective "Automatic wet waste crusher" for proper management of waste. The figure 1.1 shows the Pictorial representation of differences in wet and dry waste.

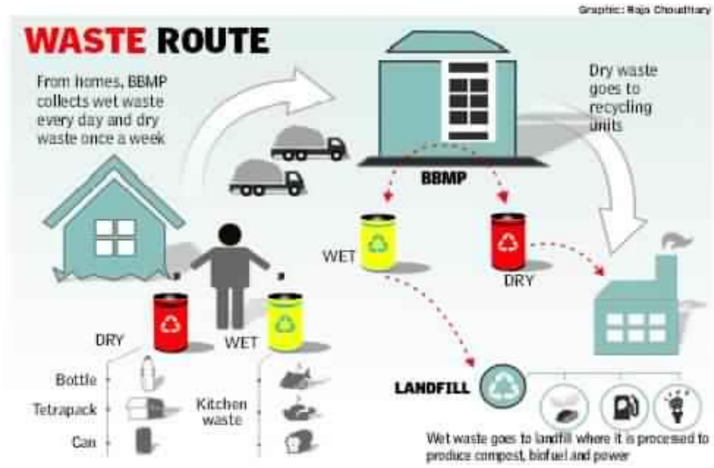

Figure 1.1: Pictorial representation of differences in wet and dry waste.

Solid waste is a general term that encloses all waste materials except unsure waste, liquid waste and region emissions. Solid wastes are often additional divided into two general groups: residential and business. The residential cluster refers to the waste that's labelled as ‘garbage’. The rubbish category are often represented because the waste that's collected by the community services. The business cluster contains industrial and agricultural customers. These purchasers are far more spread and manufacture higher amounts of waste. The foremost necessary distinction between urban routes and business routes is that the waste management company serves locations i.e. business rather than streets or quarters i.e. residential.

Figure 1.2: Constraints of wet waste.

The Figure 1.2 shows the pictorial representation of wet waste which will dispose in homes and hotels and which later can be converted into chemical fertilizers with the help of crushing process. Disposing of perishable waste product creates odor nuisance. User inconvenience caused by advanced discharge method needs a lot of maintenance value than the present system. Fuel connected issues, energy constraint over the detector nodes limits the period of time of the WSN. Improvement of routes should be followed by the truck once it involves collect wastage, wherever business waste assortment issues square measure established, the situation of the selling facilities square measure a lot of necessary than within the case of urban waste assortment, due to the upper range of disposal journeys that ought to be integrated. the employment of multiple disposal locations will improve assortment efficiency traditionally, as a result of associate degree unloading trip needs to be create to a disposal location when every client.

The monitoring system helps to monitor the waste collection process. The common method of waste disposal is by unplanned and uncontrolled dumping at landfill areas .This method is hazardous to human health, plant and animal life. When the wet waste is segregated into basic streams such as plastic, metallic and organic, the waste has a higher potential of recovery, and then, recycled and reused . The organic waste is converted either into compost or methane-gas or both . Compost can replace demand for chemical fertilizers, and biogas can be used as a source of energy. The metal waste could be reused or recycled. Even if there are large scale industrial waste crusher is present, it is always feasible to crush the wet waste at the source itself.

The benefit of doing so is that the occupational hazard for waste workers is reduced .Also, the crushed wet waste could be directly sent to the recycling and processing plant Instead of sending it to the crushing plant then to the recycling plant. Finally the crushed waste can be used as fertilizers for agricultural purpose.

II. LITERATURE REVIEW

A. Introduction

With the rapid growth of urban populations, the amount of biodegradable waste, especially food and kitchen waste has increased considerably. Traditional centralized waste management methods often struggle with issues such as high transportation expenses delayed processing, and environmental pollution. As a result, decentralized waste treatment approaches are becoming more important as sustainable alternatives. Among these, bio-waste liquefaction and anaerobic digestion technologies have gained significant attention because they can convert organic waste into useful products like liquid fertilizer and biogas [11], [16].

B. Decentralized Bio-Waste Management Systems

Decentralized waste management focuses on treating waste at or near the place where it is generated. Research shows that these systems help reduce transportation requirements, lower environmental impact, and support efficient reuse of resources [12], [16]. Small-scale composting systems and localized treatment units are increasingly being explored for urban environments.

Even though these systems offer several benefits, studies point out certain limitations such as inconsistent processing performance, slower decomposition rates, and the need for regular manual monitoring [12]. Recent studies based on circular economy concepts highlight the importance of viewing organic waste as a valuable resource rather than a disposal problem. This approach supports localized fertilizer production and contributes to long-term environmental sustainability [16], [19].

