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Smartphone-Controlled Bluetooth-Arduino Vehicle for Remote Pesticide Application

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Abstract
This study presents a low-cost, smartphone-controlled vehicle for remote pesticide application using Arduino and Bluetooth Technology. The prototype features a four-wheeled platform with a spraying mechanism, controlled via a custom Android app. The system uses solar energy to charge three lithium-ion batteries via TP4056 modules, each controlling voltage and charging independently. The Arduino Micro-controller works as a central control unit that communicates the user's commands to the other electronic components of the system via an HC-05 Bluetooth module. The vehicle's movement is governed by four DC motors, controlled via two L298N drivers, enabling multi-directional navigation. A 12V pump is activated by a relay switch to spray pesticides through a trigger sprayer head mounted on the vehicle and triggered through the mobile app. The electrical circuit, assembled on a breadboard for flexibility, includes resistors, capacitors, and diodes for voltage regulation and protection. The Chassis is constructed from aluminum beams and Formica plates that provide an enclosure to protect the sensitive electronic components from environmental conditions. This system is designed to reduce direct human exposure to pesticides, physical pain caused by carrying heavy pesticide tanks, costs from labor or power sprayers that need fuel to operate, and environmental pollution. The system operates effectively up to 20 meters. Initial tests confirmed its functionality on small, flat terrain. While limited by manual control, short-range communication, and small tank capacity, the project demonstrates a viable solution for small-scale farms. Future enhancements could include automation, GPS, and environmental sensing for broader agricultural use.

Keywords—Smartphone, Bluetooth Technology, Arduino, Remote Control, Solar Energy.

INTRODUCTION
In agriculture, a significant amount of energy is being used to perform various agricultural tasks such as field preparation operations, seeding or planting, irrigation, spraying of necessary chemicals (pesticides, herbicides, fertilizers, etc.), harvesting, and post-harvesting operations [1]. As the fossil fuels are depleting at a larger rate than they are being reproduced the world is facing a huge energy crisis [2]. The most effective solution for this energy crisis is the global shift towards energy sources that are non-exhaustible, replenished at a higher rate than the fossil fuels, and eco-friendly. These criteria can only be obtained from renewable energy sources. Of all the renewable energy sources solar energy proved to be the most suitable for the heavy agricultural tasks [3]. Besides the nuclear energy, the solar energy is the most plentiful source of energy on our planet and the fastest growing type of renewable energy. It delivers yearly about 10,000 times the energy consumed by humans. As suggested by [4] the energy that we obtain from the Sun far exceeds our demands of energy. [5] argued that the solar energy is free, unlimited, and does not cause pollution to the environment which makes it a green energy. The solar panels are made up of photovoltaic cells that are used to convert the harvested sunlight into electricity for different uses. People around the globe are using solar energy to power and heat their houses, it actually has the potential to be the major energy supply in the future. One of the most important applications of solar energy in agriculture is in pesticides spraying. According to [6] spraying of pesticides and other agricultural chemicals

is quite important in agriculture as it protects the crops from diseases, weeds, as well as keeps the pest population under control to the bare minimum biological activity that cannot affect the crops negatively, consequently when the plant protection is achieved the crop's yield increases. Chemical spraying, in particular, is the most effective method for controlling pests but it must be handled carefully, applied in rationed doses, and sprayed precisely to avoid health hazards as well as polluting the environment because these chemicals can be poisonous. When applying pesticides and other agricultural chemicals only the targeted areas and plants should be sprayed, and to achieve such accuracy specialized devices are utilized. They are commonly known as "Sprayers". As defined in [1], "a sprayer is a machine to apply herbicides, fungicides, and insecticides in the form of droplets". The invention of sprayers revolutionized agriculture and helped increasing the agricultural output greatly.

Recent researches [6], [7], [8], showed that manually lever operated knapsack sprayers cause several risks to farmers such as fatigue due to heavy weights, tiredness due to the continuous operation of the lever while moving in the field, pain in the spinal cord and muscles due to carrying the heavy pesticide tanks on their backs, and difficulty in lifting the tanks. These conventional types have limitations of inefficiency such as inability to maintain a constant spraying rate, inability to sustain adequate pressure, chemical misapplication and inefficient pest management, pesticide loss due to drift or dribbling, and they require more energy to operate. They are also hazardous to the human health and the environment, as these types are not very precise non-targets could be spayed which damages and pollutes the environment. Carrying the pesticide tank and holding the nozzles while spraying put farmers in close interaction with chemicals that cause farmers to experience intoxication such as vomiting and dizzying. Therefore, agricultural chemicals proved to cause harm to both the human health and the environment.

