Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 7, S. 217-226, 3, 2023

Araştırma Makalesi

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 7, pp. 217-226, 3, 2023

Research Article

https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

"UTU" COMPACT SOLAR PANEL CLEANING ROBOT

Sufyan Muhammed[1], Thanoon Laheb[1], Hassan Ma'ad* and Omar W. Maaroof[1]

[1]*Mechatronics Engineering Department, University of Mosul, Iraq*

*hassan.en466@student.uomosul.edu.iq *Email of the corresponding author*

(Received: 20 March 2023, Accepted: 11 April 2023)

(2nd International Conference on Engineering, Natural and Social Sciences ICENSOS 2023, April 4 - 6, 2023)

ATIF/REFERENCE: Muhammed, S., Laheb, T., Ma'ad, H. & Maaroof, O. W. (2023). "UTU" Compact Solar Panel Cleaning Robot. *International Journal of Advanced Natural Sciences and Engineering Researches*, 7(3), 217-226.

Abstract – The solar photovoltaic sector has grown significantly during the past decade as a result of rising interest in renewable energy sources. However, keeping the panels clean is a significant problem that is frequently neglected because some of them are challenging and dangerous to reach. As a result, the inventive solution of solar panel cleaning robots was developed, which uses advanced technology to navigate and clean solar panels effectively and efficiently without the need for manual labor. To keep solar panels running at their optimum level, they are equipped with a variety of equipment for cleaning dirt, dust, and other contaminants from their surface that can be found in Iraq.
The design of a compact mobile robot that can completely clean solar panels is the main topic of this report, Considering the detailed mechanical and electrical design as well as the robot's operating algorithm.
According to our research, we conclude that this type of cleaning robot is a promising and effective method for cleaning all types of solar panels especially for the growing solar photovoltaic sector in Iraq.

Keywords – Mobile Robot, Solar Panel; Automated Cleaning; Internet of Things; Solar Panels Dirt Accumulation and Removal; Solar Panel Cleaning Robot

I. INTRODUCTION

It is more important than ever to find sustainable ways to fulfill our energy needs as climate change and global warming endanger the future of our planet. Solar-powered electricity generation is one of the most effective clean renewable energy sources. Solar panels use the sun's energy to produce electricity. Solar panels are one of the most economical and low-maintenance methods of power generating considering that they don't have any moving mechanisms.

Reference [1] studied the efficiency of a solar panel, which represents how much power the panel generates in relation to its theoretical maximum efficiency. The study applied both the cleanliness and tracking mechanism of a solar panel under various conditions such as a fixed and clean panel, a dirty and fixed panel, a dirty and tracking panel, and a clean and tracking panel. Even with integrated sun-tracking, they have been shown that dust accumulation on the solar panels' surfaces reduces their efficiency. The efficiency of the cleaned solar panel increases due to the high rate of light transmission [2]. Tracking a solar panel without cleaning results in an efficiency loss of up to 50% compared to keeping the panel stationary and clean [1]. Megawatts are lost in large-scale power plants more frequently as a result of dust accumulation on solar panels [3]. The Internal Rate of Return (IRR) may be significantly affected by a 1% drop in proficiency. Small-scale solar plants, in contrast, might not be adversely impacted by low-level dust buildup [4].

Despite all of the solar panels' advantages, if dust, dirt, and contaminants are allowed to build up, solar panels' efficiency may suffer. Solar panels require routine cleaning to retain their highest power-generation efficiency. However, manual cleaning solar panels is risky and time-consuming. So, autonomously driven solar panel cleaning robot could have important role to preserve the efficiency of solar power production by ensuring that the solar panels are kept clean without putting humans at risk.

The cleaning robot helps to increase the efficiency of solar panels in different applications such as solar panels in homes, as well as in various industries especially in such severe environments of Iraq.

In this work, a compact mobile solar panel cleaner robot is designed to be applied in small and medium solar panel plants in Iraq. The proposed design consists of on the shelf components. dc motors for moving and two kinds of brushes are being used for this robot. A hard one for difficult dirt and a wet-soft one for dust and polishing. a water tank and pump, sensors, and tank tracks wheels to have higher friction will be used. All of its components will be integrated into a metal chassis with a controller circuit.

A mobile application will be utilized to wirelessly control and monitor the mobile robot. The Arduino mega is the controller which will take action according to the data received and transmitted.

