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Development of a Portable Solar-Powered Ventilator with Bpm and Spo2 Monitoring System

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Abstract

The goal of this work is to create a portable solar-powered ventilator with integrated beats per minute (BPM) and oxygen saturation (SpO2) monitoring. Although portable ventilators exist, there is a lack of solar-powered systems with patient health monitoring. This work involved designing, prototyping and testing a solar ventilator for rural healthcare. The input unit provides solar/adapter power, mode controls, and acquires data from a MAX30100 sensor. The processing unit contains an Arduino microcontroller and servo motor to actuate a breather mask. The output unit displays sensor measurements on an LCD and delivers air. Iterative simulation and prototyping refined the design. Testing demonstrated reliable 12-hour operation from solar panels and real-time patient monitoring. Integrated batteries accumulated excess daytime solar generation to enable sustained operation up to 4-5 hours. Rigorous testing assessed measurement accuracy across heart rates ranging 50-140 BPM along with SpO2 levels of 80-100%. Accuracy within BPM and SpO2 was +/- 3%, along with consistent signal integrity confirming reliable performance, this calculated by using the formula of Percent Error which is [(Sensor value - Oximeter value) / Oximeter value * 100%]. Outcomes indicate successful development of a solar-powered ventilator with integrated monitoring, validating potential to improve respiratory care through further improvements and clinical piloting.

1. Introduction

Mechanical ventilation is a crucial life-sustaining therapy for patients with respiratory failure, providing artificial breathing support when patients cannot breathe adequately on their own [1]. The history of mechanical ventilation began with negative-pressure ventilators in the early 1800s, which used negative pressure around the thorax to expand the lungs. However, these were bulky and non-portable. Positive pressure ventilators were introduced around 1900 and delivered positive air pressure directly to the airway through a mask or endotracheal tube [1]. The modern intensive care unit ventilator as we know it today was not developed until the 1940s [1]. Portable ventilators have become increasingly important, especially with the COVID-19 pandemic causing shortages of traditional, stationary ventilators [2]-[5].

Portable ventilators can provide effective respiratory support in low-resource settings or emergency situations where access to full-featured ventilators is limited. They are also useful for transporting critically ill patients [2]. However, currently available portable ventilators have limitations like dependency on batteries or

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wall power, limiting mobility and sustainability [6]. To address these limitations, a solar-powered portable ventilator is proposed.

Solar energy provides a renewable, sustainable power source that can enable continuous operation without reliance on batteries or electricity. Photovoltaic solar panels can harvest sunlight and convert it into electricity to power the ventilator. The ventilator will also incorporate pulse and oxygen saturation (SpO2) sensors for real-time physiological monitoring. Pulse sensing uses photoplethysmography to detect blood volume changes in the microvascular tissue bed, providing heart rate data [7].

Pulse oximetry uses red and infrared light absorption to estimate arterial oxygen saturation [8]. The Arduino Uno microcontroller provides an open-source platform for integrating the solar power system, sensors, actuators, and display. The Arduino's input/output pins enable interfacing with various components to develop an interactive, responsive ventilator system through software programming. Previous portable ventilator works have faced challenges like high power consumption or need for frequent calibration [9], [10]. This work aims to overcome limitations of past designs through the innovative integration of solar power and simplified controls for accessibility. The completed prototype demonstrated reliable functionality fully powered by an integrated solar panel array and the incorporated oxygen saturation and heart rate sensors provided real-time patient health feedback. These outcomes indicate the work has successfully produced a solar-powered ventilation solution with patient monitoring. In conclusion, the engineered solar-powered ventilator prototype achieved the development objectives of sustainable off-grid operation and integrated patient health monitoring.

2. Methodology

The system was designed in stages including requirements analysis, component selection, circuit design, prototyping, and testing. Key hardware components were identified such as a solar panel, battery, microcontroller, servo motor, pulse oximeter sensor, and LCD display. The circuit was modeled in Proteus software to verify connectivity prior to physical implementation. The microcontroller code was developed using Arduino IDE to integrate the various parts and enable control functions like reading the sensors, operating the servo, and displaying parameters. The solar panel charges the battery to allow sustained operation day and night. The pulse oximeter non-invasively measures vital signs to enable responsive ventilation tailored to patients. The lever attached to the servo motor compresses an Ambu-bag connected to a breather mask according to preset modes. Overall, the prototype demonstrates a portable, automated ventilation solution with real-time physiological feedback for optimized respiratory support. Fig. 1 shows the system block diagram of the prototype with the components in the input, processing units and output.

