Enhancement of Accessibility and Sustainability: A Smart Solar-Powered Outdoor Laundry Drying System

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ABSTRACT:
Assistive Technology (AT) is designed to aid elderly individuals and those with disabilities in overcoming tasks that may pose challenges or be inaccessible without support. Despite substantial research and innovation dedicated to the advancement of AT, opportunities for further improvement persist in this domain. This study aims to enhance existing technology by proposing an innovative, efficient, and environmentally friendly outdoor laundry garment hanging and retrieval system. The proposed system employs the OMRON CPM1A PLC system as the central controller for the motorized mechanism, offering a straightforward yet intelligent approach. The prototype harnesses solar power to operate the automated clothesline system, contributing to energy and carbon emissions reduction, and promoting energy efficiency and cost-effectiveness, hence improving sustainability. The prototype allows both manual and automatic modes for controlling the DC motor's actions in extending or retracting the scissor-like cloth hanger. In manual mode, a push-button switch governs the cloth hanger's movement, while automatic mode relies on input signals from rain and temperature sensors to dictate its behavior. The DC motor will operate to extend the hanger (for drying) whenever the rain sensor detects no water droplets, or, the light sensor detects more than 150 lux, or, the temperature is greater than 24.5℃. Otherwise, the motor will move to retract the hanger back into its original position when these criteria are the opposites. This proposed solution not only reduces physical strain for elderly and disabled users during laundry drying but also contributes to their enhanced well-being, accessibility, and improved quality of life.

KEYWORDS: Assistive Technology, Accessibility, Smart Home, Laundry Drying System, Solar PV, PLC.

1. INTRODUCTION

Any individual's physical, emotional, and mental well-being and quality of life are significantly influenced by their capability to carry out essential activities that contribute to their health and quality of life [1]. However, human well-being and quality of life notably declined among the elderly and individuals with disabilities as they struggle to perform even basic tasks. The World Health Organization (WHO) predicts that by 2030, one in six people worldwide will be 60 years or older, with their numbers rising from 1 billion in 2020 to 1.4 billion. By 2050, the global population of those aged 60 and above is expected to double to 2.1 billion, while the count of individuals aged 80 years or more is projected to triple from 2020 to 2050, reaching 426 million [2]. Furthermore, the current estimate indicates that around 1.3 billion individuals (constituting 16% of the global population) are facing substantial disabilities, and this figure is on the rise due to the escalation of non-communicable diseases and extended lifespans[3].

In both demographic groups, it is essential to ensure their continued comfortable living, and one of the crucial facilitators for achieving this is through the utilization of "Assistive Technology" (AT). In this study, AT refers to tools aiding individuals, especially the elderly and disabled, in performing challenging or otherwise

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impossible tasks. Well-designed AT can significantly improve various activities, empowering these individuals to maintain independent living at home [4].

However, despite the global need and recognized benefits of AT products, access to these products remains limited [4]. In many low-income and middle-income countries, only 5 to 15% of people who require AT have access to AT facilities [5]. Addressing this unmet need is essential to progress towards the achievement of the Sustainable Development Goals 10 (reduce inequality) and realizing the Convention of the Rights of Persons with Disabilities (CRPD) [6],[7]. An area of AT products requiring further advancement lies within the domain of daily household tasks, encompassing house cleaning, cooking, laundry, and more. This study, henceforth, predominantly concentrates on activities pertaining to the drying of laundry garments.

2. LITERATURE REVIEW

2.1. Outdoor Laundry Drying: Benefits and Challenges

Among low and middle-income families, outdoor drying stands as the prevalent and preferred method for drying laundry garments. This choice is primarily attributed to its inherent simplicity, cost-effectiveness, and ecologically friendly. Outdoor drying harnesses the readily available solar heat energy and utilizes the natural airflow in the environment to effectively dry damp clothes. This approach is simple and low-cost as it relies solely on basic elements like poles, cloth lines, and potentially a protective roof to shield against rainfall—all of which require only minimal setup (see Fig. 1). The following highlights several benefits intrinsic to outdoor cloth drying:

