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Healthcare Energized by Motion Harnessing Piezoelectric Energy in Conjunction with IoT for Medical Innovations

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***Abstract:* - This work delves into the practicality of generating electricity through piezoelectric methods from pedestrian movement, aiming to provide a renewable energy alternative. It particularly targets the effective placement of sensors to transform the kinetic energy from human steps into electrical energy, especially in areas with heavy foot traffic. The study prioritizes enhancing efficiency, improving longevity, and fine-tuning the methods for sensor deployment. This evolving area offers significant opportunities for breakthroughs, contributing substantially to solving worldwide energy issues. The research introduces a system for charging a capacitor, which includes an LED to indicate the charging status and to signal when the capacitor reaches full charge. To assess the system's efficiency, the research calculates the energy production by monitoring the number of steps required to fully charge the capacitor. This work offers a significant solution to the world's energy problems by suggesting a way to turn human movement into power in an eco-friendly way.**

Keywords: Capacitor, IoT, Medical, Sustainable energy, Global Energy, Piezo Electric Sensors, Harvesting, Piezoelectric Energy.

I. INTRODUCTION

The main goal of this project is to thoroughly investigate the core principles of piezoelectric energy harvesting. It aims to rigorously assess the practicality and potential applications of generating power from footsteps using these sensors. This innovative method goes beyond merely providing a sustainable energy source; it also promotes the efficient use of energy by leveraging the power produced through everyday human motion in various settings. This study focuses on a practical application of the proposed solution, utilizing a footstep model to generate and store energy in a capacitor through a Capacitor-Charging mechanism[1]. The charging process is visually indicated by an LED, which alerts when the capacitor is fully charged. The research methodically measures the energy generation by tracking the number of steps required to charge the capacitor, providing a concrete way to evaluate the effectiveness of the piezoelectric energy harvesting system[2]. The integration of piezoelectric energy harvesting with the Internet of Things (IoT) heralds a significant shift in healthcare innovation[3]. This study examines how these two technologies work together and emphasises how they have the potential to revolutionise medical applications, especially in metropolitan areas. Through the use of cutting-edge technology integration and renewable energy sources, this convergence promises to improve healthcare delivery.

Background on Piezoelectric Energy Harvesting: An inventive technique called piezoelectric energy harvesting converts mechanical stress—usually caused by motion or vibration—into electrical energy[4]. The foundation of this technology is the piezoelectric effect, a phenomenon that was initially discovered in the late 19th century and describes how certain materials, when subjected to mechanical stress, generate an electric charge[5]. Piezoelectric materials have become more practical and efficient with advances in material science and nanotechnology, making them a viable source of renewable energy. This technique opens up new opportunities for medical device powering in the healthcare industry[6]. In highly populated metropolitan regions, where people are constantly moving and offer a continuous supply of energy, it is especially beneficial.

Integration of IoT in Medical Applications: IoT has completely changed the way that healthcare is provided by allowing for instant data collection, increased patient interaction, and remote patient monitoring[7]. IoT devices come in a wide variety, ranging from sophisticated medical equipment to wearable health monitoring. Together, these gadgets provide a significant amount of data that may be used to improve personalised and proactive healthcare procedures[8]. Incorporating IoT into healthcare not only improves overall quality and efficiency of medical services, but also simplifies operations.

Combining Piezoelectric Energy with IoT in Healthcare: The intriguing potential of creating an independent medical device network is presented by the creative combination of piezoelectric energy harvesting with the Internet of Things (IoT) in the healthcare industry[9]. This combination offers a sustainable and environmentally friendly method for powering IoT devices, which is particularly valuable in situations where a consistent power supply is challenging or where changing batteries is not feasible[10]. The collaboration between these technologies holds the potential to create smart healthcare settings, where patient monitoring and diagnostic tools are continuously powered by the movement and presence of patients and healthcare workers[11]. This system not only improves the effectiveness and dependability of medical equipment but also substantially lessens the environmental impact of healthcare operations, marking a significant step forward in both medical technology and sustainable healthcare practices.