A. Previous Works

In 2017, a water-free Solar Cleaning Robot was developed by Skilancer Solar Cleaning (India) (Figure 1) to eliminate the expense of water and the associated infrastructure, such as tanker trucks, storage containers, hoses, and pipelines. It eliminates 99% of soiling every day, Through the use of a combination of three elements, Controlled airflow over the panel surface, a particular microfiber that removes soiling gently, and gravity to ensure that soiling is transported downward and off panel rows [5].

A safe and sustainable solar panel cleaning ecology was also ensured by the SolarCleano robot, which was developed in 2017 (Luxembourg) (Figure 2). It can even be launched just after sandstorms and clean solar panels in desert places with high heat concentrations. Through specialized web and smartphone apps, the solar plant team may remotely monitor the robot's cleaning and functioning status [6].

In 2022 clean-tech startup ART robotics unveils HELIOS (Figure 3), a drone-mounted autonomous cleaning robot service that offers completely automated solar panel cleaning. a small, light robot that uses edge detection and precise location estimate to navigate on its own the panel surface is cleaned using a brush and vacuum. And the Helios Drone both deploys and collects the cleaning robots from the solar panels [7].

Fig. 1 Skilancer Solar Cleaning [5]

Fig. 2 SolarCleano [6]

Fig. 3 HELIOS [7]

II. Background

A. Solar Panel Cleaning techniques

It is challenging to maintain solar panels after they have been installed on a roof or in a far-off solar farm. Currently, a number of cleaning methods, such as the conventional approach of brushing off dust, coating procedures, and robotic cleaning machines, can be used to clean solar panels [8]. This procedure has been automated since using water and manual brushes to clean industrial solar installations is very time-consuming, labor-intensive, and expensive. A sensor- and controller-based autonomous unit and a water- or waterless-cleaning mechanism unit make up an automated cleaning system for solar panels. Solar panels can be cleaned using several techniques of removing dirt listed in Table 1.

Robotics techniques for cleaning the solar panel with or without water combines mechanical and electronic components to control the brush's movement, the turn-on and turn-off operation is automated. The motor receives a signal from the electrical component to drive the cleaning system. In order to accomplish various complex tasks with better precision, flexibility, and control than using traditional techniques, the system must be robust. Additionally, the created system enhances performance, which increases the solar panels' output power and efficiency

Table 1 - Comparison of various cleaning techniques [8].

Reference	Cleaning Technique	Merits	Demerits	Power Output Efficiency Compared to Clean Panels
[9]	Natural cleaning	No investment cost is involved.	Depends on the location's weather condition.	4%
[10]	Manual cleaning	Involves simple design.	Requires expensive materials and the use of human labor.	90.67%
[11]	Robotic cleaning	Effective and sustainable in all climates.	Requires complex construction.	99.5%
[12]	Heliotex cleaning	Effective for non-sticky dirt.	Requires a lot of water.	12.5%
[13]	Electrostatic cleaning	Effective for dry dust and requires no moving parts.	High voltage is required and design is costly.	3.35–11.5%
[14]	Hydrophobic and hydrophilic coating	Does not require water and labor.	Coating presence reduces screen efficiency	6.62%
[15]	Vibrating cleaning system	Applicable for dry dirt in dry weather.	An external source is required to power the vibrating motor	95%
[16]	Forced-air cleaning system	Applicable for dry dirt in dry weather	An external source is required to power the air pump. Only removes small dust larger than 20_m.	86.4%

B. Dust Detection

There is much research done on solar system cleaning and monitoring. Predicting the rate of inorganic and organic particle deposition on the solar module surfaces prior to the cleaning system's performance might be challenging. Therefore, it is essential to check the solar panels for dust in order to guarantee the efficiency for operating the cleaning system to maximize energy generation as possible.

Reference [17] developed one of the dirt-detecting systems for solar panels. The system's weight sensor continually monitors the dust. When the sensors provide specific input, the Arduino controller sends a command to clear the dust. Weight sensors installed in solar panels monitor dust thickness in response to variations in weight. The panel weight exceeding the predetermined value due to dust is the feedback for cleaning. A solar panel covered in dust will weigh more than the one that is clean. The actual weight of the solar panel may be used as a reference by the controller. According to their research, the microcontroller's constant weight monitoring via the load cell helps with solar panel cleaning and dirt identification. However, such a method can be adversely affected by the wind on the panels. Another option can be by applying image processing and monitoring dust accumulation.