C. Bio-Waste Liquefaction and Anaerobic Digestion

Bio-waste liquefaction is the process of converting solid organic waste into a semi-liquid slurry that can be easily processed further. Anaerobic digestion (AD) is considered one of the most effective techniques for this purpose because it enables both waste reduction and resource recovery [2], [7].

Research indicates that anaerobic digestion produces nutrient-rich digestate containing important nutrients such as nitrogen, phosphorus, and potassium, which makes it suitable for use as liquid fertilizer [1], [2]. In addition, co-digestion methods have been shown to improve methane production and enhance overall system performance by maintaining better microbial balance and substrate conditions [3], [10].

Several studies also emphasize that maintaining parameters such as pH, temperature, and organic loading rate is essential for ensuring stable operation and maximizing output efficiency [7], [8]. Researchers have further explored the use of materials like biochar and activated carbon to improve microbial activity and digestion efficiency [6], [9]. Despite these developments, maintaining consistent fertilizer quality and managing variations in waste composition continue to be major challenges.

D. Automation in Bio-Waste Processing Systems

Automation has become an important factor in improving the performance and scalability of bio-waste processing systems. The use of Internet of Things (IoT) technologies, sensors, and intelligent monitoring systems allows real-time tracking and control of important parameters such as temperature, moisture content, and gas generation [14].

Recent studies have shown that automated biodigesters equipped with sensor-based control mechanisms can reduce the need for manual intervention while improving operational efficiency [20]. Machine learning techniques are also being explored to predict system behavior and optimize digestion conditions, especially when dealing with variations in organic waste composition [15].

In addition, smart waste management systems that integrate robotics and AI-based waste segregation technologies have been proposed to improve pre-processing efficiency [14]. However, there is still limited research on fully integrated decentralized systems that combine waste liquefaction, anaerobic digestion, and automated fertilizer production within a single framework.

E. Fertilizer Production from Bio-Waste

Converting organic waste into fertilizer is one of the key goals of sustainable waste management practices. Digestate obtained from anaerobic digestion has been widely recognized for its ability to improve soil fertility, support microbial growth, and reduce dependence on chemical fertilizers [17].

Studies suggest that nutrient recovery from digestate can be enhanced through methods such as bio augmentation and co-composting, which help improve nutrient stability and minimize environmental risks [18]. The addition of materials like biochar has also been found to improve nutrient retention and reduce harmful effects caused by toxicity [6], [9]. However, certain issues such as pathogen contamination, heavy metal presence, and odor control must be carefully managed to ensure the safe agricultural use of bio-based fertilizers [1], [17].

F. Application in Urban Agriculture

Urban agriculture is increasingly being viewed as a practical and sustainable approach to food production in cities. Integrating decentralized waste management systems with urban farming creates a closed-loop model in which organic waste is transformed into valuable agricultural resources [19]. Liquid fertilizers produced from bio-waste are especially suitable for applications such as hydroponics, rooftop gardens, and vertical farming because they provide readily available nutrients and are easily absorbed by plants [17]. Research has shown that these systems can improve crop productivity while reducing the use of synthetic fertilizers, making urban agriculture more sustainable and environmentally friendly [17], [19].

G. Research Gaps Identified

Based on the reviewed literature, the following research gaps are identified:

Lack of Fully Automated Systems

Existing decentralized systems require manual intervention and lack complete automation [14], [20].

Limited Integration of Liquefaction and Fertilizer Generation Most studies focus on either digestion or fertilizer production, with limited integration of both processes.

Inconsistent Output Quality

Variability in feedstock composition affects digestate quality and system performance [2], [7]. Insufficient Real-Time Monitoring Although IoT-based systems exist, their adoption in decentralized applications is limited [14].

Underutilization in Urban Agriculture

Direct integration with urban farming systems remains insufficiently explored [19].

This research focuses on overcoming the limitations of existing bio-waste management methods by developing an automated and decentralized system that converts organic waste into liquid fertilizer directly at the source. The proposed approach not only helps reduce the amount of waste sent to landfills but also promotes efficient resource utilization and supports sustainable urban farming practices through eco-friendly fertilizer production.

H. Problem Statement

Right now, we have a massive waste problem and a growing need for sustainable urban farming, but no easy way to connect the two. Current methods are too slow, too manual, and too unpredictable. We need a unified, "set-it-and-forget-it" system. Our goal is to create a fully automated, decentralized unit that turns raw waste into high-quality fertilizer in real-time, making sustainable city living actually practical.