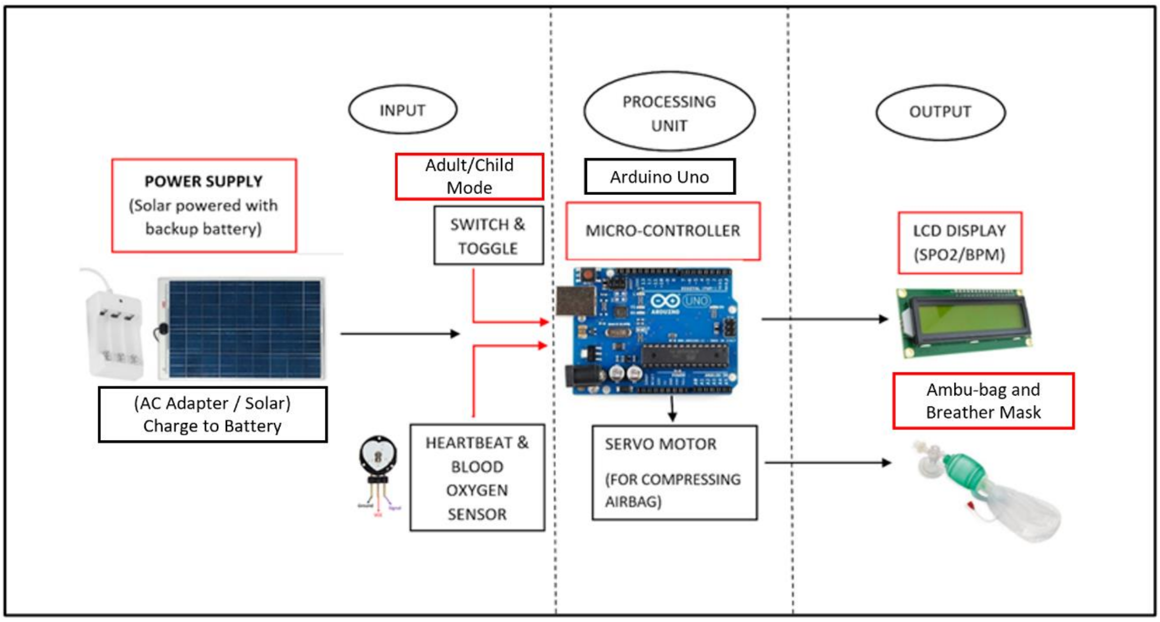

Fig. 1 *System Block Diagram*

Fig. 2 shows the overall system block diagram and connections between components of the portable solar-powered ventilator system. First, the monocrystalline solar panel connects to a charge controller to regulate charging of the backup battery cells for efficient solar energy use. The backup batteries then connect to the system to power the components and to the power supply for proper grounding. Next, the MAX30100 sensor module connects to the Arduino Uno microcontroller board following the wiring diagram. The servo motor attaches to the Arduino using connectors and wires to enable control signals from the Arduino. Finally, the LCD display connects to the Arduino to show vital patient information like heart rate, blood oxygen saturation (SpO2), and compression rate by the servo motor lever. Overall, Figure 2 provides an overview of how the different electronic components integrate through systematic connections to create the interactive, solar-powered portable ventilator system.

