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Experimental Implementation of Arduino-Controlled Solar Powered Washing Machine Prototype

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ABSTRACT

This research is centered on the development of a solar-powered washing machine prototype, expertly controlled by an Arduino microcontroller and featuring a sturdy metal frame, with bucket-based washing and drying processes. This design addresses the global need for a reliable and eco-conscious household appliance in regions with limited access to grid electricity. This research provides an innovative and low-cost solution for washing clothes using solar energy, which resolved some of the problems arising from the use of existing methods, including the difficulty of washing clothes with no electricity supply and the higher electricity price. The system is designed to effectively wash up to three sets of clothes per cycle while consuming a mere 1.75 ± 0.2 Amperes of current and 24 Watts of power, showcasing remarkable energy efficiency and a profound commitment to environmental responsibility. The research not only emphasizes autonomous and clean operation but also prioritizes user safety, offering a sustainable, cost-effective, and user-friendly laundry solution.

1. INTRODUCTION

The design and development of washing machines has evolved significantly over the years, all in an effort to find an alternative way to overcome the difficulties associated with washing clothes using hands, which is laborious and time consuming [1]. One such approach involved the use of a stationary bicycle which utilized the pedals to power the washing machine by rotating an impeller that paddles and cleans the clothes. In [2], a pedal washing machine was designed and fabricated. This machine incorporates a unique mechanism for optimizing washing cycles, resulting in improved washing efficiency.

The ongoing development resulted in the evolution of washing machines powered by electricity, which are controlled by time switches. The work in [3] focused on designing a lightweight and vertical axis washing machine, addressing the issues of rotational slip when the mass of the washer is not aligned with the laundry mass rotation. The research was aimed at reduction in cost and weight of the washing machine. The study highlighted the goals of reducing size, cost and weight, but lacked technical details on how to achieve these goals and impact on users.

The use of a computers allows multiple washing machines to be networked. In [4], a computer con-trolled washing machine was designed and constructed. The research focused on developing a software program for a washing machine which ensured accurate and fast response. However, the impact of the software on the overall efficiency of the washing machine should be further explored to evaluate its significance.

The integration of microcontrollers into washing machine systems has revolutionized the washing process, allowing it to operate based on pre-defined time parameters. A washing machine manipulator using an Arduino (Uno) microcontroller was designed in [5]. It provides a convenient solution which allowed the user to automate the soap/fragrance filling process, making it easier and more efficient. While the design focused on automation, it did not mention whether there is a user inter-face or control panel for setting preferences. It also did not discuss practical or testing outcomes of the prototype created. Information on how well the system performs in real washing and its impact on washing machine efficiency would also be valuable.

In [6], energy and water analysis of washing machines was presented. The research work addressed the inefficiency of traditional washing machines in terms of water and energy consumption, promoting a more sustainable laundry approach. It used a data-driven method with a polynomial equation to optimize water and energy usage based on load capacity, potentially improving wash quality and resource efficiency. However, it lacks specific technical details about the machine model, the derived polynomial equation, or the methodology used for the analysis.

The work in [7] used solar energy to power a washing machine, making it independent of conventional electricity. The use of Arduino for control provided flexibility, allowing a customizable washing cycle and efficient energy management. The concept provides an overview of solar energy based washing machine system and its benefits but did not provide details about how this machine works and its impact on laundry efficiency.

A washing machine with flexible components was presented in [8]. The study acknowledged the growing demand for efficient and cost-effective washing machines, emphasizing the need for advanced numerical tools to predict, evaluate, and optimize designs. Such tools can potentially lead to more efficient and affordable washing machines, benefiting consumers. It also demonstrated the application of commercial multi-body simulation software (MSC. Adams) to model and predict the dynamic behaviour of a horizontal axis front loading washing machine. This approach reduces the need for physical prototypes, saving time and development costs. The research addresses the need for efficient and cost-effective washing machines and demonstrates the application of numerical tools for modelling dynamic behaviour. However, it could benefit from providing specific findings, expanding its scope, and discussing practical applications and implications of the research.

A fuzzy controller was used to design and simulate a washing machine in [9]. The design incorporates two distinct control systems, the first being a fuzzy logic control system that determines washing speed based on four inputs. This demonstrates the utilization of advanced control techniques for washing machine operation. The system allows for inputs to be provided either manually or automatically using corresponding sensors, making it adaptable to different user preferences and laundry conditions. The second system focuses on regulating motor speed stability, considering factors like the difference between reference speed and actual speed as well as the current error difference from the previous state. This approach can lead to more precise and stable washing machine performance. The research provides a brief overview of the two control systems but lacks context about the specific washing machine design or the problem it aims to address. Also, the outcomes or results achieved with this design are not mentioned. It would be valuable to know how well the control systems perform, whether they improve washing machine efficiency, or how they benefit end-users.