1) **Energy Efficient**: Drying clothes outdoors harnesses the natural heat and airflow from the sun and wind, reducing reliance on electricity-consuming appliances like dryers.
2) **Cost Savings:** Since outdoor drying doesn't require electricity, it can significantly lower utility bills and save money in the long run.
3) **Environmental Benefits**: By avoiding energy consumption, outdoor drying reduces carbon footprint and contributes to a more sustainable lifestyle.
4) **Fresher Smell**: Sunlight has natural sanitizing properties that can eliminate odors and bacteria, leaving clothes smelling fresher.
5) **Whiter Whites**: Sunlight's UV rays can act as a natural bleach, helping to keep white clothes bright and vibrant.
6) **Gentler on Fabrics**: Air drying is less harsh on fabrics, preserving their texture, color, and overall quality compared to the heat and tumbling of a dryer.
7) **Reduced Wrinkles**: Hanging clothes properly can minimize wrinkles, reducing the need for ironing and saving time.
8) **Health benefit**: Spending time outdoors while hanging clothes can offer a bonus dose of vitamin D, promoting overall health. Also, the act of hanging clothes can offer a moment of mindfulness and relaxation amidst daily routines.

Fig. 1. Outdoor drying of laundry garments[8].

Nevertheless, the conventional approach of outdoor clothes drying has several challenges in various factors, encompassing unpredictable weather conditions, constraints in secure and convenient space allocation, and the pressing demands of daily commitments [9]. The following summarizes some of the main issues and challenges of outdoor drying:

1) **Unpredictable Weather Conditions:** Outdoor drying is heavily reliant on weather, making it unreliable when unexpected rain or adverse weather occurs. Clothes can become wet and dirty if exposed to sudden rainfall.
2) **Limited Outdoor Space**: Urban areas or densely populated neighborhoods may lack sufficient outdoor space for hanging clothes, making it difficult to accommodate large laundry loads.
3) **Extended Drying Time**: The drying process can take longer, especially during humid or overcast days, potentially leading to clothes not drying completely and resulting in musty odors or mold growth.
4) **Sun Exposure and Health Concerns**: People with health conditions aggravated by sun exposure, such as skin allergies or respiratory disorders, may find outdoor drying unsuitable due to prolonged exposure to the sun.
5) **Inconvenience during Rainy Season**: During the rainy season, it can be challenging to time outdoor drying correctly, often leading to interruptions in the drying process and the need to bring clothes indoors suddenly.
6) **Dependence on Wind Conditions:** Effective outdoor drying requires adequate wind flow to

facilitate the drying process. Insufficient wind can prolong drying time or lead to uneven drying.

7) **Risk of Theft or Damage**: Leaving clothes outdoors can expose them to the risk of theft, damage from animals, or other external factors.
8) **Aesthetic and Neighborhood Regulations**: Some housing communities or neighborhoods may have regulations against outdoor drying due to aesthetic considerations, affecting the choice of drying method.
9) **Seasonal Variations**: Outdoor drying might not be suitable during certain seasons, such as heavy rain or cold winter, which can limit its year-round usability.
10) **Labor-Intensive Retrieval**: The physical effort required to hang and retrieve clothes, particularly for the elderly or individuals with disabilities, can be demanding and pose challenges.

2.2. Indoor Laundry Drying and Electric Dryer as Alternative to Outdoor Drying

To address the aforementioned challenges, individuals might opt to perform indoor cloth drying, thereby mitigating exposure to unpredictable weather conditions and the need for outdoor access. However, it is noteworthy that indoor cloth drying has been associated with potential health hazards [10]. The reason is that wet washing releases significant water vapor into the indoor environment, promoting mold growth and posing health risks, such as lung infections, especially in vulnerable individuals. Thus, it is advisable to dry wet clothes outside or in well-ventilated indoor areas, avoiding bedrooms and living spaces where moisture and mold can accumulate.

In order to mitigate the infection risks posed by mold growth due to indoor drying, consumers may consider purchasing a cloth dryer machine. However, despite the convenience of cloth dryer machines, they are often expensive, particularly for low-income families. Furthermore, indoor cloth dryer machines consume a significant amount of electrical energy, hence significantly contributing to an increased carbon footprint and energy cost. It is reported that 79% of Americans use clothes-drying machines at home that are powered by electricity or gas. However, the technology and efficiency of heat-powered drying have not improved much between the 1980s and 2012, hence, it's considered the least efficient of all household appliances (see Fig. 2) [11]. According to the US Natural Resources Defense Council (NRDC), electric dryers cost Americans $9 billion each year in energy costs, and, lowering the dryer's temperature and drying time could save up to $4 billion each year and cut 16 million tons of carbon dioxide emissions from dryers, which is "equivalent to the pollution from three coal-fired power plants [8],[12].