The main objective of this study is to develop a mobile-controlled system for maneuvering the vehicle and spraying pesticides, integrating solar energy as the primary power source for the system, aiming at incorporating an effective spraying mechanism suitable for small to medium-sized farms. As well as evaluating the performance and efficiency of the proposed system. The scope of the study primarily targets smallholder farms or gardens where manual pesticide application presents health risks, and large-scale agricultural machinery is impractical or unavailable.

The following sections present a review of related studies, the methodology used in the development of the system, the results of its implementation, and the conclusion.

LITERATURE REVIEW

REVIEW OF SIMILAR ROBOTIC AGRICULTURAL SPRAYING SYSTEMS

Traditional methods for spraying pesticides proved to be inefficient, causing various limitations such as excessive and uneven application of pesticides, health hazards, and pollution to the environment. Some researches based on robotics had been made to address these problems. [9], proposed a semi-automated solar-powered pesticides spraying machine. Their Robot sprayed the pesticides based on the height of the targeted plants. It was controlled by WIFI enabled android application to help in its movement and used IP camera to provide live streaming of the field during its operation. The Robot also had a sensor to measure the moisture content of the soil. [10], proposed the project of "Smart Pesticide Sprayer Robot". Their project focused on developing an efficient and user-friendly system that could detect affected areas, target them precisely, and accurately spray pesticides only where needed. The automation of the spraying process ensured minimum and even application of pesticides and reduction in health risks previously caused by manual spraying. Their Robot combines sensors technology alongside automation and precise control mechanisms to provide a sustainable and modern solution to the present problems that farmers frequently face during the application of agricultural chemicals.

Related work using Arduino and Bluetooth-controlled systems

Previous research [11] proposed a project of a multipurpose solar-powered, remote controlled, semi-automated robot with an additional mowing system. Their robot was designed to target insects and weeds individually so as to reduce the excessive application of agricultural chemicals. It also removed undesired plants selectively by remotely controlling the mowing system. Their goal was to eliminate the close interaction with pesticides while handling them and remove the task of manually cutting weeds because the farmers could remotely complete these tasks without a need for external labor, which in turn cut down labor costs. They used Bluetooth HC-05 connected to Arduino and to android smartphone wirelessly for remotely controlling their robot, the Arduino microcontroller worked as the brain for the control system, executing the user's commands that they sent wirelessly through the Bluetooth module. Thus, the other electric and electronic components acted according to the user's commands.

MOBILE APPLICATIONS IN AGRICULTURE

According to [8], the explosive spread of smartphones allowed their applications to be applied in various fields, covering nearly every aspect of our lives. One of the recent and innovative developments of mobile applications and Information Technology are in the field of Agriculture, more specifically in smart farming processes. Information Technology is also used in the farm's protection systems against wild animals. [10], developed a smartphone application for an agricultural chemicals spraying system using Bluetooth communication. The application controlled the system by a smartphone to setup its devices such as a water pump, a stirrer, a high pressure pump, and five solenoid valves. The control module of the device was built on an electric circuit board with ATMEGA's 89C51 microcontroller. It was much safer to spray pesticides and control solenoid valves remotely instead of manually completing these tasks. The integration of smartphones in agriculture makes it more attractive for farmers as it saves money, energy, and effort. They are also easy to use.

SUMMARY OF GAPS

Despite the fact that recent studies on solar powered sprayers such as [7], focused on remote control models, this raised the need for trained labor and in turn formed new limitations for small-scale farmers, these limitations are; increasing cost due to the need for skilled labor, and reduced accessibility for those farmers. While solar powered remote controlled sprayers solved most of the problems faced by the past sprayers, they do not fully address the usability challenges in rural and small-scale farms. Smartphone operated solar sprayers suggest a viable alternative solution that eliminates the need for specialized training. However, limited research has explored the feasibility, cost reduction, and user adoption of such real world agricultural settings. Therefore, this project bridges the gap by designing and evaluating a farmer friendly, Solar-powered sprayer car controlled via smartphone that encourages farmers to use this system independently reducing the need for external skilled labor.