In [11], design and simulation of a cycle time control system for a washing machine using fuzzy logic was proposed. The study compared various components of fuzzy control in the context of a washing machine, including inference engines and defuzzification methods. The study identified that the combination of trapezoidal fuzzification, minimum inference engine, and center of gravity defuzzification yielded the most suitable results for washing time, leading to an optimal configuration for the washing machine control system. While the simulation is a good starting point, real-world testing and validation are crucial to confirm the practicality and reliability of the fuzzy controller in an actual washing machine.

2. MATERIALS AND METHOD

2.1 Description of Experimental Setup

The experimental setup consist of Arduino microcontroller for control, a DC motor for the drying tube, a water pump and motor for the washing bucket, solar panels, and a charge controller for power, relays for motor control, as well as hoses and connectors for water supply and drainage. Figure 1 shows a photograph of the experimental setup while Figure 2 shows the system block diagram.

The size of the washing machine was determined, taking into account the dimensions of both the metal frame and buckets. Following this, appropriate components were selected, which include an Arduino microcontroller for control, a DC motor for the drying tube, a water pump and motor for the washing bucket, solar panels, and a charge controller for power, relays for motor control, as well as hoses and connectors for water supply and drainage. The selection of the components was informed by several factors, such as; durability, efficiency and cost. We considered the quality of the motors for efficient operation and durability of the frame and buckets to withstand repeated use. The energy efficiency of the system design to ensure lower operating cost for the user.

Fig 1. Photograph of the Experimental Setup

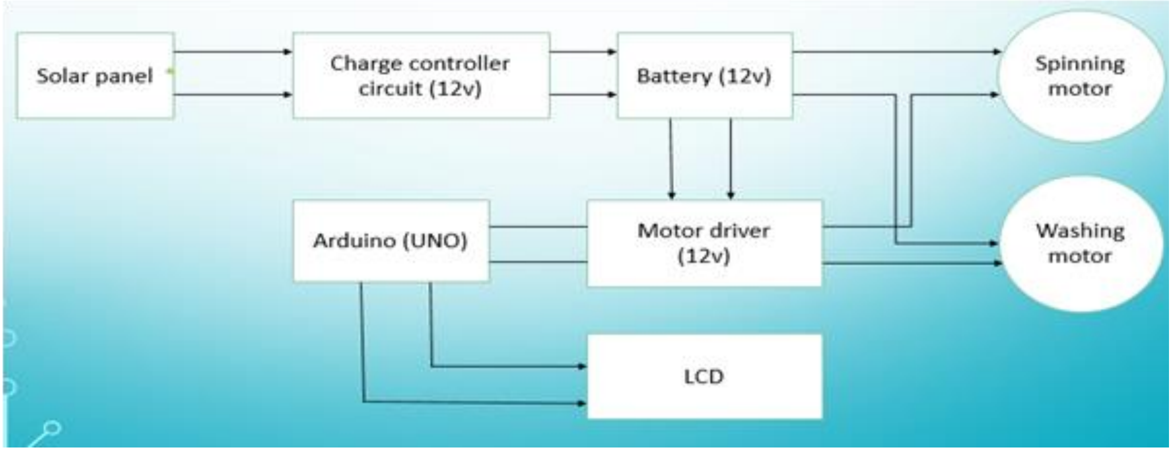

Fig 2. Block Diagram of the System

2.2 Electrical and Control System

The electrical and control systems of the washing machine prototype include an Arduino microcontroller, DC motors, relay, display system and few passive components. The Arduino microcontroller serves as the central control unit, coordinating the operation of various components such as motors, and displays. The chosen motor has a voltage rating of 12V and a current rating of 2.5A; resulting in a power rating of 30W while the supporting motor driver has a voltage rating of 12V and a peak current of 2A; resulting in a power rating of 24W. The incorporation of motor driver and other electronic components is to ensure a reliable operation throughout the washing and drying process.

The Arduino board was connected to all other components, ensuring a tidy and organized wiring arrangement. The Arduino board was then programmed, configuring it to oversee the washing cycle while taking into account parameters such as the duration of the wash.