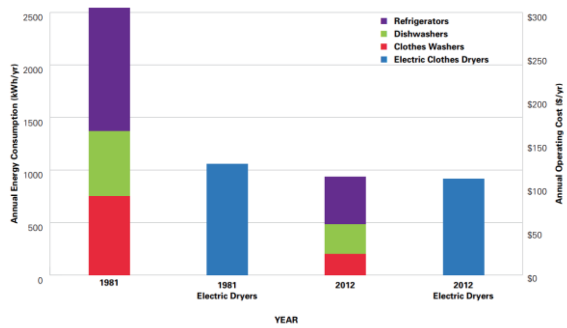

Fig. 2. Annual energy consumption of electric clothes dryers vs. other major home appliances in 1981 and 2012 [12].

2.3. State-of-the-art Innovations and Research Works In Outdoor Laundry Drying Technologies

Numerous researchers, innovators, and engineers have been exploring on developing innovative solutions to improve outdoor laundry drying, such as by introducing automation retrieval systems and smart clotheslines. These innovative solutions utilize different types of sensors and microcontrollers, Internet of Things (IoT) devices (such as Arduino and different types of PLC devices), wireless communication (such as Wi-Fi and RFID), Artificial Intelligence (AI), configurations, operating principles and features (e.g. automatic and motorized retractable laundry mechanism), hanger design and other parameters to develop new and improved cloth hanging and retrieval device. Some of these works can be found in [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25] and [26]. However, of all the previous works found, only one (1) of them is found to have utilized solar energy to power the device, which is in [22]. Today, it is important to realize the use of solar PV as a renewable and green energy source is one of the many ways to reduce dependence on fossil fuel power generation, hence reducing global carbon emissions [27].

Other than electric dryer, there are also commercially available automated or smart cloth drying devices, primarily designed for indoor use, utilizing artificial light and forced airflow (via a fan) to facilitate the drying process [28],[29] and [30]. However, these offerings present cost challenges, particularly in regions like Malaysia, where prices range from RM 1000 to RM 2000, rendering them relatively expensive for households with low- and medium-income household. Additionally, their capacity for hanging laundry is limited compared to the outdoor drying method (refer to Fig. 3). Furthermore, each of these devices consumes a substantial amount of electrical energy, with power requirements approaching 1000W, encompassing the heating element, electric motor (for fan operation, as well as raising and lowering laundry garments), and supplementary lighting. Furthermore, a number of patents have surfaced for automatic and intelligent outdoor laundry garment retrieval systems, highlighting diverse configurations and retrieval mechanisms, potentially poised for commercial production[31]–[35].

Fig. 3. Example of a commercially available indoor smart cloth drying system in Malaysia

In recent years, there has been a growing interest in the adoption of "Smart Home" technology, encompassing home automation and AT devices, to modernize the operation of household appliances and equipment, such as lighting, cooking, washing, ventilation, security, and more. Smart Home technology integrates advanced monitoring, sensing, voice-activated features, robotics, and communication devices, serving to facilitate the continued independent living of both healthy elderly individuals and those with disabilities within their own residences as they age [36],[37]. An illustrative instance of such technological advancement can be found in [38], where voice activation empowers a disabled individual to effortlessly execute certain household tasks (refer to Fig. 4).

Nevertheless, despite the substantial efforts in research and development focused on AT and Smart Home innovations, the adoption of sophisticated cloth drying solutions remains limited. Accessibility constraints, primarily attributed to cost and availability, are particularly evident in low- and middle-income households. Consequently, these demographics continue to favor conventional outdoor cloth drying practices over investing in costly commercially available alternatives. As a result, ongoing research efforts persist in addressing this pertinent area of study.

2.4. Highlights of This Study

This study presents a prototype development of a smart, simple, and low-cost prototype automatic outdoor laundry garment drying system. The aim is to design a system that can automatically move the wet laundry garments outside an open area on sunny days and retract them back inside (indoors or under a roofed area) during rainy weather. The key technologies involved in this smart laundry system include the integration of sensors, namely rain sensors, temperature sensors, and light sensors. These sensors will trigger the automatic retrieval and retraction of laundry garment hangers based on weather conditions and natural light. The benefits of this design can be further utilized as a basis to further develop a complete and commercially viable solution that can be part of an AT device for disabled persons.

Fig. 4. Example of using IoT to remotely control household devices by elderly and disabled persons [38].