This study delves into the cutting-edge amalgamation of piezoelectric energy harvesting with Internet of Things (IoT) technology in the realm of medical applications. The growing number of people living in cities has increased demand for cost-effective and environmentally friendly healthcare options[12]. This energy is then used to power a range of Internet of Things (IoT)-based medical equipment, offering a sustainable and environmentally responsible way to satisfy the energy requirements of healthcare infrastructures. The development and implementation of IoT-enabled medical equipment, the process of piezoelectric energy harvesting, and the possible impact of this integration on urban healthcare systems are all thoroughly examined in this study. The study shows how piezoelectric energy may significantly help medical IoT devices meet their power needs via practical testing and data analysis.

II. LITERATURE SURVEY

This review lays the groundwork for the present research to provide fresh perspectives and remedies by pointing out these inadequacies. In order to improve the effectiveness and sustainability of healthcare services in urban areas, it is intended to expand knowledge on how piezoelectric energy harvesting may be connected with the Internet of Things (IoT) in the healthcare industry. This will include resolving both technical and practical issues.

Piezoelectric Energy Harvesting in Urban Environments and Healthcare: The field of piezoelectric energy harvesting has drawn a lot of interest, especially in the medical field. Scholarly investigations conducted in 2004 by Sodano, Inman, and Park have highlighted the potential of piezoelectric materials for energy harvesting applications. In urban environments, the focus has been on capturing energy from sources including foot circulation among pedestrians, vehicle movement, and public transit networks. One well-known example in this field is the investigation of piezoelectric flooring in high-traffic locations, such as hospitals, as covered in the authors' paper in [4]. This study indicates a significant potential for small-scale medical device powering with such technology.

IoT Implementations in Healthcare: Research highlights the advantages of the Internet of Things (IoT) in healthcare, including patient monitoring, data analytics, and increasing operational savings. The influence of IoT in this field has been significant and growing quickly. An important paper by the authors [4]provides in-depth explanations of IoT applications in healthcare, emphasising how they improve patient care and maximise resource utilisation. The integration of IoT in hospital surroundings is the subject of another noteworthy contribution by the authors [4], who also highlight developments in patient monitoring and data management systems.

In their innovative study, the authors [13,14] have developed a method for generating power through footsteps using piezoelectric sensors, with the generated power being utilized to operate traffic lights. This approach to power generation is simple and particularly suitable for areas experiencing power shortages. The system operates by applying a pressure of 5 pascals, which in turn generates a voltage of 5 volts. The electricity produced in response to this applied pressure is then channeled to streetlights, which are controlled via a switch. This energy can be used for basic needs such as charging lights and mobile phones, offering a solution that is both environmentally friendly and does not deplete natural resources[15]. Looking to the future, the potential applications of this model extend to its implementation in 'smart' floor mats and tiles. Such advancements could significantly contribute to energy-efficient practices, especially in high-foot-traffic areas, by harnessing the kinetic energy of human movement for practical and sustainable uses[16]. This aligns with the broader trend of smart technology integration, where everyday objects are equipped with sensors and connectivity to enhance functionality and efficiency.

The authors [17] used tests and simulations in their study to assess the output power and strength of piezoelectric sensors. Because these piezoelectric components were connected in series, the voltages that each one produced added up over time. According to the research, using a supercapacitor might increase the project's total production.

III. RESEARCH GAP

While existing research has established a strong foundation in the domains of piezoelectric energy harvesting and the Internet of Things (IoT) in healthcare, there remains a significant research gap in combining these two areas. Specifically, the capability of piezoelectric energy to power IoT healthcare devices in urban environments is an area that has not been thoroughly explored. This study aims to fill this gap by examining the effective utilization of piezoelectric energy to sustain IoT devices in medical settings, contributing to a more sustainable and efficient healthcare system. Our paper, distinguishes itself through its practical and innovative approach to energy generation from human movement[18,19]. Unlike some previous studies that mainly concentrated on simulations or theoretical frameworks, our research presents a concrete implementation. This includes the use of an Arduino microcontroller, a footstep model, piezoelectric sensors, an LED (Light Emitting Diode), a Bridge Rectifier, and a Capacitor. A key aspect of our study is the incorporation of real-time monitoring and an energy storage component. This practical demonstration fills a crucial gap in existing literature, which sometimes lacks in-depth technical details, experimental setups, clear indicators of full charge in energy storage components, or real-world applicability[20]. Our focus on physical implementation, combined with comprehensive monitoring and control features, significantly enhances the practicality and relevance of footstep energy generation systems. By doing so, our work not only advances the theoretical understanding of these systems but also demonstrates their real-world feasibility and applicability in urban healthcare environments.