2.3 Solar System Components

The solar system components used include solar panel, charge controller and battery. A monocrystalline solar panel with power rating of 80W and voltage of 12V was chosen while the power rating of the charge controller was determined based on its ability to handle the maximum power output of the PV panel and regulate the charging of the battery effectively. To this extent, a charge controller of 40W power rating was used. The battery's voltage and current capacity were specified as 12V and 18Ah respectively. This indicated the voltage output and amount of charge it could store.

The solar panels were installed in an optimal location, maximizing sunlight exposure. Subsequently, a connection was established between the solar panels and a charge controller, integrating batteries for effective energy storage.

2.4 Mechanical Components and Washing Mechanism

The mechanical components consist of a metal frame, drying tube, washing and drying bucket and water pump. The metal frame provides a sturdy support structure for the system, while the bucket-based washing and drying tubes are needed in order to facilitate an efficient washing and drying process. The integration of these components provides a compact and robust washing machine system.

The metal frame was assembled, ensuring its stability and capacity to hold the buckets. Next, the washing and drying buckets were securely attached to the frame. The washing bucket was then connected to the washing motor, ensuring proper water inlet and drainage. Finally, the drying tube was attached to the DC motor for a complete setup.

The system parameters used in developing the prototype are:
N = Number of buckets = 2
h = Height of each buckets = 36cm
H = Height of the frame
A = Adjustment
D_1 = Diameter of each bucket at button = 29.2cm
D_2 = Diameter of each bucket at top = 33.6cm
S = Space between the buckets = 5cm
The dimension of the frame needed to accommodate the buckets:
Diameter of the bucket, D is given by

$$D = \frac{(D_1 - D_2)}{2} \ldots\ldots (1)$$

$$D = \frac{(D_1 - D_2)}{2} = \frac{29.2 - 33.6}{2} = 31.4cm$$

The width, B required for the frame to accommodate the buckets side by side including the space between them is given by

$$B = DN + S(N-1) \ldots\ldots (2)$$

$$B = (31.4x2) + 5(2-1) = 67.5cm$$

The depth of the frame will be determined by the diameter of the buckets.

Depth = diameter of the bucket = 31.4cm

Hence, the depth of frame required to accommodate the buckets is = 31.4cm

The height of the frame, H depend on the height of the buckets and any additional adjustment needed

$$H = h + A \ldots\ldots (3)$$

$$H = 36 + 5 = 41cm$$

Therefore, the frame will should have dimension of approximately = 67.5cm × 31.4cm × 41cm

Since, 1 inch = 2.54cm

Therefore, the frame has dimension of approximately 26.56inches × 12.36inches × 16.14inches.

3. RESULTS AND DISCUSSION

3.1 Testing and Calibration

The performance of the washing machine was evaluated through testing and validation procedures. A controlled load was used to initiate the testing phase and confirm its proper operation. The washing and drying cycles were executed successfully, achieving the desired cleaning and drying results. Two type of test was carried on the system. The first test was carried in form of simulation in proteus before the system construction so as to observe the behavior and response of the system, and the final test was carried after the implementation of the system.

3.1.1. Simulation Test

This test was carried out in the simulation environment of proteus software to check the performance of the system before building the real construction. This test allowed us to know the system performance so as to prevent spending of money in constructing a system that could not provide its required function. Result from the motor controller and display unit was carried out so as to ensure good operation of each unit. The test result is shown in Figure 3.