Another key highlight is that this system also integrates standalone solar power as an eco-friendly energy source, harnessing the sun's abundant energy to automate the laundry garments hanger movement based on weather conditions, hence reducing carbon emission as well as the cost of energy. To achieve seamless operation, the Programmable Logic Controller (PLC) OMRON model CPM1A serves as the brain of the system, efficiently managing and executing commands.

The project's objectives are threefold: to design an automatic laundry garments system powered by solar energy, to develop a programmable system using a PLC (Programmable Logic Controller), and to analyze and incorporate appropriate sensors to ensure the system functions as programmed, responding accurately to environmental conditions. By achieving these objectives, the project seeks to address the challenges faced by individuals in managing laundry garments drying efficiently and effectively, offering a practical and time-saving solution that aligns with contemporary societal as well as environmental needs.

2.5. Methodology

In this project, the materials and equipment employed are small-scale, inexpensive, and easily accessible off the shelf, considering it is a prototype. Prior to integration into the project prototype, all materials and equipment undergo thorough testing and experimentation to ensure correct functions. Table 1 shows the list of components and tools used in this project. The input components include a Light Dependent Resistors sensor (LDR) for light detection, a water sensor for detecting moisture, a limit switch, and a push button.

The output components consist of a 12V DC motor for laundry garments movement and an ‘LED’ pilot light to indicate the hanger’s position. The microcontroller utilized in this project is a CPM1A PLC system. The laundry garments hanger prototype comprises of inexpensive and off the shelf materials such as boards, cardboard, and iron rods. Fig. 5 and 6 show the overall block and schematic diagram of the system, while Figs. 7 and 8 show the actual hardware setup of the system prototype.

This study employed a solar energy system as the energy source to power the automated laundry garments system. The specific solar panel variant adopted for this study was the polycrystalline solar panel. The selection of the polycrystalline variant was driven by considerations of cost-effectiveness and operational efficiency, with an efficiency range of 15-17%. The chosen solar panel model yields an output of 12V, aligning seamlessly with the energy requirements of the automated laundry garments system.

Table 1. Hardware components and tools.

No.	Component
1.	Push Button Switch
2.	Limit Switch
3.	Jumper Wire
4.	Rain Sensor
5.	Light Sensor
6.	Temperature sensor
7.	Micro Programmable Controller (CPM1A)
8.	Relay module 16 channels
9.	Geared Mini DC Motor
10.	Light Emittance Diode
11.	Solar Panel (Polycrystalline)
12.	Aluminum scissor-like cloth hanger
No.	**Tools**
1.	Portable Light Meter AMPROBE LM-120
2.	Portable Digital Thermometer
3.	CX-Programmer (OMRON) software
4.	Host Link Communication

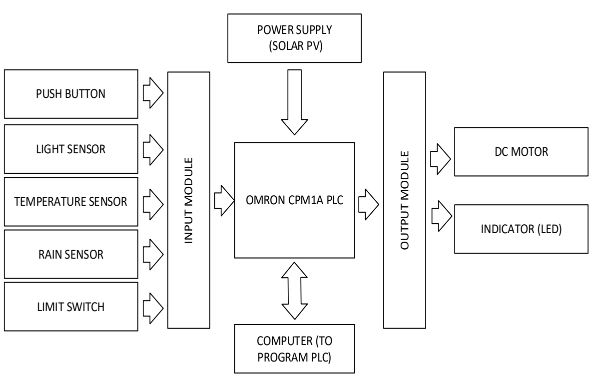

Fig. 5. Overall control system block diagram.

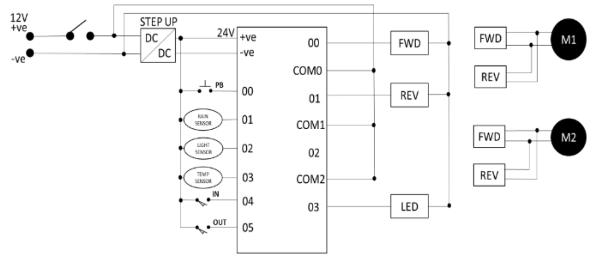

Fig. 6. Schematic diagram.

