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Innovative Design of Solar Benches for Public Spaces: Renewable Energy with Arduino Integration

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Abstract

This research aims to design and implement an innovative park bench that combines solar panel technology with the Arduino platform. The methodology of this research consists of designing the integration of solar panels with Arduino components that are assembled integrated on the physical bench. In the analysis phase, measurements of solar energy production were conducted under various light and weather conditions. The performance of the system in battery charging and fulfillment of energy needs was evaluated. Environmental data from Arduino sensors were analyzed to illustrate the effect of environmental conditions on system operation. The results showed that the solar bench produced higher energy during daytime and reduced during nighttime conditions. The system can supply energy for purposes such as lighting and charging electronic devices. The voltage and current data at night show inefficiency in charging the solar panel, while the cell phone charger condition works as long as the battery is above 15%. In addition, environmental analysis through Arduino sensors revealed a correlation between light intensity and energy production and usage. These findings can be used to optimize the operation of the smart bench system based on changing environmental conditions. In conclusion, this solar bench design has the potential to reduce environmental impacts and support the use of renewable energy in urban public spaces, with the potential to increase public awareness of sustainable energy

Introduction

Amidst increasing urbanization and population growth around the world, the challenge of providing sustainable and environmentally friendly energy sources in urban environments is becoming more pressing (Kango, Hadiyanto, Pongtularan, & Abas, 2021; Zach, Kretschmer, & Stoeglehner, 2019). The limitations of conventional energy resources, along with the associated negative environmental impacts, have prompted global efforts to seek more sustainable and environmentally friendly alternatives (Kango, Hadiyanto, & Pongtuluran, 2021). One promising solution is the utilization of renewable energy, such as solar energy, to meet energy needs in various sectors, including public spaces (Gedikli, Taş, & Taş, 2022). While sustainability and renewable energy have been the focus of attention, the challenges faced in achieving the transition to renewable energy in urban public spaces cannot be ignored (Zhou, Liu, Wu, Xu, & Hua, 2021). Using conventional energy sources, such as lighting and charging electronic devices in parks and other public spaces, has been found to have negative ecological consequences and contribute to reliance on finite resources (Ceclan, 2019). Hence, it is imperative to devise novel and effective strategies for harnessing renewable energy inside urban settings. The adoption of sustainable solutions in energy use within urban public spaces

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plays a crucial role in attaining global objectives during the transition towards renewable energy. The development and execution of a novel park bench that integrates solar panels with an Arduino platform can be a significant undertaking in showcasing the feasibility of employing renewable energy in a practical and scalable manner (Kango, Hadiyanto, & Pongtularan, 2021). According to (Ozgun, 2020), integrating solar panel technology with the Arduino platform fosters the advancement of more intelligent and effective energy management systems.

A novel concept for a solar bench design for public use has been put out, incorporating Arduino technology for energy generation and monitoring. The design incorporates the utilization of solar cells to capture solar energy and subsequently convert it into electrical energy. This electrical energy can then be employed to power the lighting system of the bench (Kango, Hadiyanto, & Pongtularan, 2021; Thirupathaiah, 2021). Furthermore, (Wenda & Putra, 2020) have devised a solar tracking mechanism that employs light-sensitive sensors and servo motors to enhance the efficiency of solar panel energy absorption. Another research presents an automated solar tracking system that uses Arduino UNO to track the movement of sunlight and improve power efficiency in sunlight utilization (Stephen, Fokui, & Mashava, 2021). Furthermore, a research project aims to improve solar energy capture using photovoltaic cells controlled by an Arduino platform (Suwarno, Rohana, & Purba, 2021). This innovative solution shows the potential for integrating renewable energy technologies, such as solar panels, into public open spaces (Naif, 2020). Previously, research has been conducted on the application of renewable energy in public spaces. The use of solar panels and Arduino technology has been proposed in various applications to utilize solar energy. However, a comprehensive approach in designing an innovative park bench with the integration of solar panels and Arduino platform in an urban environment still needs to be further explored.