Table I, demonstrates a comparison between a manual sprayer and this remotely controlled solar sprayer.

TABLE I. COMPARISON WITH MANUAL SPRAYING

Feature	Manual Sprayer	Proposed System
Power Source	Human operated or fuel based	Solar powered with rechargeable batteries
Control Method	Physical handling	Smartphone App
Spray Precision	Inconsistent	Consistent
User Effort Required	High	Low
Operator Safety	Risks of direct exposure to chemicals	Minimal exposure, user maintain distance
Positive Environmental Impact	Lower	Higher
Initial Investment	High	Low
Chemical Consumption	High	Low
Tank Capacity	Large	Small

System design and architecture

The proposed sprayer system is composed of three subsystems: the mechanical design, electrical and electronic control system, and the software design.

To better understand the following sections
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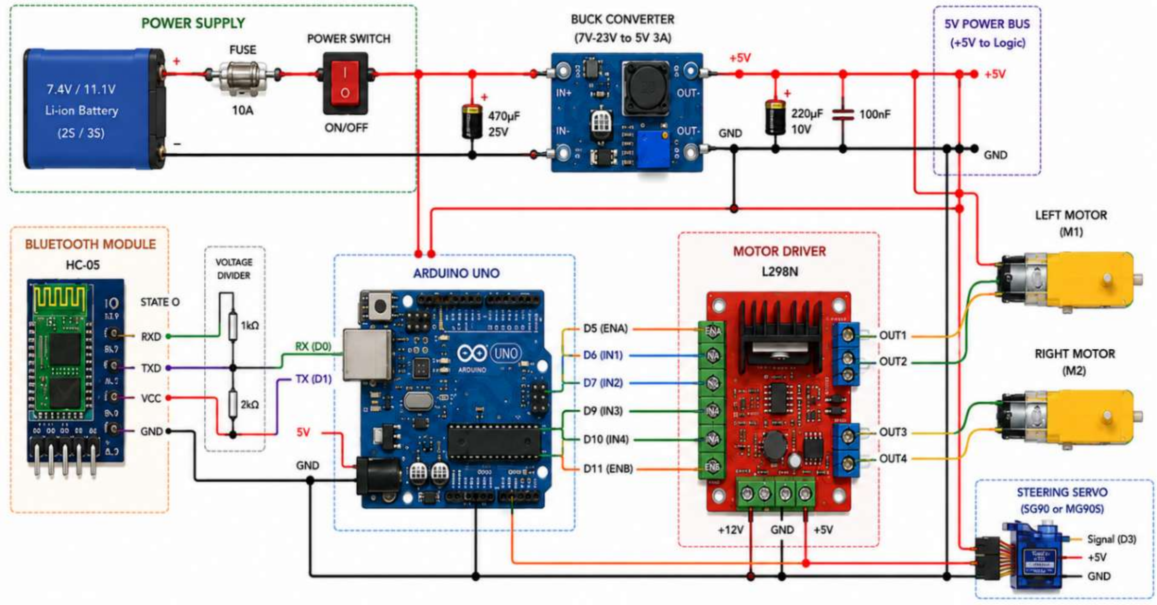

FIG. 1: ARDUINO BLUETOOTH 2FWD RC-CAR- ELECTRONIC CIRCUIT DIAGRAM

System Overview

The operational workflow begins with the user sending commands from a smartphone application. These commands are transmitted via HC-05 Bluetooth module connected to Arduino UNO Microcontroller. The Arduino processes these commands activating the relevant components: two L298N motor drivers to control the vehicle's movement and a relay module to activate the pump for spraying the pesticide. The entire system is powered by a battery pack, which is recharged by a solar panel. This is summarized by a block diagram in Fig. 2.