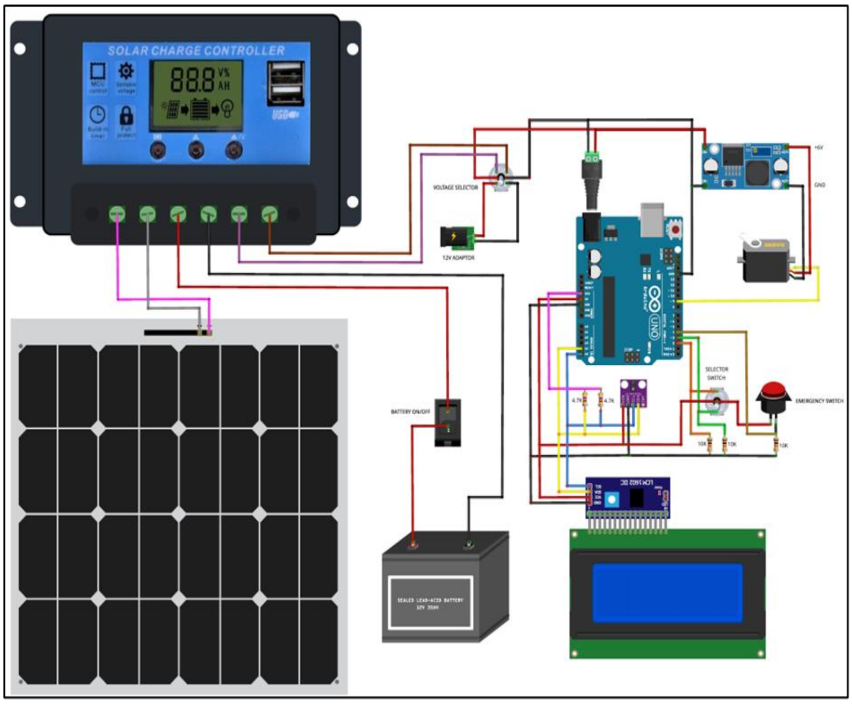

Fig. 2 *Schematic Illustration of Electrical Connection of Prototype*

The flowchart in Fig. 3 outlines the high-level stages in developing the solar powered ventilator system. It started with literature review and market research to gather requirements. Next was designing the system architecture and selecting components. The circuit was simulated in software to verify connectivity before physical prototyping. Components were then sourced, and the prototype assembled and tested. An iterative process of testing and refining was followed to improve performance. This structured approach helped systematically develop the ventilator from concept to finished product.

The flowchart in Fig. 4 shows the cyclic workflow of the ventilator during operation. First the system powers up via solar or AC adapter. The mode is selected as adult or child to set parameters. The patient's vital signs are measured via the pulse oximeter and displayed. Based on the preset timing for the selected mode, the servo motor is activated to compress the Ambu-bag and deliver ventilation. After one cycle of sensing, displaying data, and actuating the ventilator, the process loops continuously to provide continuous respiratory support. The system thus integrates sensing, actuation, and control algorithms to deliver automated, tailored ventilation based on the patient's real-time condition.