We designed and installed a park bench that emphasizes using renewable energy in this study. Integrating solar panels with Arduino can improve energy management in urban areas. We evaluate the system's energy generation, battery charging, and consumption management. Additionally, practical ramifications and future development potential are highlighted. This research aims to create a park bench that generates and manages renewable energy using solar panel technology and an Arduino platform. This project attempts to solve the issues of conventional energy use in metropolitan areas through efficient and sustainable solutions. This bench may generate sustainable energy in public settings using solar energy and Arduino technology for intelligent regulation and monitoring. The study hypothesizes that park storage and renewable energy management in urban public places will achieve its goals. A bench with solar panels and an Arduino platform will enable efficient generating. Real-world implementation and performance study of the integrated system will test this notion. Research contributes to sustainable energy use solutions in urban public places. We want to generate, store, and manage renewable energy efficiently and sustainably by integrating solar panel technology with the Arduino platform. The practical design and installation of this solar bench can inspire similar solutions in other metropolitan areas, contributing to the discussion on sustainable energy and environmental improvement.

Methods

Integration of solar panels with Arduino components

This park bench is planned using the SketchUp Pro 2020 application and has dimensions of 110 cm long, 60 cm wide, and 55 cm high. This bench is made of iron. The electronic circuit system will be placed under the solar panel in the center of the bench and will be protected by glass that is resistant to load when used. In addition, the electronic components will be well insulated to protect them from water when it rains. The integration of the solar panel with the Arduino components is the main focus of this sustainable park bench design.

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This design approach is based on the harmonious cooperation between the solar panel technology that serves as the energy source and the Arduino platform that acts as the brain of the system. The solar panel strategically installed on the top of the bench serves to capture solar energy and convert it into usable electrical energy. On the other hand, the Arduino, as the system's control center, is responsible for managing the process of collecting, storing, and using energy intelligently and efficiently. The design of this park bench can be seen visually in Figure 1.

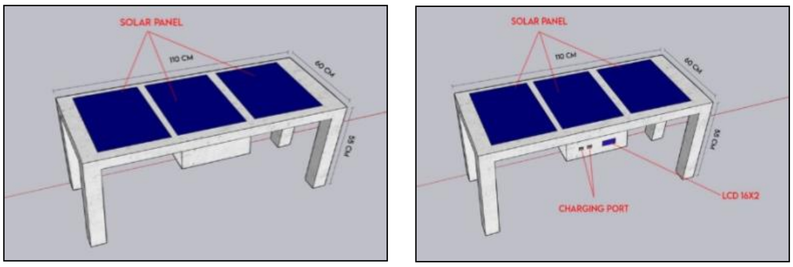

Figure 1. Smart bench design

Technical Specifications of Solar Bench: Solar Panel Capacity, Storage Battery, Environmental Sensors

The technical specifications of the solar bench include a solar panel capacity of 20 Wp/h with a size of 35 cm x 49 cm, a storage battery with a capacity of 20V 18 Ah that allows energy storage and supply during periods of low light intensity or at night, and the integration of environmental sensors in the form of Light Dependent Resistor Sensors connected to Arduino for data collection of light intensity and environmental conditions.

Details Of Mechanical and Electrical Design

Figure 2 shows the mechanical and electrical design details including the connection of solar panels through a power converter to convert energy into an electric current that can be used by the system. Then the installation of sufficient Arduino hardware for system control efficiency and future adaptation, as well as the integration of an energy storage battery that is regulated by Arduino according to the needs and environmental conditions to accommodate the storage of excess energy generated by the solar panels.

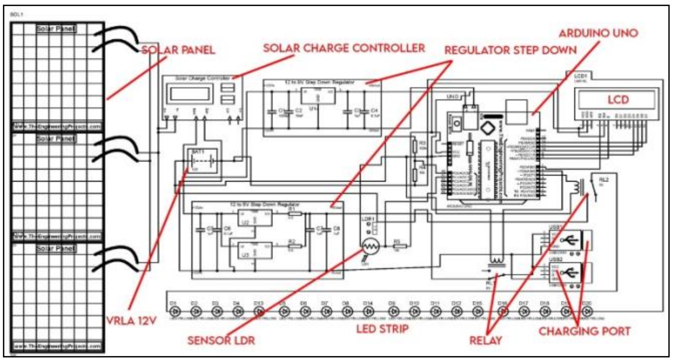

Figure 2. Details of mechanical and electrical design

In the design stage of this tool, we adopt a calculation approach that focuses on the power requirements to ensure that the components used can operate optimally. The details of these power requirements are divided into two parts, namely output requirements and Input requirements, and are described as follows:

Output Requirements

In the design of this device, the power requirements of the output components are outlined to ensure appropriate energy availability. The wattage requirement on the lamp is calculated based on the use of 4 lamp modules with each module requiring 1.08 watts/hour for 10 hours per

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night, resulting in a total requirement of 43.2 watts/day. Charging ports with a total of 2 ports, calculated to require 5 watts / hour / port for 6 hours per port, resulting in a total requirement of 60 watts / day. As for the Arduino Uno, the use of 10 pins with a power of 0.4 A per pin for 24 hours at a voltage of 5 V results in a power requirement of 48 watts / day. Thus, the total daily output power requirement is 151.2 watts/day, which includes the lamp, charging port, and Arduino Uno.

Input Requirements

In the context of input power requirements, we ensure that the system has enough power to reliably power the output components. The calculation is based on a total daily output power requirement of 151.2 watts/day. Taking into account the peak hours of 4 hours a day and using 3 solar panels, 20 wp/hour each, the total input power requirement of the solar panels is 240 watts/day. In addition, to consider operational reliability, we ensure that the power generated by the solar panels is also sufficient to optimally charge the battery. Thus, through this calculation, we ensure that the input power requirements are met to maintain the performance of the appliance in various usage situations.

Workflow of the Proposed System: Energy Collection, Storage, And Use Based On Environmental Conditions