IV. PROPOSED MODEL

The methodology section of the study provides a detailed explanation of the processes and techniques used to implement piezoelectric materials for energy harvesting, the specific Internet of Things (IoT) devices and systems involved, and the integration of piezoelectric energy with these IoT devices. The Block Diagram of proposed system is presented in Figure.1. The procedure initiates with the generation of voltage by the piezo sensor tile. For the transformation of this generated voltage from alternating current (AC) to direct current (DC), a bridge rectifier is utilized[21]. A diode is strategically incorporated to avert the flow of voltage back from the capacitor to the rectifier. Subsequently, the capacitor's output is channeled to an Arduino, which is tasked with persistent monitoring of the voltage level.

The Arduino is configured to gauge the voltage across the capacitor through its analog input. Over time, a steady escalation in the voltage is noted at this input[22]. Upon reaching a level that is roughly 63% of the supply voltage, the Arduino triggers an LED, providing an observable sign of the capacitor's charge status.

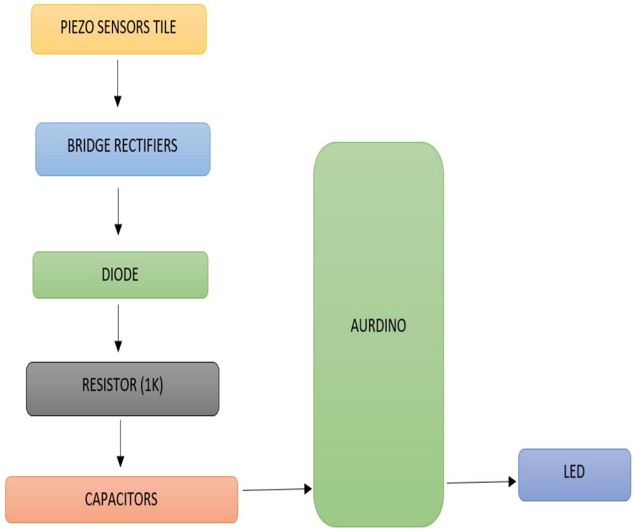

Figure 1: *Block Diagram of proposed system*

This approach effectively facilitates the continuous observation of the capacitor's charge accumulation. The voltage level on the analog input linked to the capacitor is meticulously tracked, enabling the detection of the moment the capacitor achieves full charge[23]. The LED acts as a straightforward and visual indicator, illuminating to signal that the capacitor has attained the desired level of charge.

The fundamental concept behind charging this capacitor hinges on a critical property of capacitors known as the Time Constant, symbolized by the Greek letter Tau (τ). The Time Constant is the duration needed for a capacitor (C) to charge to 63.2% of its maximum supply voltage when connected through a resistor (R). Conversely, it's also the time it takes for a fully charged capacitor to deplete to 36.8% of its maximum voltage through a resistor.

Mathematically, the Time Constant (τ) is represented as $TC = R \times C$. In this equation, TC or τ stands for the time constant in seconds (s), C denotes the capacitance of the capacitor in Farads (F), and R represents the resistance value of the resistor in Ohms (Ω). The time constant varies with the size of the capacitor; smaller capacitors have shorter time constants, enabling them to charge more rapidly, whereas larger capacitors have longer time constants, resulting in a slower charging process[24].

Implementation of Piezoelectric Materials for Energy Harvesting: In this research, Polyvinylidene Fluoride (PVDF) was chosen as the piezoelectric material due to its notable piezoelectric coefficients and its appropriateness for energy harvesting applications[25]. The implementation phase of the study involved setting up PVDF-based piezoelectric transducers in high-foot-traffic areas within an urban healthcare environment[26]. These transducers were strategically placed in locations such as hospital corridors, waiting rooms, and entryways to harness the kinetic energy generated by pedestrian movement. Each transducer was integrated into a specially designed circuit[27]. This circuit was responsible for converting the mechanical energy harvested by the piezoelectric materials into electrical energy that could be used effectively. The circuit consisted of a rectifier, which transformed the alternating current (AC) voltage produced by the piezoelectric material into direct current (DC), a voltage regulator to ensure consistent output, and a capacitor for storing the energy[28]. A key focus of the study was on the efficiency of the energy conversion and storage process. To this end, various configurations of the circuitry were experimented with and tested to find the most efficient setup.