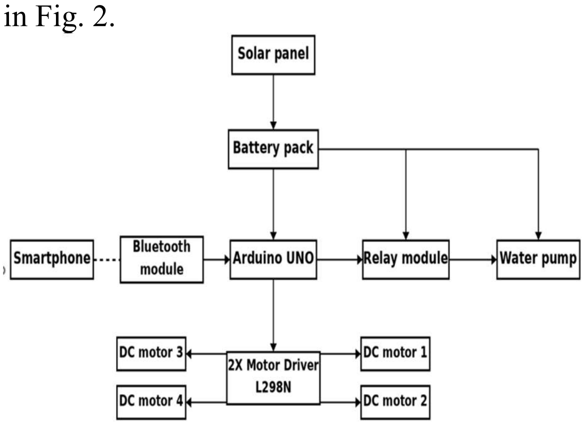

FIG. 2. FUNCTIONAL BLOCK DIAGRAM OF THE SPRAYER CAR SYSTEM

Mechanical Design

The prototype was constructed using aluminum beams and Formica plates (58cm × 35cm) to provide durability while protecting sensitive electronic components. Four U-shaped brackets secure the DC motors; each directly connected to a wheel for smooth movement and easy turning, as demonstrated by the 3D CAD Model designed on SolidWorks in Fig. 3. The Pesticide tank is positioned at the rear with a 12V pump connected to a trigger sprayer head. Fig. 4 show an enhanced Model of the prototype. The trigger head sub-assembly used in the design was obtained from GrabCAD [12].

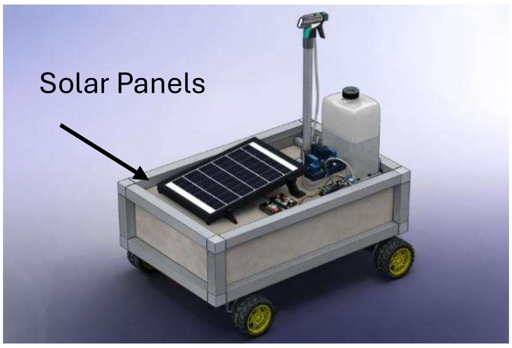

FIG. 3. ISOMETRIC VIEW OF THE 3D CAD MODEL OF THE SPRAYER CAR PROTOTYPE

FIG. 4. ENHANCED CAD MODEL OF THE PROTOTYPE

Electrical and Electronic Design

The electronic subsystem is centered around an Arduino UNO, which acts as the main controller. Communication is handled by an HC-05 Bluetooth module that pairs with the user's smartphone. The Arduino cannot directly supply the current needed by the motors; therefore, two L298N dual H-bridge motor drivers are used to control the four 12V DC motors. This setup allows for control over both speed (via Pulse Width Modulation, PWM) and direction. The power subsystem consists of a 6V, 5.8W solar panel that charges three 1Ah lithium ion batteries. Each battery is connected to a TP4056 charging module to manage the charging process safely and efficiently. When in operation, the batteries are connected in series to provide a 12V supply to the motors and pump. The 12V pesticide pump is switched on and off by a 5V relay module, which is triggered by a digital signal from the Arduino. Fig. 5 shows Arduino flowchart.

D. Power and Energy Calculations

The power requirements of the proposed sprayer vehicle were estimated by analyzing the electrical loads of the drive motors and the pesticide pump. In addition, the available battery capacity and the contribution of the solar charging system were considered. The calculations in this section are based on the rated specifications of the selected components and are intended to provide an approximate estimate for evaluating the performance of the prototype.

i. DC Motor Power Consumption

The sprayer vehicle uses four DC motors for locomotion. Each motor operates at a rated voltage of **12 V** and a rated current of **0.65 A**, [13]. The electrical power consumed by one motor is calculated using:

$$P_m = V_m \times I_m \qquad (1)$$

where P_m is the power of one motor in watts (W), V_m is the motor voltage in volts (V), and I_m is the motor current in amperes (A).

Thus, for one motor:

$P_m = 12 \times 0.65 = 7.8\ W$

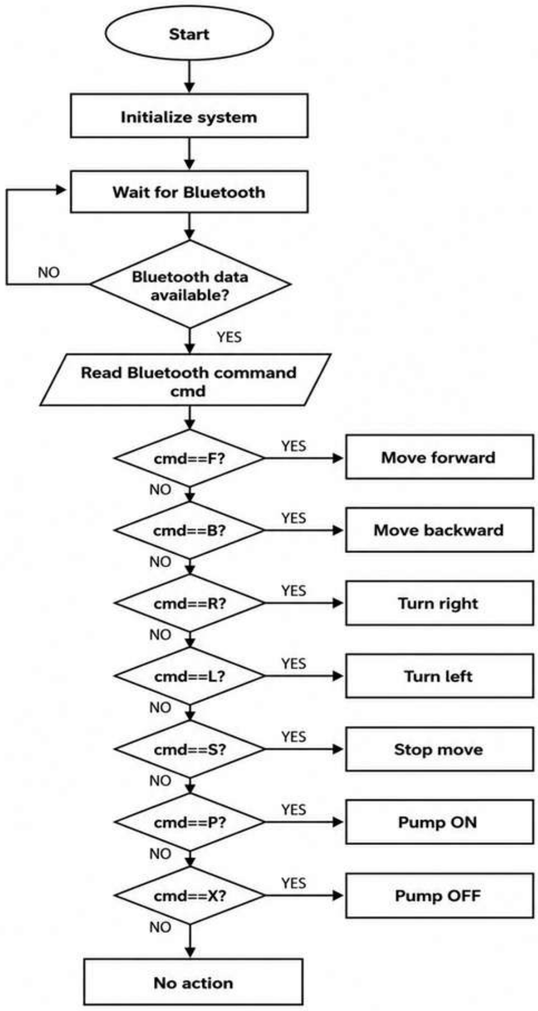

FIG. 5. ARDUINO FLOWCHART

Since the system uses four motors, the total power consumed by the motors is:

$$P_{motors} = N \times P_m \qquad (2)$$

$P_{motors} = 4 \times 7.8 = 31.2\ W$

where $N$is the number of motors.

The energy consumed by the four motors during one hour of continuous operation is given by:

$$E_{motors} = P_{motors} \times t \qquad (3)$$

$E_{motors} = 31.2 \times 1 = 31.2\ Wh$

where $E_{motors}$is the electrical energy consumed by the motors in watt-hours (Wh), and $t$is the operating time in hours (h).

ii. Pump Power Consumption

The spraying unit uses a **12 V DC diaphragm pump** rated at **3 W**, [14]. The energy required by the pump over a period of operation is calculated as:

$$E_{pump} = P_{pump} \times t \qquad (4)$$

For one hour of continuous operation:

$E_{pump} = 3 \times 1 = 3\ Wh$

where $E_{pump}$is the pump energy consumption in watt-hours (Wh), and $P_{pump}$is the pump power in watts (W).

iii. Total System Power and Energy Requirement

The total electrical power demand of the system is the sum of the motor power and pump power:

$$P_{total} = P_{motors} + P_{pump} \qquad (5)$$

$P_{total} = 31.2 + 3 = 34.2\ W$

Similarly, the total energy consumed during one hour of continuous operation is:

$$E_{total} = E_{motors} + E_{pump} \qquad (6)$$

$E_{total} = 31.2 + 3 = 34.2\ Wh$

Thus, under full-load continuous operation, the prototype requires approximately **34.2 W** of power and **34.2 Wh** of energy per hour.

iv. Effect of PWM on Power Consumption

Pulse Width Modulation (PWM) is used in the Arduino control system to regulate motor speed. When the motors operate at a reduced duty cycle, the average electrical power drawn by the motors decreases. Assuming an average PWM duty cycle of **50%**, the effective motor power can be approximated as:

$$P_{motors,PWM} = P_{motors} \times D \qquad (7)$$

$P_{motors,PWM} = 31.2 \times 0.5 = 15.6\ W$

where $D$is the PWM duty cycle.

The corresponding total system power under this condition becomes:

$$P_{total,PWM} = P_{motors,PWM} + P_{pump} \qquad (8)$$

$P_{total,PWM} = 15.6 + 3 = 18.6\ W$

Therefore, operation under PWM speed control reduces the average power demand and increases the expected runtime of the battery-powered system.

v. Battery Pack Capacity

The prototype uses **three lithium-ion batteries connected in series**, [15]. Each battery has a fully charged voltage of approximately **4 V** and a capacity of **1 Ah**. The total battery pack voltage is:

$$V_B = N_B \times V_b \qquad (9)$$

$V_B = 3 \times 4 = 12\ V$

where $V_B$is the total battery pack voltage, $N_B$is the number of batteries, and $V_b$is the voltage of one battery.

For batteries connected in series, the pack capacity in ampere-hours remains equal to the capacity of a single cell. Therefore, the stored energy in the battery pack is:

$$E_B = V_B \times C_B \qquad (10)$$

$E_B = 12 \times 1 = 12\ Wh$

where $E_B$is the battery energy stored in watt-hours (Wh), and $C_B$is the battery pack capacity in ampere-hours (Ah).