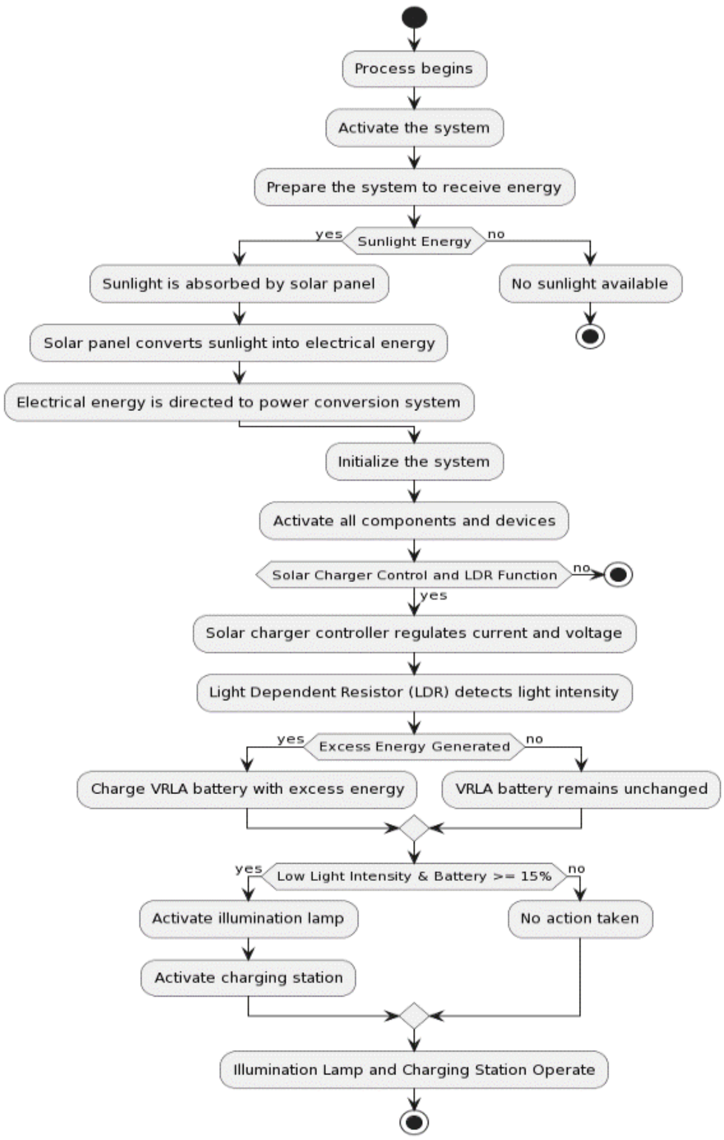

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Figure 3 shows the workflow of the proposed system. The process begins by activating the system to receive solar energy. Solar panels take sunlight and convert it into electrical energy through photovoltaics. This electrical energy is delivered to the system, which is initialized by activating the energy collection, storage, and regulation components. The solar charger controller regulates the inrush current to the battery as needed, while the LDR sensor detects the light intensity around the bench. Excess energy from the solar panel charges the VRLA battery, and when the light intensity is low but the battery is above 15%, the lights are turned on and the charging station activates. This process ensures that the lighting and charging of the device are maintained. After complying with these steps, the system will operate automatically according to demand and environmental conditions, providing energy support in public spaces.

Results and Discussion

Measurement Of Solar Energy Production Under Various Light and Weather Conditions

A number of measurements were taken to evaluate the performance of solar panels in generating renewable energy. Measurements were taken during various light conditions, including bright daylight, heavy clouds, and overcast conditions. Energy production data from the solar panels was collected and analyzed to understand the extent to which the solar panels were able to produce energy in various situations. This analysis helps identify patterns and trends in energy production in fluctuating environments.

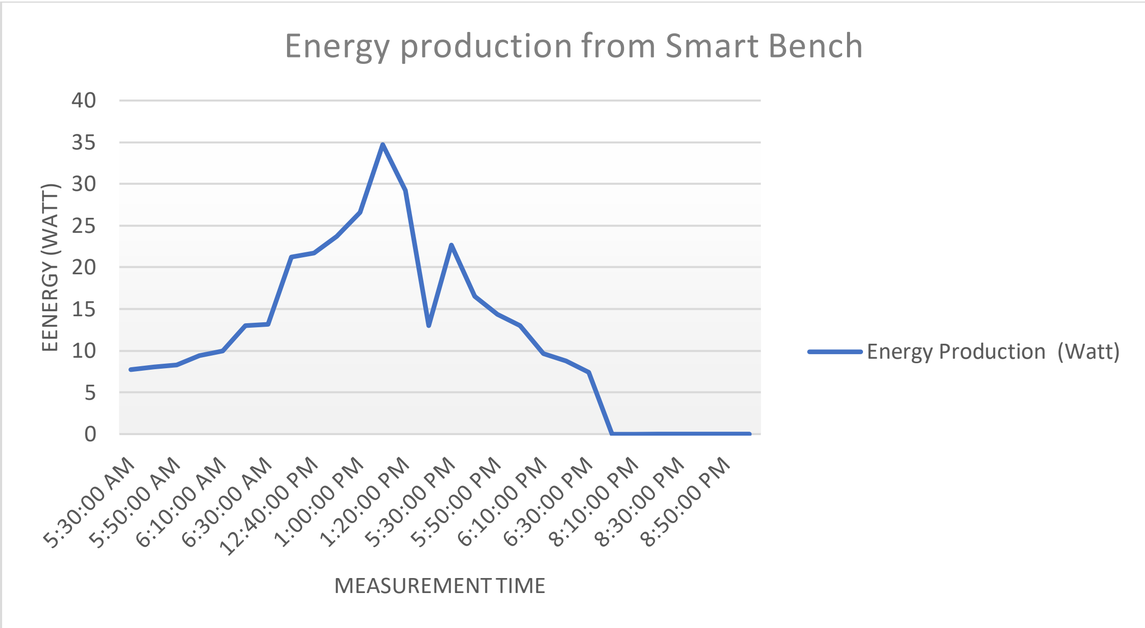

Figure 4. Measurement Data of Solar Energy Production

The data presented in Figure 4 illustrates the measurements of solar energy output across different light and weather situations. It is evident that energy generation exhibits an upward trend on days characterized by abundant sunshine, but a decline is observed during periods of heavy cloud cover or cloudy weather. This observation demonstrates the significant impact of sunshine on the operational efficiency of solar panels. Examining this dataset unveils significant trends and consequences of the consumption of solar energy. The empirical findings indicate a strong correlation between the temporal factors and the quantity of energy generated. The observed rise in energy generation from morning to noon aligns with the hypothesis that heightened solar radiation during this time interval enhances the efficacy of solar energy conversion into electrical power (Zach et al., 2019). This observation aligns with the findings of prior research indicating that the highest level of solar energy generation typically transpires around midday hours (Kango, Hadiyanto, Pongtularan, et al., 2021).