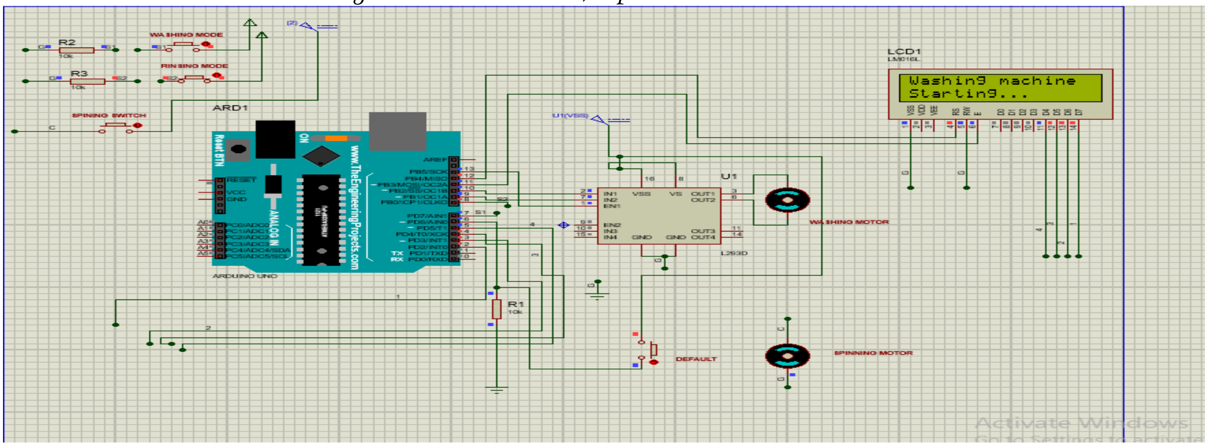

Fig. 3. Initial Test Based on Simulation

3.1.2 Construction Test

The final test (load test) took place after successful implementation of the system in order to observe the workability of the system. A controlled load was used to initiate the testing phase and confirm its proper operation. The washing and drying cycles were executed successfully, achieving the desired cleaning and drying results. The performance of the washing machine was evaluated through several testing and validation procedures where the maximum set of clothes which the machine can wash found to be around three to four sets of medium cloth.

3.2 Final Integration and User Testing

All components were connected and a final system test was executed. Following successful assembly and testing, the operation of the washing machine was demonstrated to the user.

The result of this design is a solar-powered washing machine that can effectively wash 3 sets of clothes while consuming 1.75 ± 0.2A of current, 12 ± 1V voltage and 24W of power.

Table 1. Washing Capability of the System

Weight of Clothes (kg)	Washing Time (minutes)	Energy (Joule)
0.5	20	480
1	30	720
1.5	40	920
2	50	1200

The table shows the washing times obtained during the project for various load sizes starting from 0.5kg, with increments of 0.5kg. This demonstrates that the machine can effectively clean various loads of laundry, from lighter to heavier ones. This indicated that the machine's washing mechanism is well designed to handle different load sizes effectively.

3.3 Discussion of Results

Table 1 shows the washing times obtained during the research for various load sizes starting from 0.5kg, with increments of 0.5kg. This demonstrates that the machine can effectively clean various loads of laundry, from lighter to heavier ones. This indicated that the machine's washing mechanism is well designed to handle different load sizes effectively.

The integration of solar power into the washing machine was successful, providing a renewable and environmentally friendly power source. Solar panel were connected to a charge controller, which regulated the charging of the battery. This arrangement ensured continuous power supply to the washing machine, even in the places that do not have access to electricity. Despite its modest power requirement, the machine boast a substantial capacity, capable of washing up to 1.5 kg of clothes in a single cycle

Other attractive features and functionalities of the Arduino-controlled solar-powered washing machine prototype can be outlined under the following parameters:

A. *Capacity:* The washing machine prototype can handle 3 sets of clothes per cycle, making it suitable for small to medium-sized loads.

B. *Power Consumption:* It consumes 1.75 ± 0.2A of current, 12 ± 1V voltage and 24W of power, which indicates that it is relatively energy-efficient, especially when using solar power.

C. *Energy Efficiency:* By utilizing solar power, the washing machine prototype reduces reliance on grid electricity, making it more environmentally friendly and potentially cost-effective.

D. *Sustainability:* Solar power integration contributes to reducing the carbon footprint and promoting sustainable living.

E. *Cost Savings:* Depending on the availability of sunlight, users can save on electricity bills of almost 80% by harnessing solar energy for washing 1.5kg of clothes.

F. *Clean Operation:* Solar power eliminates the need for fossil fuels, reducing air pollution and greenhouse gas emissions.

G. *Convenience:* Users can operate the washing machine prototype independent of the electrical grid, which can be especially beneficial in areas with unreliable or no access to electricity.

Overall, the design and construction of the Arduino-controlled solar powered washing machine prototype demonstrated feasibility, effectiveness, and potential for addressing the need for sustainable and off grid laundry solution.

4. CONCLUSION

The design and implementation of the solar-powered washing machine prototype presented in this research embodies a commitment to sustainable and energy-efficient domestic laundry. The machine is capable of washing three sets of clothes with a minimal power consumption of 1.75 Amperes and 24 Watts, demonstrating its eco-friendliness and cost-effectiveness. By harnessing solar energy, it significantly reduces reliance on conventional grid electricity, thereby lowering environmental impact and promoting cleaner energy use. The robust mechanical construction, integrated solar power system, and effective electrical control ensure both reliability and safety. This research emphasizes user accessibility through comprehensive documentation and ongoing improvement based on real-world testing and feedback. As a result, the solar-powered washing machine serves as an innovative and responsible choice for households seeking a more environmentally conscious and efficient approach to laundry, contributing to a cleaner and more sustainable future.

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