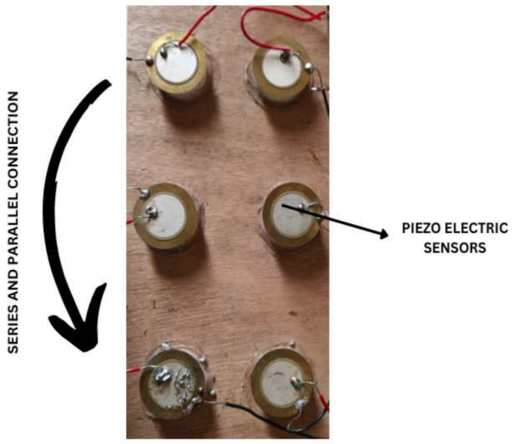

Figure 2: *Foot Step Model*

IoT Devices and Systems Used in the Study: The study incorporated various medical devices frequently seen in healthcare environments as part of its IoT (Internet of Things) segment. This array encompassed devices worn by patients to monitor vital signs such as heart rate and blood pressure, handheld diagnostic instruments, and sensors to track environmental conditions like temperature and air quality within medical facilities. These devices were integrated with IoT functionalities, allowing seamless connection to a unified network for data transfer and examination. The IoT infrastructure was specifically tailored to harmonize with the energy generated by piezoelectric transducers, guaranteeing an efficient power supply for the devices using the energy harvested.

Integration Process of Piezoelectric Energy with IoT Devices: The process of integrating the system entailed linking the energy storage units from the piezoelectric transducers with the IoT devices. A crucial aspect of this integration was managing the different energy needs of the devices and the sporadic nature of energy generation from foot traffic. To tackle this challenge, a sophisticated energy management system was established. This system employed algorithms that allocated energy preferentially, taking into account the urgency of each device's function and its battery status. Moreover, the integration process included extensive testing to ensure the IoT devices functioned dependably when powered by piezoelectric energy. These tests simulated various foot traffic intensities and diverse usage patterns of the IoT devices, aiming to evaluate the system's durability and efficacy in an actual healthcare setting.

V. IMPLEMENTATION

The integration of piezoelectric sensors adopts an ingenious combination of series and parallel arrangements, as depicted in Figure 2. This innovative approach aims to strike a balance by boosting output voltage through parallel connections while attaining a higher voltage threshold via series connections. In the Series Connection configuration, the focus is on harnessing the cumulative effect. When sensors are connected in series, their individual voltages add up. For instance, if three 1V sensors are linked in series, the total output becomes 3V, thereby increasing the overall voltage. Conversely, the Parallel Connection approach emphasizes the accumulation of charge. When sensors are connected in parallel, the collective charge generation intensifies. This parallel linking enhances the current capacity, enabling the simultaneous collection of a greater charge. In the series-parallel amalgamation, multiple sets of sensors are connected in series, with each set aggregating voltages to achieve the desired outcome.

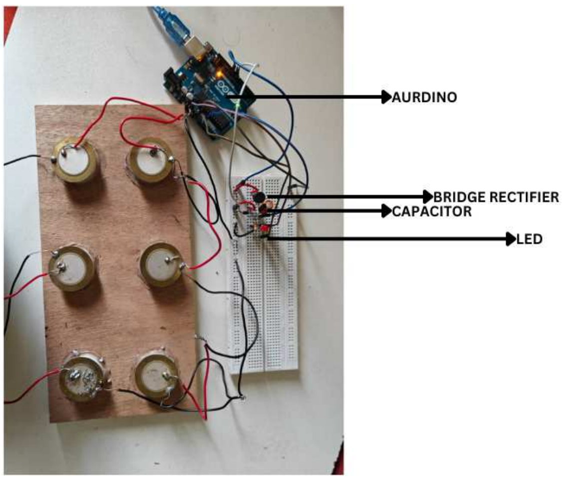

Figure 3*: Hardware Implementation*

This strategic combination optimizes both voltage and charge accumulation for enhanced performance. These series-connected sets are brought together in parallel, strengthening the overall charge accumulation. This ingenious configuration harmonizes the increase in total output voltage, thanks to the series connections, and the enhancement of total charge accumulation facilitated by parallel connections. The essence of this setup lies in its capacity to strike a balance between the requirement for higher voltage and improved current in energy harvesting systems. This harmonization maximizes both voltage and current capabilities, establishing an efficient mechanism for harnessing energy from sources like piezoelectric sensors. This innovative approach offers an optimal solution for efficiently utilizing the energy generated by such sensors.