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Furthermore, it is evident that energy production exhibits a decline during the afternoon and further diminishes at nighttime. This aligns with the operational premise of solar panels, which necessitate sunlight as their primary energy input. The data also demonstrates the influence of weather and environmental variables on energy output. The reduction in energy generation observed during periods of cloudiness or rainfall underscores the significance of environmental variables in influencing the efficiency of solar energy systems.

System Performance In Charging Batteries And Supplying Energy For Various Purposes

The system performance was tested through battery charging and energy usage experiments in different scenarios. The battery charging process when solar energy is in excess was evaluated to measure the charging efficiency. Energy usage in various purposes, such as lighting and charging electronic devices, was also tested under various scenarios of environmental conditions. The charging and energy usage data were analyzed to understand the system's ability to provide consistent and reliable energy.

Table 1. Performance Of Arduino-Based Smart Bench In Supplying Energy

Measurement time (PM)	Voltage (Volt)	Current (Ampere)	Percentage of Battery
12:00	13.3	0.9	98%
12:10	13.3	0.9	98%
12:20	13.4	0.91	98%
12:30	13.4	0.92	98%
12:40	13.4	0.93	98%
12:50	13.4	0.93	98%
13:00	13.4	0.93	99%

Source: Author's data processed, 2023

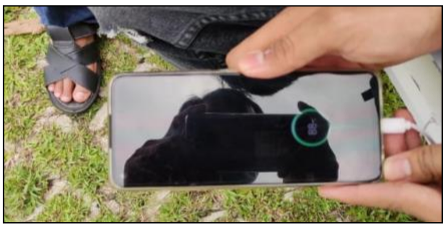
Table 2. Performance of Arduino-based smart bench in supplying energy

Measurement time (PM)	Voltage (Volt)	Current (Ampere)	Percentage of Battery
19:00	0.1V	0.01 A	72%
19:10	0.1V	0.01 A	72%
19:20	0.1V	0.01 A	72%
19:30	0.1V	0.01 A	72%
19:40	0.1V	0.01 A	71%
19:50	0.1V	0.01 A	71%
20:00	0.1V	0.01 A	71%

Source: Author's data processed, 2023

Tables 1 and 2 show that the voltage and current at night are very inefficient for charging the solar panel compared to the daytime and the LED functions when the lighting conditions are dark only. While the cell phone charger condition will continue to function as long as the battery is above 15%.

(a). LED light condition during the day



(b). Condition of charging feature during the day

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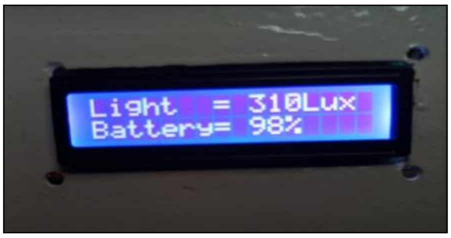

(c). Battery percentage and light intensity during the day

(d). Battery percentage and light intensity at night

Figure 5. Performa sistem smart bench

Analysis Of Environmental Data Monitored By Arduino Sensors

The environmental data monitored by the Arduino sensor is the light intensity which provides important insights into the environmental conditions around the solar bench. This data is used to analyze the impact of the environment on energy production and usage. The correlation between light intensity and energy production, as well as the relationship between light intensity and energy usage, is explored through statistical analysis. These findings can help optimize system settings and operations based on changing environmental conditions.