III. METHODOLOGY

3.1 Block Diagram and Description

Figure 3.1 illustrates the overall block diagram of the proposed system. The system mainly consists of an ultrasonic sensor, odor sensor, microcontroller, LCD display, buzzer, motor driver, relay module, BLDC motor, and gear motor.

In the proposed setup, the microcontroller functions as the central controlling unit of the entire system. It continuously monitors and controls all connected components through programmed instructions. The main objective of this system is to automate the wet waste crushing process with minimal human involvement while converting the processed waste into nutrient-rich material that can be used for plant growth and agricultural applications.

To achieve efficient crushing of wet waste, a BLDC motor is used as the primary grinding mechanism. During the grinding process, additional nutrients are supplied through a separate channel controlled by a gear motor. The gear motor regulates the flow of nutrients from the storage container into the grinding chamber. Once the waste is properly processed, the final semi-solid nutrient mixture is collected in a storage bin and can later be used directly for plants or other agricultural purposes.

The ultrasonic sensor is used to monitor the waste level inside the bin. When the garbage level reaches a predefined limit, the sensor sends a signal to the microcontroller. In addition, the odor sensor continuously checks the smell level of the wet waste to help identify excessive decomposition or spoilage conditions. Based on the sensor readings, the microcontroller activates the grinding process.

After receiving the signal, the BLDC motor starts crushing the wet waste, while the gear motor simultaneously supplies nutrients into the system. Once the grinding process is completed, the processed waste is collected for further use as organic fertilizer.

This approach helps reduce waste accumulation and promotes eco-friendly recycling of biodegradable waste.

3.1.1 Ultrasonic Sensor

The ultrasonic sensor is used to detect and measure the level of garbage present inside the waste bin. It works by transmitting high-frequency sound waves and receiving the reflected echo from the surface of the waste material. By calculating the time taken for the sound wave to travel to the object and return back, the sensor determines the distance between the sensor and the waste level.

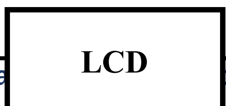

Figure 3.1: Block Diagram of Proposed System.

3.1.2 Odour Sensor

Odour sensor is used here to detect odour gas of the wet waste collected in the garbage bon. It is a simple gas sensor which monitors the different gas level and it will alarms when the minimum acceptable range of smoke exceeds and also it acts often as a part of safety system. The sensor monitors the input level of smoke with its threshold kept level.

3.1.3 Microcontroller (At mega 328)

The microcontroller is used as heart of the proposed system. The controller used here is Atmega328. ATmega-328 is basically an Advanced Virtual RISC (AVR) micro-controller. It supports the data up to eight (8) bits. ATmega-328 has 32KB internal built-in memory. This micro-controller has a lot of other characteristics.

3.1.4 LCD Display

LCD connected to the microcontrollers is 2x16. The display is used her to display the intermediate and alert messages during the crushing process which happens with the help of motors and controller. Liquid crystal display is an optical electro-mechanical system that uses fluid crystal light properties. Instead than using the reflector or backlight, it does not specifically emit light to acquire colour images. LCDs are used in a wide variety of applications, including

LCD televisions, Computer monitors, instrument boards, cockpit airplane shows and indoor and outdoor signage. Little LCD screens, such as advanced cameras, watches, number crunchers and cell phones including cell phones, are usual in convenient buyers' gadgets.

3.1.5 L293D, Motor Driver

The driver is used here to control the direction of gear motor in turn which control the content of adding the nutrients to waste bin during crushing process. There are 4 input pins for L293D, the pin 2and 7 on the left side and pin 15 regulate the rotation of motor connected beyond left side and right input for motor on the right hand side. The motors are moving on the basis of the inputs provided beyond the input pins as LOGIC 0 or LOGIC 1.In easy to provide Logic 0 or 1 beyond the input pins for rotating the motor.

3.1.6 Relay

It is used to turn on/Off the BLDC motor which is used for crushing the wet waste and is driven by a relay driver. Relays are remote control electrical switches that are controlled by another switch, such as a horn switch or a computer as in a power train control module. Relays allow a small current flow circuit to control a higher current circuit. Several designs of relays are in use today, 3-pin, 4-pin, 5-pin, and 6- pin, single switch or dual switches. Relays which come in various sizes, ratings, and applications, are used as remote control switches. Fig. 5 shows different types of relays.

3.1.7 Gear Motor

The gear motor is used to control the input channel of nutrient container which is used to add the nutrient during crushing process. This is a unique type of electric motor that's evolved to achieve a high torque by way of preserving low HP or more output or low speed

3.1.8 BLDC Motor (Waste Crusher)

BLDC motor is used here to crush the wet waste with the help of blades. A brushless DC motor (also known as a BLDC motor or BL motor) is an electronically commuted DC motor which does not have brushes. ... In brushless motors, permanent magnets rotate around a fixed armature and overcome the problem of connecting current to the armature. A brushed DC motor has permanent magnets on the outside of its structure, with a spinning armature on the inside.