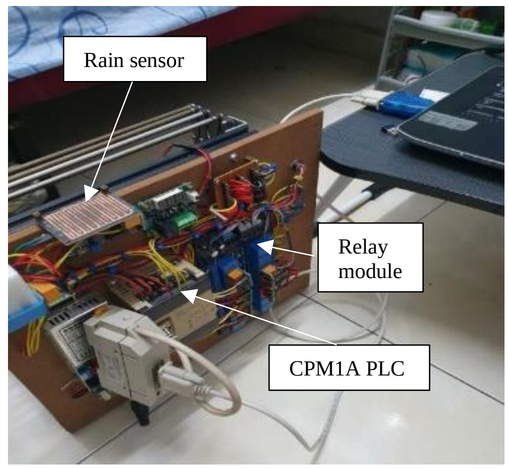

Fig. 7. Hardware setup (back view).

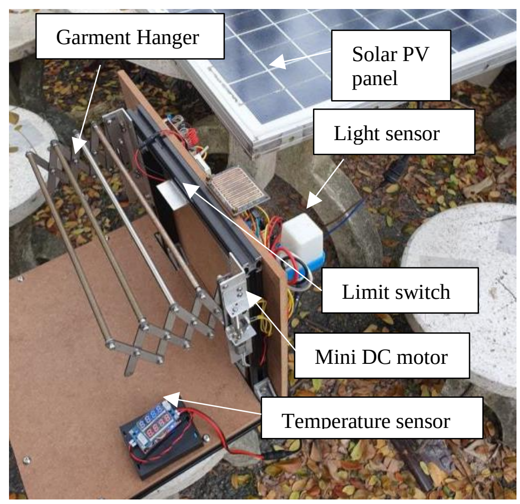

Fig. 8. Hardware setup (side and front view).

Fig. 9 shows the process flow of the proposed system. The system starts with the user hanging the wet laundry garments onto the hanger. Next, the user will decide whether to use automatic or manual mode. If the manual mode is selected, the user may use the push button to extend or retract the hanger manually, no matter what the outdoor weather is. Conversely, if the user selects the automatic mode, all the sensors are then activated (rain sensor, light sensor, and temperature sensor). For this prototype, the DC motor will operate automatically to extend the hanger (for drying) whenever the rain sensor detects no water drops OR light sensor detects more than 150 Lux OR the temperature is greater than 24.5°C. On the other hand, the motor will move to retract the hanger back into its original position when these criteria are the opposites. At this moment, the automated process to check whether the laundry garments are fully dried or not available, but can be a potential future improvement. Thus, the user has to manually check their clothes by changing it back to manual mode, retract the laundry, and decide whether to continue to restart the process or not.

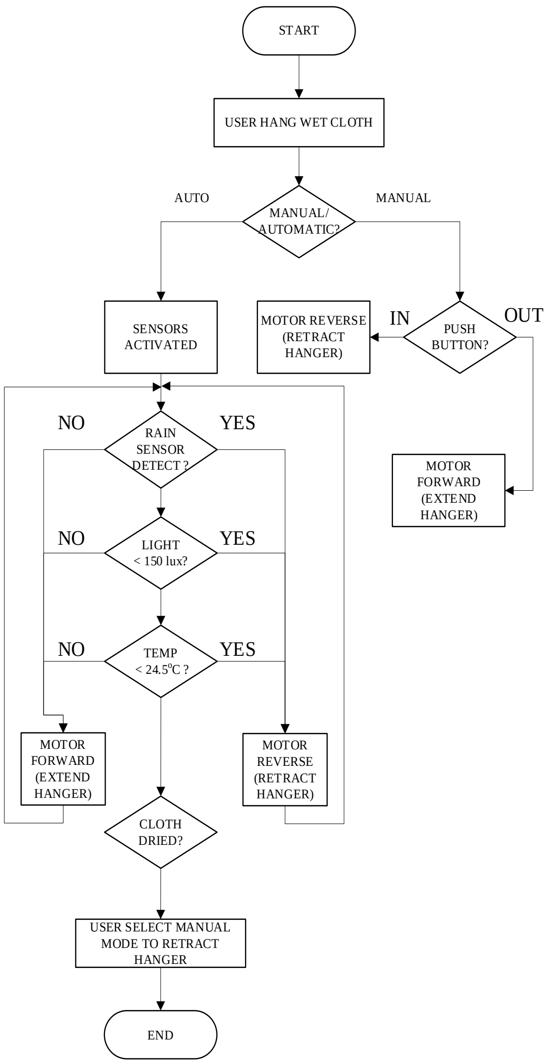

Fig. 9. Process flow.