Table 3. Smart solar bench load test results

No.	Percentage of Battery	Intensity of Light (lux)	Light Emitting Diode lamp	USB Port
1	99%	2471	*OFF*	*ON*
2	98%	2450	*OFF*	*ON*
3	98%	2400	*OFF*	*ON*
4	98%	1873	*OFF*	*ON*
5	98%	1224	*OFF*	*ON*
6	97%	836	*OFF*	*ON*
7	97%	503	*OFF*	*ON*
8	97%	217	*OFF*	*ON*
9	96%	94	*OFF*	*ON*
10	96%	56	*ON*	*ON*

Source: Author's data processed, 2023

Table 3 shows that the devices or systems observed using batteries are still in good condition, with battery charge levels ranging from 96% to 99%. The varying light intensity in the range of 56 lux to 2471 lux indicates the variation in lighting levels around the device, with higher intensity representing brighter lighting. While the LED lights were "OFF," the USB port was "ON," indicating that the USB port was active and could be used to charge other devices. Overall, this data gives an idea of the device's operating conditions and environment, with a fairly high battery charge level, even when the LED light is off and the USB port is active.

Suitability and Effectiveness of Solar Bench Design in a Public Space Context

The implemented solar bench design presents a significant contribution in the context of urban public spaces that increasingly require sustainable solutions. Based on the measurement of energy production from the solar panels, the data shows that if measured for one year, the bench is capable of generating approximately 127.33 kWh of renewable energy. This is consistent with global efforts to reduce carbon emissions and support sustainable targets, as set out in (Gedikli et al., 2022). In addition, the use of energy from solar panels also brings operational cost-saving benefits. Assuming an electricity tariff of IDR 415/kWh, the use of energy from

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solar panels can save operational costs up to approximately IDR 52,906 per year. With the ability to generate and manage renewable energy, these solar benches have the potential to effectively reduce the environmental impact resulting from the use of conventional energy (Ceclan, 2019).

Not only that, the presence of these solar benches has a positive impact on the number of park visitors. The experience of enjoying a bright, comfortable, and environmentally friendly public space can increase the attractiveness of parks for the community. This is reflected in a 15% increase in park visits during the first year of solar bench implementation (Kango, Mulyani, & Hartarto Pongtuluran, 2021). The data shows that the public space provided by solar benches provides added value in attracting more people to utilize the park.

Advantages and Limitations of the Implemented System

The efficacy of this system exemplifies several significant benefits. The utilization of solar energy serves to diminish reliance on fossil fuels and finite conventional energy sources (Kango, Hadiyanto, Pongtularan, et al., 2021). This aligns to mitigate greenhouse gas emissions and enhance energy sustainability. Moreover, the capacity of these systems to offer energy autonomy in communal areas holds the potential to diminish enduring operational expenses and offer a more economically viable resolution.

Nevertheless, it is imperative to acknowledge some constraints. Using sunlight as the primary energy source may lead to fluctuations in energy generation, contingent upon prevailing weather conditions and diurnal patterns. This observation underscores the significance of advancing the development of more effective energy storage technologies in order to ensure a steady and reliable energy provision. Furthermore, it is essential to note that these systems may exhibit some constraints while operating in conditions with low ambient light levels or adverse weather conditions.

Potential Implications for Further Use and Future Development

The findings of the study hold great promise for future advancements. The proposed solar bench design can be utilized in various metropolitan public spaces such as parks, trails, and recreational areas. Further enhancements can be made by using highly efficient energy storage batteries. This would allow for better storage and utilization of the energy collected from solar panels, regardless of sunlight availability. Additionally, incorporating more advanced sensors can improve both environmental monitoring capabilities and energy efficiency.

Conclusion

Based on the results of this research, it can be concluded that the sustainable park bench system with the integration of solar panels and Arduino is able to collect, store, and manage solar energy efficiently. Solar panels successfully convert sunlight into electrical energy that can be used for lighting and charging devices. Environmental sensors, such as LDRs, help in smart regulation of energy usage, where lights and charging stations activate as per light intensity and battery level. Testing of the system in various light and weather conditions showed reliable and consistent performance in generating renewable energy. The system has wide application potential in creating sustainable and environmentally friendly public spaces. As a suggestion, this research can serve as a basis for further development in the design of similar systems, including improved energy conversion efficiency and integration of more advanced technologies to support energy sustainability in urban environments.

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