3.1.9 ESC (Electronic Speed Controller)

An electronic speed control or ESC is an electronic circuit that controls and regulates the speed of an electric motor. It may also provide reversing of the motor and dynamic braking.

IV. RESULTS & ANALYSIS

The ultrasonic sensor is used for detecting the waste level in the bin and odor sensor is used to detect odor level of wet waste. When the garbage bin reaches the level of the sensor, then the indication will be given to a microcontroller as shown in figure 4.2. The microcontroller based on sensed signal closes the bin and then the BLDC motor starts to grind the waste by addition nutrients with the help of gear motor as shown in figure 4.4 and figure 4.5.

Finally, those grinded wastes are collected through the waste collection vehicle and those are directly used as a nutrient for plants or to any agriculture purpose.

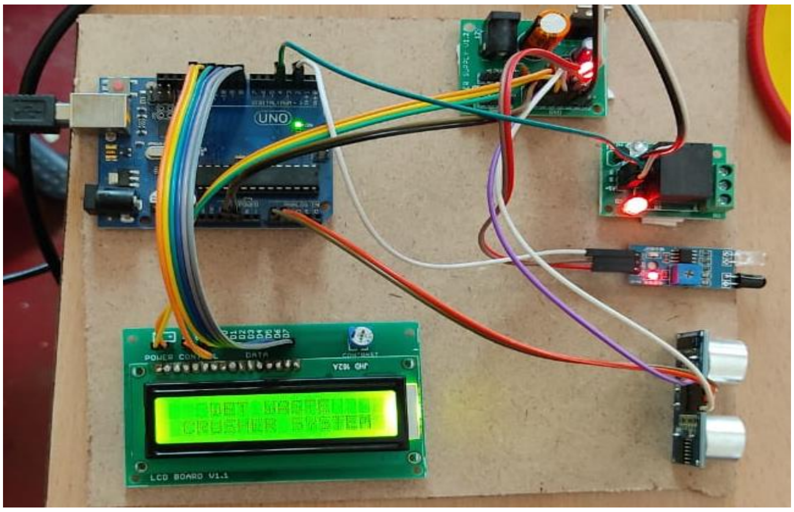

Figure 4.1: Wet waste crusher system

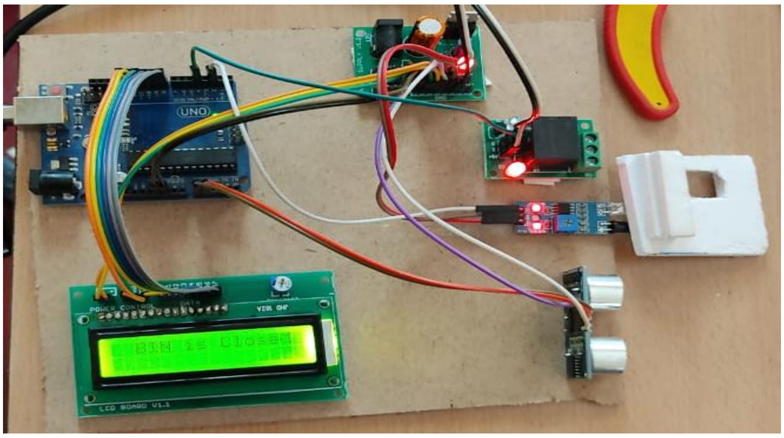

Figure 4.2: When wet waste reaches the maximum level in bin, the bin will be closed.

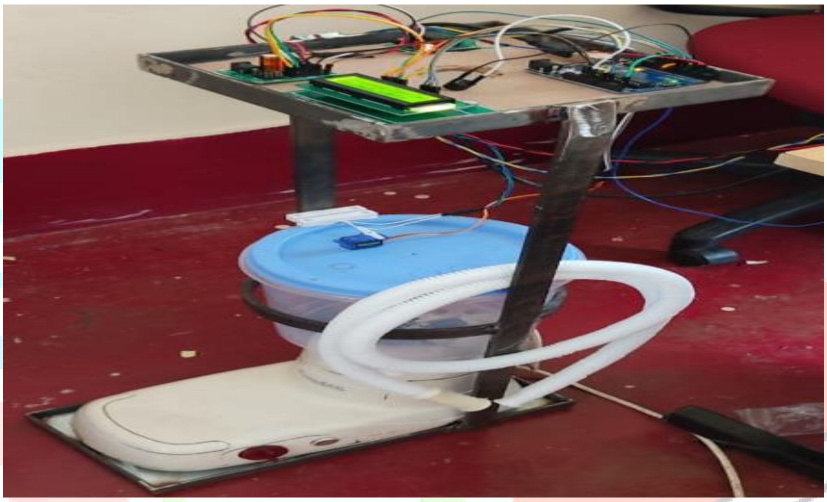

Figure 4.3: The BLDC motor setup for crushing of the nutrients.