3. RESULTS AND DISCUSSION

3.1. Result and Analysis of Rain Sensor

In order to evaluate the functionality of the rain sensors, a controlled simulation was conducted using a syringe to drip-feed water onto the sensor. The experiment encompassed altering the quantity of water droplets, with each individual drop measuring 0.05 ml. The assessment of the sensor's effectiveness and reliability was predicated upon the illumination of an indicator light. The sensor's accuracy was deemed satisfactory when it successfully detected water and activated the indicator light. The outcomes of this rain sensor evaluation are provided in Table 2.

The sensor's sensitivity is intentionally configured to remain inactive when the input received is less than 0.1 mL (equivalent to less than two drops from the syringe). This adjustment is made to differentiate inputs from rain and inputs from other water sources, such as dew or water vapor. The test results in the table above confirm this distinction, ensuring the sensor's reliability in accurately detecting rainwater while disregarding insignificant amounts of moisture from other sources.

Table 2. Test results for rain sensor

Test No.	Water (ml)	Light indicator	Amount of water drops
1	0	OFF	None (Dry)
2	0.05	OFF	1
3	0.10	ON	2
4	0.15	ON	3
5	0.20	ON	4

3.2. Result and Analysis of Light Sensor

During the testing process, a flashlight was utilized to illuminate the light sensor. To measure the exposure levels, a lux meter and a Lux Application were employed in the experiment. The exposure levels were varied by adjusting the distance of the flashlight, either moving it closer or farther from the light sensor. The accuracy of the sensor was assessed based on the behavior of the indicator light. When the lighting level exceeded the high threshold, the indicator light illuminated (ON), and it turned OFF when the lighting level was below the low threshold. The test results for the light sensors, conducted with the two different tools, are presented in Table 3. The indicator light on the light sensor illuminates for input samples greater than 150 lux when measured with the Light Meter, and greater than 170 lux when measured with the Lux Application. These findings confirm that the Light Meter is the appropriate tool for testing the sensitivity of the light sensor, as it aligns with the specified threshold for light detection.

Table 3. Test result for light sensors.

Test no	Lux meter	Lux Application	Light Indicator
1	154	178	ON
2	74	56	OFF
3	200	224	ON
4	65	55	OFF
5	320	335	ON
6	50	38	OFF
7	380	394	ON
8	28	21	OFF

Test no	Lux meter	Lux Application	Light Indicator
9	400	418	ON
10	3	0	OFF

3.3. Result and Analysis of Temperature Sensor

In this test, a thermometer was employed to measure the temperature. As temperature sensors lack indicator lights, the functionality test involves the motor's operation. The temperature sensor is considered accurate if the motor turns to extend OUT the hanger when it detects a temperature above 24.5℃ and turns to retract IN the hanger when it detects a temperature below 24.5℃. Furthermore, the test involves comparing the temperatures recorded by the thermometer and the temperature sensor to calculate the percentage of errors.

The results in Table 4 indicate that the motor responds correctly to temperatures above and below 24.5°C, affirming the accuracy of the temperature sensor. The average difference between the thermometer measurement and the sensor is 0.52, and the average error is determined to be 2.04%. Consequently, the sensor's accuracy value for temperature detection is 97.96%.

Table 4. Test results for temperature sensor.

Test Run No.	Thermometer (℃)	Temperature Sensor (℃)	Hanger position	Deviation	Errors (%)
1	24	24.5	IN	0.5	2.04
2	29.5	30.1	OUT	0.6	1.99
3	23.2	23.8	IN	0.6	2.58
4	19.1	29.5	OUT	0.4	1.35
5	22	22.4	IN	0.4	1.78
6	27.6	28.2	OUT	0.6	2.12
7	21.1	21.6	IN	0.5	2.31
8	27.2	27.8	OUT	0.6	2.2
9	20	20.2	IN	0.2	1
10	26.4	27.2	OUT	0.8	3.03
			Average	0.52	2.04

3.4. Testing and Analysis of Manual Mode

The system offers two operating modes: manual and automated. In manual mode, the system responds to user inputs, disregarding any sensor input. This test aims to determine the delay time for the system to react to user commands. A timer is used to calculate the operating time for the motor to turn inward and outward. The success criterion for manual mode is an average operation of no more than 5 seconds. The test results in the table below display the outcomes of testing the motor operating in manual mode. Based on the test result data in Table 5, the average operating in manual mode testing with the motor is 7.38 seconds. This indicates that the manual mode does not fully meet the target criterion of an operating time of no longer than 5 seconds, suggesting further improvements are required to enhance the system's response time in manual mode.