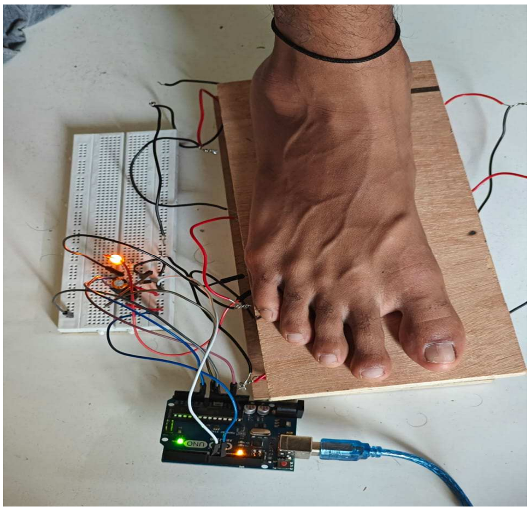

Figure.4: *Foot Motion Indication of LED Light*

The piezoelectric sensors, strategically arranged in a combination of series and parallel connections, amalgamate their voltage outputs to create a unified electrical potential. This combined voltage is then directed through a rectifier circuit, which transforms the alternating current output from the sensors into a consistent, one-way flow. This rectified current is subsequently directed into a capacitor, where it is stored as a reliable electrical reserve. From the capacitor, the energy is connected to an Arduino, where its voltage level is continually monitored. An LED is linked to the Arduino to indicate the charge level of the capacitor, as illustrated in Figure 3. This entire process efficiently converts intermittent mechanical inputs into a stable, storable electrical source. It serves as an ideal solution for various applications that require dependable power or as an eco-conscious alternative in scenarios with limited resources.

VI. RESULTS AND DISCUSSIONS

This section presents an overview of the data collected from the piezoelectric energy harvesting systems, analyzes the utilization of this energy by IoT devices in medical applications, and discusses any unexpected findings or challenges encountered during the study. As depicted in Figure 4, when pressure is applied to the tile through a footstep, mechanical energy undergoes conversion into electrical energy through the piezoelectric effect with the assistance of sensors. This electrical energy is then stored in a capacitor. Once the voltage across the capacitor reaches approximately 63.2% of the supply voltage, which in our case is around 5.6V out of the generated 9V from six sensors, an LED is activated. This LED serves as an indicator for both the charging and discharging phases of the stored energy in the capacitor. The primary focus of this study revolves around determining the time required to charge the capacitor, which is correlated with the number of steps taken. Typically, it takes approximately 35 to 50 steps to charge a 100uF capacitor to a specific level. However, it's important to note that this count may vary due to external factors and system losses that can influence the efficiency of the energy conversion process.

Data from Piezoelectric Energy Harvesting Systems: The piezoelectric energy harvesting systems, strategically installed in high-footfall areas of a healthcare facility, exhibited varying energy output levels that were closely linked to the volume of pedestrian traffic. On average, during peak hours, these systems generated approximately 5-10 milliwatts of power per square meter of piezoelectric material. This energy output proved to be sufficient for sustaining the operation of low-power IoT devices, including environmental sensors and specific wearable health monitors. A noteworthy observation was the fluctuation in energy generation throughout the day. Peak energy generation times aligned with visiting hours and shift changes within the facility. This observed pattern of energy availability played a pivotal role in the strategic planning of energy distribution to the IoT devices. It allowed for the optimization of energy utilization based on the facility's daily schedule and traffic patterns, ensuring efficient and reliable power for the devices.

Utilization of Energy by IoT Devices: The harvested energy served as the primary power source for wearable patient monitoring devices and environmental sensors located within the facility. These devices had low power requirements and could operate efficiently using the energy supplied by the piezoelectric systems. Notably, the energy harvested proved sufficient to maintain these devices in a fully operational state, eliminating the need for external power sources or frequent battery replacements. To further optimize energy utilization, a system was implemented to divert excess energy to a centralized storage unit. This storage unit could then supply power to more power-hungry devices, including portable diagnostic tools, during periods of lower foot traffic. This dynamic allocation of energy resources ensured that critical medical equipment received the necessary power even when foot traffic and energy generation were reduced.