Hence, the battery pack can ideally supply **12 Wh** of energy per full charge.

vi. Estimated Battery Runtime

The runtime of the system can be estimated by dividing the available battery energy by the total load power. Under full-load operation:

$$t_{run} = \frac{E_B}{P_{total}} \qquad (11)$$

$t_{run} = \frac{12}{34.2} = 0.35\ h$

$t_{run} \approx 21\ min$

Under PWM-controlled operation:

$$t_{run,PWM} = \frac{E_B}{P_{total,PWM}} \qquad (12)$$

$t_{run,PWM} = \frac{12}{18.6} = 0.65\ h$

$t_{run,PWM} \approx 39\ min$

These theoretical results indicate that the system runtime is strongly affected by motor operating speed and duty cycle. The experimentally observed runtime of approximately **40–50 minutes** is therefore reasonable, since practical field operation involves intermittent spraying and variable motor loading rather than continuous full-load operation.

vii. Solar Panel Output

The prototype includes a solar panel rated at **6 V** and **5.8 W**. The current output of the panel under ideal conditions is calculated as:

$$I_{solar} = \frac{P_{solar}}{V_{solar}} \qquad (13)$$

$$I_{solar} = \frac{5.8}{6} = 0.97\ A$$

where I_{solar} is the solar panel current, P_{solar} is the solar panel power, and V_{solar} is the solar panel voltage.

Thus, the panel can ideally deliver approximately **0.97 A** under full sunlight conditions.

viii. Battery Charging Time

The theoretical charging time required to recharge the battery pack can be estimated from the ratio of battery energy to solar panel power:

$$T_{charge} = \frac{E_B}{P_{solar}} \qquad (14)$$

$$T_{charge} = \frac{12}{5.8} = 2.1\ h$$

Therefore, under ideal solar irradiance, the battery pack requires approximately **2.1 hours** for full charging. In practice, however, charging losses, solar intensity variation, and conversion inefficiencies increase the actual charging time. Accordingly, the experimentally observed charging duration of about **3 hours** is consistent with real operating conditions.

ix. Summary of Power and Energy Results

The power and energy analysis shows that the prototype requires **34.2 W** under full-load continuous operation, while PWM-based motor control reduces the average system demand to approximately **18.6 W**. The battery pack stores about **12 Wh**, yielding a theoretical runtime of approximately **21 minutes** at full load and about **39 minutes** under PWM-controlled operation. The **5.8 W** solar panel can theoretically recharge the battery in about **2.1 hours**, although the practical recharge time is closer to **3 hours** due to real-world losses. These results confirm that the proposed system is suitable for short-duration spraying tasks in small-scale agricultural applications.

It should be noted that these calculations are based on rated component values and ideal operating assumptions; therefore, actual field performance may vary depending on terrain resistance, spraying duty cycle, battery condition, and solar irradiance.

The solar panel in the present prototype does not directly power the propulsion system during operation; rather, it serves as a supplementary charging source for the battery pack. Since the maximum solar panel output is 5.8 W, which is significantly lower than the vehicle's propulsion and spraying power demand, the vehicle relies primarily on stored battery energy during movement and spraying.

Conclusion

The vehicle is powered mainly by the battery pack during operation, while the solar panel serves as a supplementary charging source. Since the solar panel output of 5.8 W is much lower than the system operating demand of 18.6 to 34.2 W, it cannot directly propel the vehicle in real time.

TABLE II. POWER AND ENERGY CALCULATIONS

Component	Voltage (V)	Current (A)	Power (W)	Energy for 1 h (Wh)
Pump	12	0.25	3.0	3.0
DC Motors (4×)	12	2.60	31.2	31.2
Total system	–	–	34.2	34.2
Total system with PWM (50%)	–	–	18.6	18.6

Table III. Battery Capacity and Estimated Runtime

Parameter	Value
Number of batteries	3
Battery pack voltage	12 V
Capacity of each battery	1 Ah
Battery pack capacity	1 Ah
Stored battery energy	12 Wh
Estimated runtime at full load	21 min
Estimated runtime with PWM	39 min

TABLE IV. SOLAR PANEL CONTRIBUTION

Parameter	Value
Solar panel voltage	6 V
Solar panel power	5.8 W
Solar panel current	0.97 A
Battery energy	12 Wh
Theoretical charging time	2.1 h
Practical charging time	about 3 h

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