Table 5. Test results for extending and retracting time.

Test Run No.	Initial hanger movement status	Final hanger movement status	Operating time (s)
1	IN	OUT	7.56
2	OUT	IN	7.22
3	IN	OUT	7.41
4	OUT	IN	7.34
5	IN	OUT	7.26
6	OUT	IN	7.31
7	IN	OUT	7.43
8	OUT	IN	7.29
9	IN	OUT	7.52
10	OUT	IN	7.47
		Average	7.38

3.5. Testing and Analysis of Automatic Mode

In automatic mode, the system operates based on the data collected by the sensors. This test aims to assess the system's response delay and validate its accuracy in handling various input changes. Using a stopwatch, the delay time is measured from when the auto mode button is pressed until the motor initiates movement. Table 6 presents the test results for the automatic mode with the motor starting from its inside position. The system's response was found to be satisfactory for all conditions, and an average motor delay of 5.15 seconds was obtained from the test result data in the table above. These results affirm the effectiveness of the automated mode in promptly responding to sensor inputs and initiating the necessary hanger’s movement, ensuring efficient and reliable operation of the system.

Table 6. Test results of automatic mode.

Test	Input			Output		
	Light sensor	Rain sensor	Temperature sensor (℃)	LED	Motor	
				Status	Status	Time(s)
1	Day	No rain	> 24.5	OFF	OUT	5.21
2	Night	No rain	< 24.5	ON	IN	5.15
3	Day	No rain	> 24.5	OFF	OUT	5.24
4	Night	Rain	< 24.5	ON	IN	5.22
5	Day	No rain	> 24.5	OFF	OUT	5.10
6	Day	No rain	< 24.5	ON	IN	5.08
7	Day	No rain	> 24.5	OFF	OUT	5.14
8	Day	Rain	> 24.5	ON	IN	5.17
9	Day	No rain	> 24.5	OFF	OUT	5.13
10	Night	Rain	> 24.5	ON	IN	5.11
Average						5.15

3.6. Testing and Analysis of Solar PV

Solar panels were subjected to testing by directly placing them under sunlight during the day, and voltage meters were used to measure their output voltage. The experiment was conducted from sunrise to sunset, with the solar panel's performance monitored throughout this period. The test results in Fig. 9 illustrate the output voltage variations of the solar panel. It is evident that the solar panel's output voltage increases from 7.6V to 13.8V during the hours of 0800 hrs to 1200 hrs due to the high irradiance from sunlight at its peak intensity.

However, between 1200 hrs and 1800 hrs, the output voltage starts to decline, dropping from 13.8V to 8.9V as the intensity of sunlight wanes. The average output voltage of the solar panels is calculated to be 11.11V, indicating that it is sufficient to support the automatic system. It shows the morning starting voltage at 7.6V, gradually increasing until 1200 hrs when the sunlight irradiance reaches its peak at 13.8V, and then declining down to 8.9V until late evening at around 1800hrs.

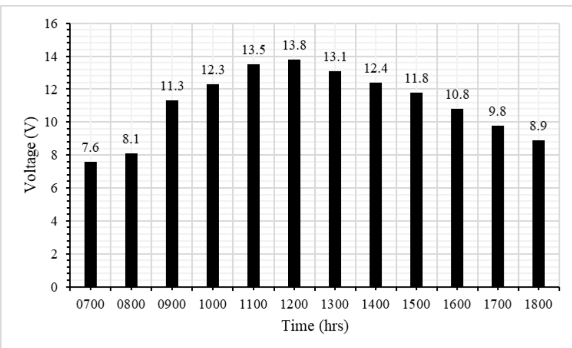

Fig. 9. Measured voltage from solar PV.

In summary, the test and analysis results demonstrate that the solar-powered automatic clothesline retrieval system has been successfully designed to respond automatically to various environmental factors as intended. When the sensors detect darkness (lighting below 150 lux) or detect rain (water exceeding 0.1 mL), the motor initiates the clothesline movement accordingly. In manual mode, the motor typically takes 7.38 seconds to respond to user inputs or instructions.