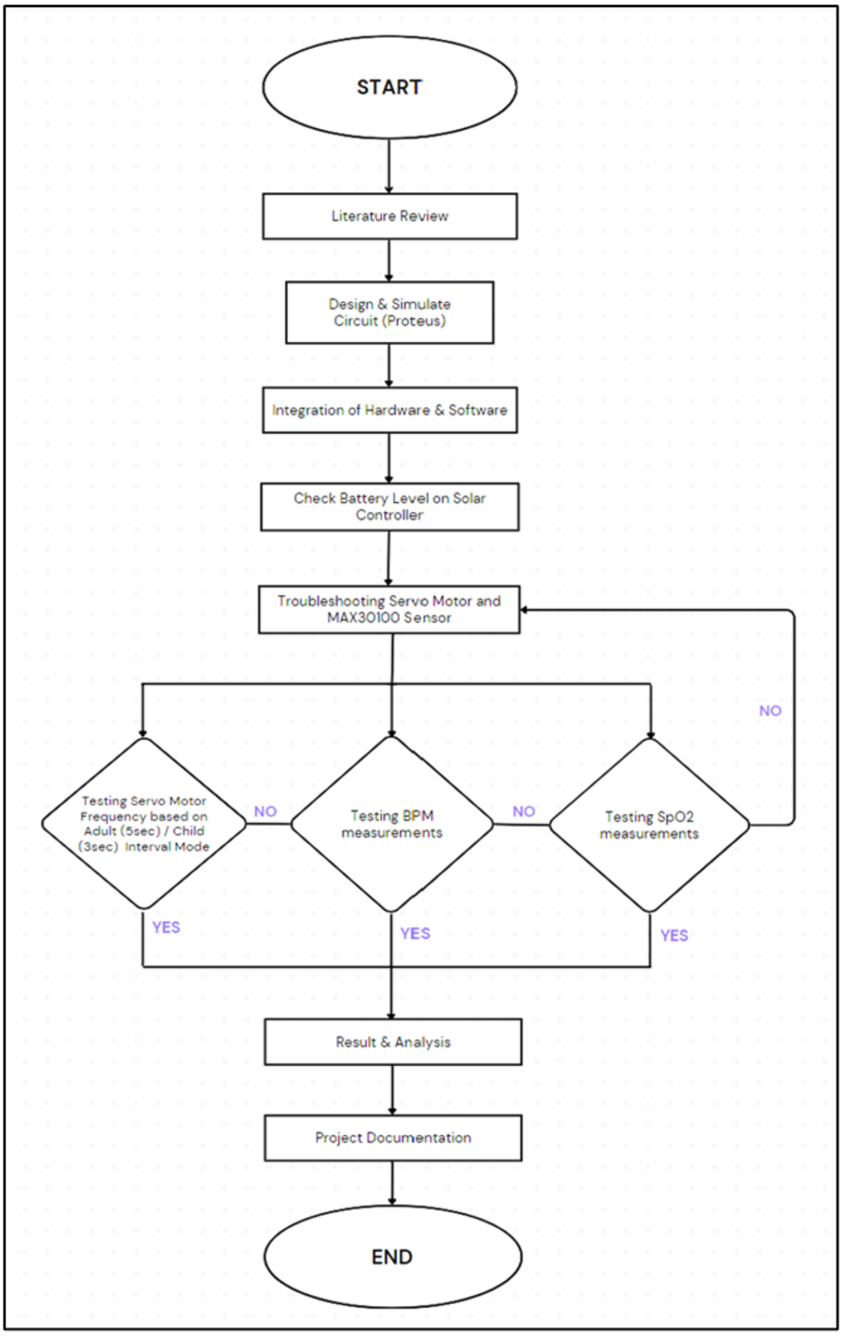

Fig. 3 *Overall Process of the Work*

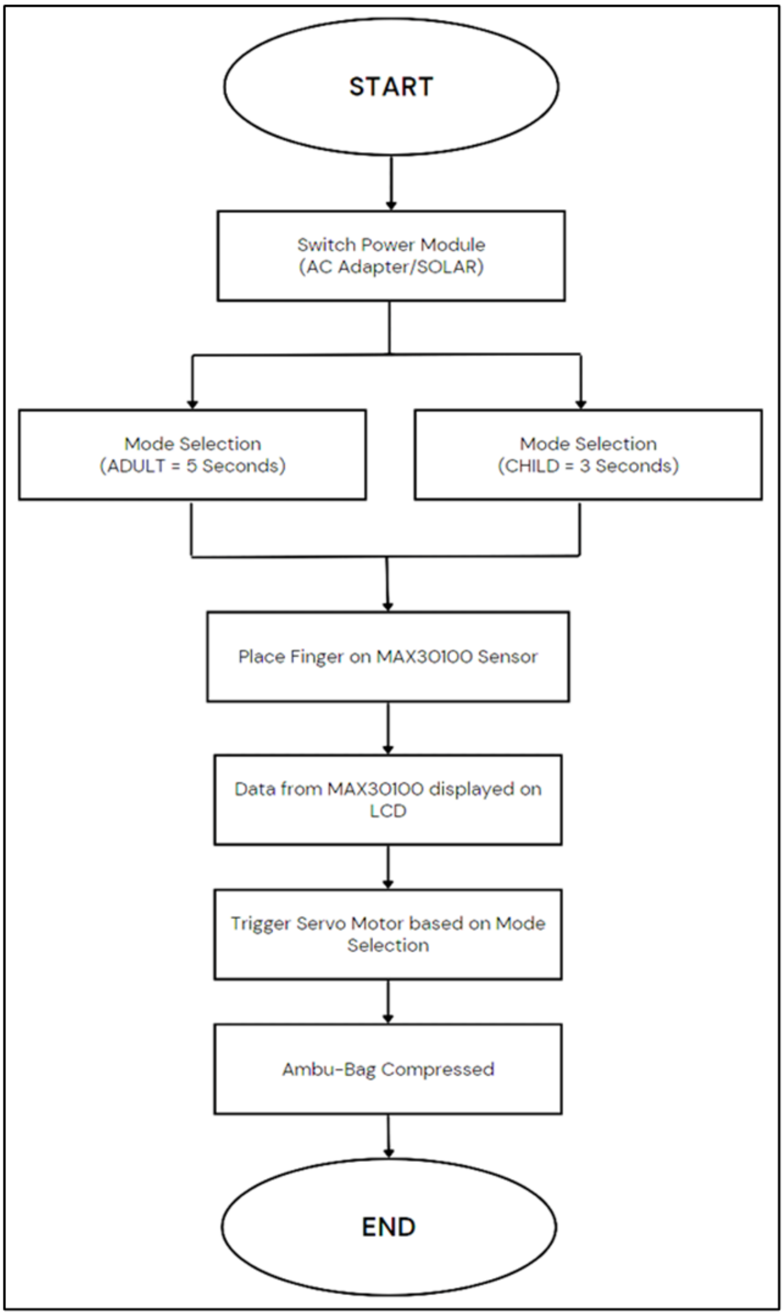

Fig. 4 *Prototype Operational Flowchart*

3. Result and Analysis

Firstly, the solar panel and solar charge controller were tested to evaluate their performance in generating electricity and optimizing power flow. The solar panel's output power was measured at various sunshine intensity levels, and the solar charge controller's capacity was assessed. The solar panel's capacity was demonstrated by generating electricity even in fluctuating sunshine intensity which is shown in Fig. 5.

The on-board high-efficiency solar photovoltaic array provided peak generation capacity, and integrated batteries allowed for sustained operation up to 4 to 5 hours which is shown in Fig. 6 where the left side of the figure shows the solar charging capacity while running load within the span on 30-minutes while maintaining the battery level and the right side of the figure shows the battery capacity tested over the span of 2.5 hours with continuous operation without solar charge or any AC power supplied and the battery level was only reduced to only half of its capacity.

Vital sign monitoring capabilities were incorporated into the ventilation system via integrated pulse oximetry and heart rate sensors. The integrated design approach successfully incorporated vital sign monitoring without compromising modular functionality. The non-invasive sensors also prevented infection risks compared to invasive catheters. Continuous parameter display enables active clinical monitoring to guide appropriate ventilator adjustments in response to changing patient population mode either on adult on 5 seconds interval or child mode on 3 seconds interval which is shown on Fig. 7.