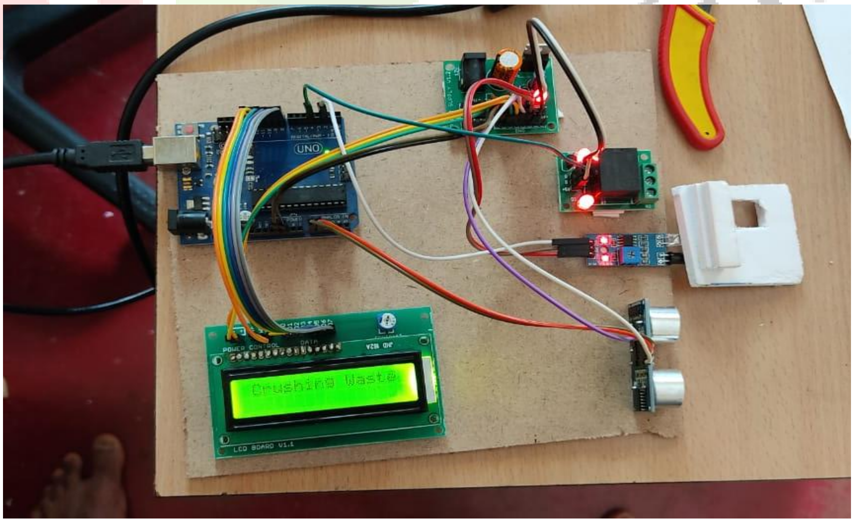

Figure 4.4: The wet waste is crushed using BLDC motor

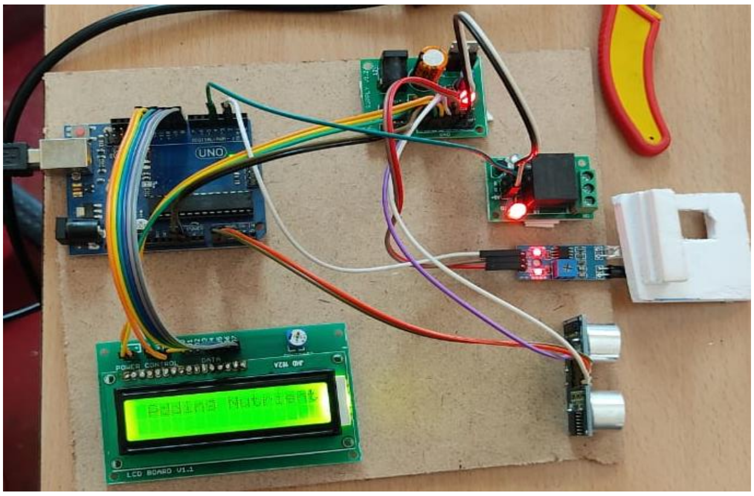

Figure 4.5: Nutrients are added to the crushed waste and supplied to the plants

V. CONCLUSION

The development of the Automated Wet Waste Crusher and Nutrient Distribution System successfully demonstrates a decentralized approach to urban waste management. By integrating dual-motor architecture, the project effectively bridges the gap between mechanical waste reduction and automated agricultural application.

Automation of Waste Processing: The system successfully eliminates manual handling by synchronizing a high-torque crushing phase with a secondary distribution phase, making it viable for high-volume environments like hotels and residential complexes.

Closed-Loop Resource Recovery: The transformation of organic "waste" into a liquid mineral substrate provides a sustainable alternative to synthetic fertilizers, promoting a circular bio-economy at the source of generation.

Operational Efficiency: The transition to a "liquefaction" model bypasses the traditional, time-consuming composting process, offering an immediate solution for on-site nutrient recycling.

VI. FUTURE WORK

Future iterations of this work will focus on integrating IoT-based nutrient sensors to analyze the NPK (Nitrogen, Phosphorus, Potassium) levels of the slurry in real-time, allowing for "smart-fertigation" tailored to specific plant species. Ultimately, this technology serves as a foundational step toward smarter, greener, and more self-sufficient urban living environments.

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