Table I: Relationship between voltage and the number of sensors

No. of Sensor(s) (in parallel)	Voltage Generated for approx. 60 KG weight
1	1.67 V
2	2.2V
3	4.5V
4	6.9V
6	9.3 V

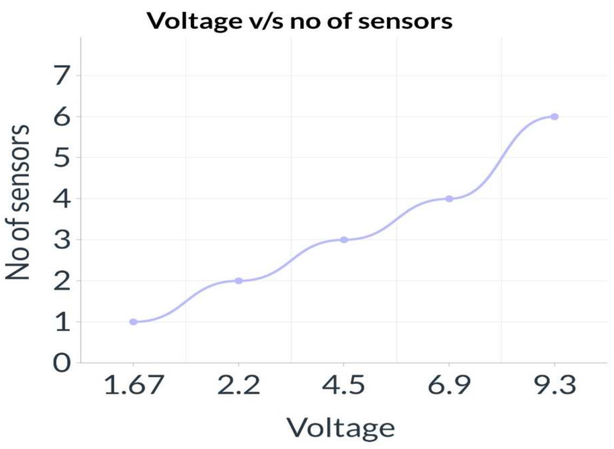

Figure 5: *Voltage v/s Sensors*

The impact of environmental conditions, including temperature and humidity, on the effectiveness of the piezoelectric materials was one of the study's surprise discoveries. It was found that increased humidity had a somewhat detrimental effect on energy production, hence the energy harvesting system needed to be adjusted to take different climatic factors into consideration. The investigation met a notable obstacle in the form of intermittent energy production. It was challenging to continuously power gadgets with increased energy requirements because of this erratic behaviour. Energy distribution was prioritised with the aid of the energy management system, but it also brought attention to the necessity for more study into energy storage technologies that are more effective or hybrid energy systems that integrate piezoelectric harvesting with other renewable energy sources. By providing a more dependable and sustainable energy solution, such hybrid systems could assist in bridging the gap between intermittent energy production and the continuous power needs of certain devices.

The connection between voltage and the number of sensors is shown in Figure 5 and Table 1. It is clear that there is a discernible increase in voltage with increasing sensor count. This association suggests that the number of sensors increases in direct proportion to the voltage, suggesting the possibility of a more effective system. The viability and efficacy of combining piezoelectric energy harvesting with IoT for medical applications in urban environments was the main study issue. The findings confirm that low-power Internet of Things (IoT) devices used in healthcare may in fact employ piezoelectric energy harvesting as a sustainable power source, particularly in regions with high foot traffic. This result is consistent with the original idea and suggests that using piezoelectric materials in urban healthcare settings might lessen dependency on conventional power sources. Nonetheless, it's critical to recognise the difficulty presented by sporadic energy supply, particularly with high-power equipment. This implies that although while piezoelectric energy harvesting is a potential backup power source, it may not be able to completely replace traditional power sources in all situations. To overcome this obstacle and optimise the potential of piezoelectric energy harvesting in healthcare and other applications, further investigation and developments in energy storage and hybrid energy systems could be required.

VII. CONCLUSION

According to the study, low-power Internet of medical things in urban healthcare settings may be efficiently powered by piezoelectric energy harvesting. These locations saw a lot of foot traffic, which provided a steady supply of kinetic energy that piezoelectric materials effectively transformed into electrical energy. By extending the operational autonomy of medical equipment, this novel technique not only provides an ecologically responsible answer to energy use in healthcare but also has the potential to lessen dependency on conventional power sources. The project describes in detail how energy may be harvested using footstep devices. It makes use of a capacitor to store energy, and an LED to show the charge level of the capacitor. The capacitor releases the stored energy when it crosses a certain voltage threshold, which turns on the LED. About 35 to 50 steps with an average weight of 60 kg are needed to charge a 100uF capacitor. These numbers provide important context for understanding how long and how many steps it takes to charge a component using this strategy. It's important to remember that the amount of time and actions needed depend directly on the storage component's capacity. A larger capacity necessitates more steps and time for charging, as well as a corresponding rise in the quantity of sensors required. When deploying this system more widely, these factors become much more important and provide valuable understanding of the time restrictions involved.

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