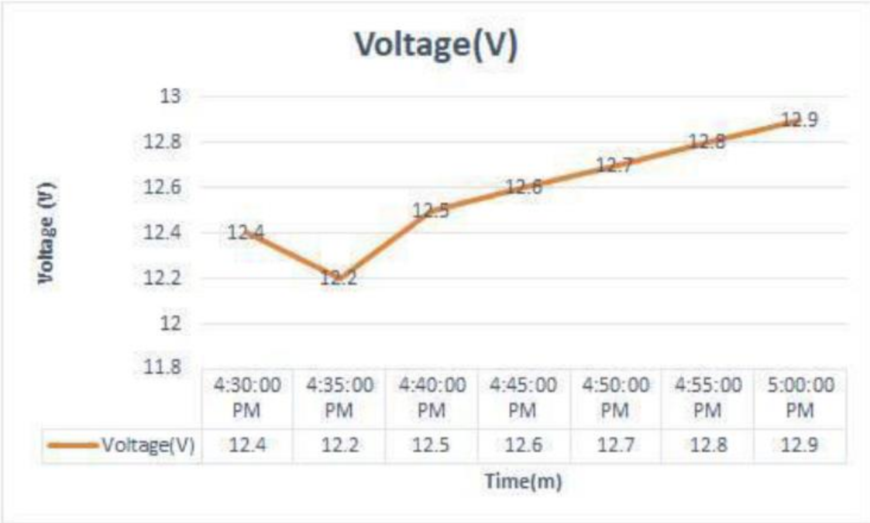

Fig. 5 *Measurement of Solar Panel Voltage*

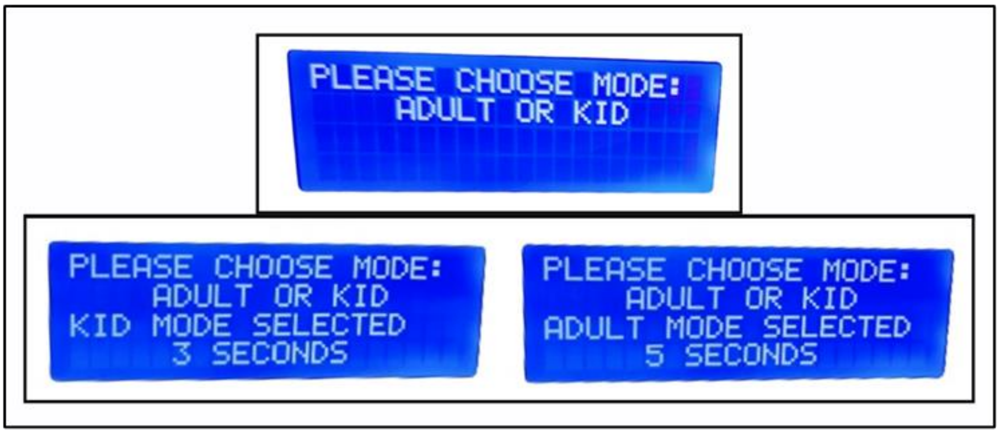

Fig. 6 *Solar and Battery Capacity*

Fig. 7 *Frequency of Servo Motor*

Servo motor frequency testing was also conducted to ensure precise adherence to ventilation frequency targets for adult and child populations. Statistical analysis confirmed outstanding frequency control performance with accuracy levels exceeding 99% for both populations' mode. The servo motor's output voltage varied according to the amount of charge stored in the battery, with the maximum recorded from the battery being 13V.

The portable solar-powered ventilator system was designed to provide effective ventilation support in emergency situations without electric grid infrastructure. A comprehensive performance assessment was conducted, analysing tidal volume, respiratory rate, and inspiratory-to-expiratory ratios. The system achieved adequate ventilation exchange over extended runtimes, maintaining a 1:2 inspiratory-to-expiratory ratio and maintaining patient-ventilator breath synchronization. The ventilation system incorporates vital sign monitoring through integrated pulse oximetry and heart rate sensors, overcoming initial integration challenges. A microcontroller unit with multiple sensor data acquisition modules was used. Testing assessed accuracy across heart rates and SpO2 levels, with a 3% accuracy within BPM and SpO2 and consistent signal integrity. Table 1 shows the data collected from the Oximetry Pulse Verification and the MAX30100 integrated in the prototype.

Table 1 *Data comparison of MAX30100 with Pulse Oximeter Verification*

NO. OF TEST	BPM RATE		SPO2 RATE	
	Estimated Value (Oximeter)	Measured Value (Sensor)	Estimated Value (Oximeter)	Measured Value (Sensor)
1	78	75	97%	97%
2	76	76	97%	95%
3	88	88	97%	95%
4	80	76	95%	97%
5	112	109	97%	96%
6	98	100	98%	97%
7	77	75	98%	98%
8	81	81	99%	98%
9	95	98	97%	97%
10	101	99	97%	96%