The system's efficiency in addressing different conditions makes it a practical and user-friendly solution for clothes drying automation. This project is focused mainly on household usage and also small-scale business usage. From initial estimation, this prototype is expected to hold up to 8 kg of laundry. However, due to the limitation of development materials, this prototype would be able to hold up to 3 kg of laundry as it is mainly used to demonstrate how the idea works and how it would be able to help out busy people in their daily lives. Besides that, the prototype is also able to hang up to 20 clothes per session, but due to the limitation of development materials in building it, the prototype aims to demonstrate at least 6 clothes per hang.

4. CONCLUSION AND FUTURE WORK

The main purpose of this project is to develop a smart, simple, and low-cost solar-powered automatic clothesline retrieval prototype for household use applications using CPM1A PLC. This system design improves user chores, time, and cleanness of clothes from unpleasant odors caused by dust and unpredictable weather conditions. The research shows that the project turns out to be excellent and reliable in durability test which is validated in high humidity and high temperature conditions. Thus, the project is successfully executed and aligns with its objectives and targeted outcomes.

Many countries are prioritizing renewable energy (RE) initiatives as a key aspect of sustainable energy development. By adopting technologies like solar harvesting, wind energy, and biomass, nations can ensure a cleaner environment, boost economic growth, and diversify their energy sources. The shift towards clean energy is essential to reduce environmental impact, particularly on the atmosphere, by decreasing reliance on non-renewable sources. Notably, the introduction of solar-powered automatic outdoor clothes retrieval systems marks a substantial advancement in energy conservation endeavors, representing a practical and impactful approach to supporting energy conservation efforts.

Based on observations of current Smart Home technologies, we can propose several improvements that can further improve the functionality and effectiveness of the system, as listed below:

1) **Efficiency Enhancement:** Optimize the system's energy consumption by refining the motor's efficiency and reducing power losses during the cloth retrieval process. This can be achieved through advanced motor control algorithms and efficient mechanical design.
2) **Sensor Integration:** Integrate more advanced sensors, such as humidity sensors, to detect the actual moisture content of clothes. This will allow the system to adjust drying time based on real-time conditions, preventing over-drying or under-drying.
3) **Weather Prediction Integration:** Incorporate weather prediction data to anticipate rain or adverse weather conditions. By doing so, the system can proactively retract clothes before rainfall, ensuring clothes are not exposed to moisture.
4) **Remote Monitoring and Control:** Develop a mobile app or web interface that enables users to monitor and control the system remotely. This adds convenience and flexibility, allowing users to adjust settings or check the drying status from anywhere.
5) **Smart Scheduling**: Implement a scheduling feature that enables users to set preferred drying times based on weather forecasts or their daily routine. This way, the system can optimize energy usage by running during peak

sunlight hours or when the weather is favorable.

6) **UV Sterilization**: Integrate ultraviolet (UV) sterilization technology into the system to disinfect clothes during the drying process, enhancing hygiene and reducing the need for additional steps like ironing.
7) **Clothing Capacity**: Design a system to accommodate larger loads of laundry by expanding the clothesline or optimizing the hanger arrangement. This ensures that the system remains suitable for various household sizes.
8) **Material Compatibility**: Ensure that the system's materials are compatible with different types of clothing fabrics to prevent damage or wear during the drying process.
9) **User-Friendly Interface**: Enhance the user interface by incorporating voice commands, touch screens, or intuitive buttons for easy interaction and customization.
10) **Integration with Smart Home Systems**: Enable seamless integration with existing smart home systems, allowing users to incorporate laundry drying into broader home automation scenarios.
11) **Energy Storage:** Incorporate energy storage solutions, such as batteries or capacitors, to store excess energy generated by the solar panels. This stored energy can be used during non-sunny periods, ensuring continuous operation.
12) **Drying Time Optimization:** Develop algorithms that calculate the optimal drying time based on various factors, including clothing type, weather conditions, and energy availability.
13) **Material Innovations**: Explore new materials that are more resistant to weather conditions, UV exposure, and wear, ensuring the longevity of the system.
14) **User Feedback and Adaptation**: Implement a feedback loop that allows the system to learn from user preferences and adapt its behavior over time for improved performance.
15) **Lifecycle Assessment:** Conduct a comprehensive lifecycle assessment to identify opportunities for reducing the system's environmental impact throughout its entire lifecycle, from manufacturing to disposal.

By implementing these improvements, the outdoor automatic laundry drying system can become even more efficient, user-friendly, and environmentally friendly, catering to the evolving needs of users and advancing sustainable living.

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