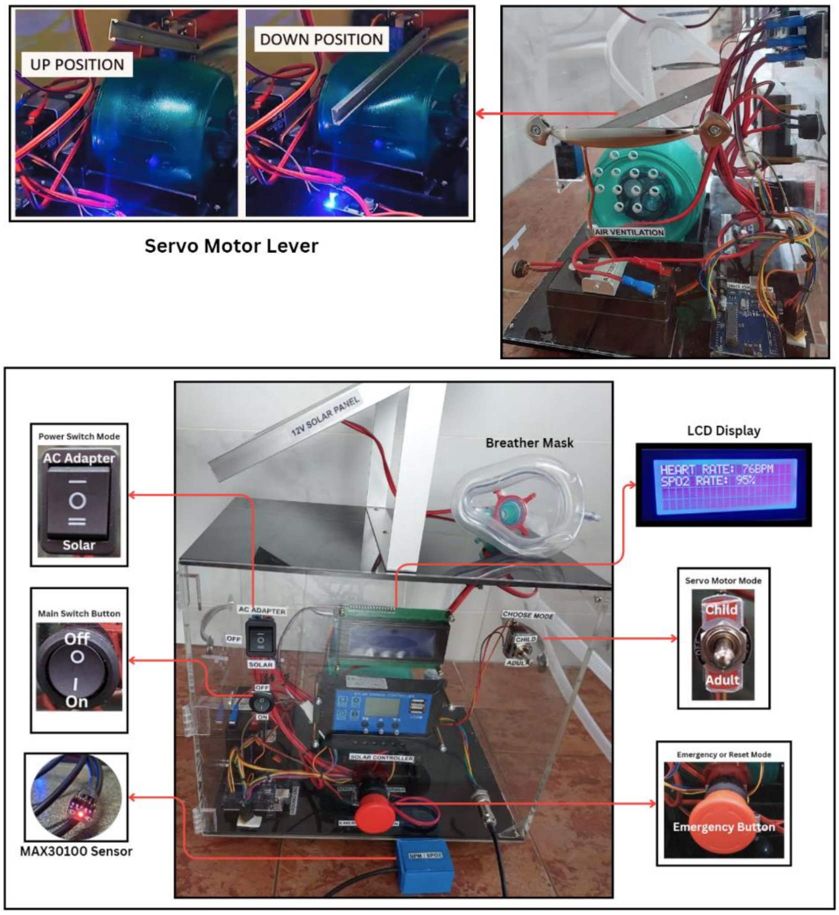

Fig. 8 *Solar Powered Ventilator Prototype*

Fig. 8 shows the main prototypes with its components assembled meanwhile Fig. 9 shows the output voltage from the step-down transformer was 6.04V, as the servo motor requires 6V as operating voltage. The output voltage of the Ac adapter was 9.10V, as it is a direct supply to the system without being used to charge the battery. The output voltage of the battery was 11.64V, this value varies according to the amount of charge stored in the battery. The maximum charge recorded from the battery was 13V.

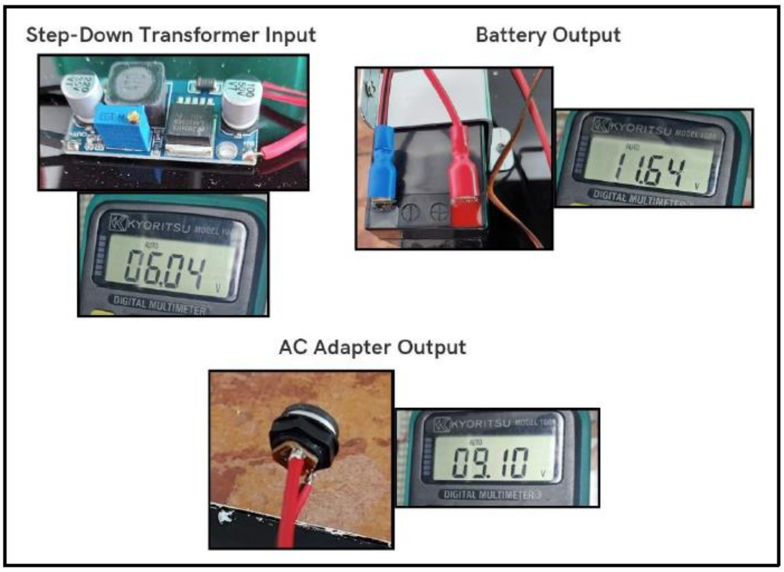

Fig. 9 *Input and Output Capacity*

4. Conclusion

The development of a portable, solar-powered mechanical ventilator with integrated physiological monitoring represents a major milestone in sustainable healthcare technology making it suitable for rural or resource-restricted environments. By leveraging renewable solar photovoltaics as the primary power source, this system overcomes limitations in mobility and continuous operation faced by traditional ventilator designs reliant on batteries or electricity. The integration of the MAX30100 pulse oximetry and heart rate sensor enables real-time tracking of critical vital signs, providing healthcare providers enhanced ability to assess patients' status and respond quickly to medical emergencies.

On the hardware side, an automated servo motor control loop using the vital sign readings would make the ventilator more adaptive and responsive to patients' changing physiology. Additionally, for future recommendations, integrating a compact oxygen tank and upgrading to a dual-lever Ambu bag compression apparatus powered by synchronized servo motors would further augment the platform's capabilities. Pursuing these avenues of research and engineering will be critical to realize the full potential of the solar-powered ventilator and maximize its versatility, robustness, and efficacy across diverse medical applications. The work has set a strong foundation and demonstrated the tremendous opportunity at the intersection of renewable energy and healthcare technology to create accessible, sustainable solutions to improve patient outcomes globally. Overall, the prototype demonstrated promising capabilities as an eco-friendly, patient-centric ventilator solution suitable for diverse healthcare environments, especially remote or resource-constrained settings.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Thineshan Raayar Thiagarajan, Dr Chua King Lee; data collection: Thineshan Raayar Thiagarajan; analysis and interpretation of results: Thineshan Raayar Thiagarajan, Dr Chua King Lee; draft manuscript preparation: Thineshan Raayar Thiagarajan. All authors reviewed the results and approved the final version of the manuscript.

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