III. Methodology

A. Working Philosophy

Maximizing the performance and effectiveness of the solar panel system should be the core principle of the robot's operation. To get this objective accomplished, first the following design conditions are listed:

• Keeps solar panels clean, preserving their effectiveness.

• Wireless operation ensures that employees are not at risk.

• All dust, dirt, contaminants, and debris are cleaned up with two roller brushes.

• Compact, transportable, and user-friendly design, provided with onboard water tank and water sprayer for efficient usage.

The proposed solar panel cleaning robot is shown in Figure 4. We called this robot "UTU" which is driven from the Sumerian god of the sun.

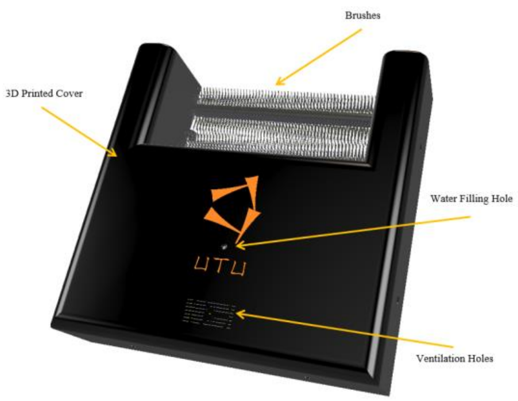


Fig. 4 UTU the compact solar panel cleaning robot

Using two roller brushes as shown in Figure 5, UTU can accomplish cleaning the solar panels to get rid of dirt, dust, and other contaminants that could block sunlight and reduce the panels' ability to generate electricity. The first brush is hard for solid dirt and waterless. The other is moist and soft for polishing and dusting.

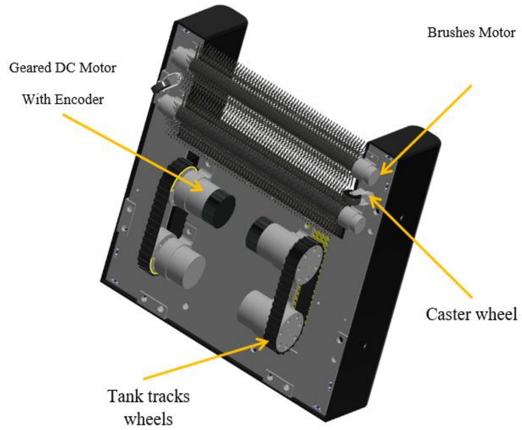


Fig. 5 Bottom view of UTU

UTU designed to use a methodical technique to clean the panels, throughout intelligent navigation by the use of 8 IR sensors spread on its borders as shown in Figure 6. The eight IR sensors along with a 9 DOF (Degrees of Freedom) IMU sensor, navigation can be performed completely and efficiently. Along with efficiency, the solar panel's slope and the weather conditions were taken into consideration during design to ensure the safety of the robot.

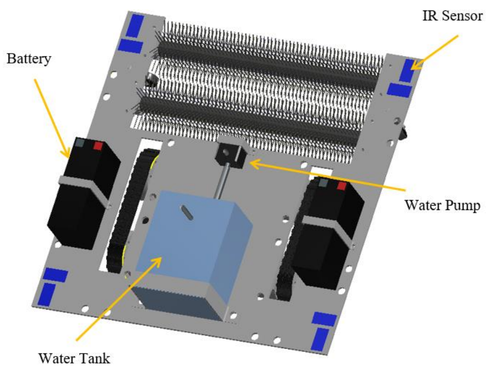


Fig. 6 IR sensors and internal components

B. Electrical design

The system's electrical circuit diagram is shown in Figure 7. For the electrical design of the internal components, the following on the shelf components are used:

1. Arduino Mega with Wi-Fi

The MEGA board is an Arduino®-compatible board with 54 digital I/O pins, 15 PWM outputs, 16 analog inputs, 4 UARTs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It can be powered through USB or an AC-to-DC converter or battery to get started.

2. Adafruit's 9 DOF

9 DOF breakout board that allows you to record nine distinct types of motion or orientation-related data: three degrees each of acceleration, magnetic orientation, and angular velocity.

3. Infrared Obstacle Sensor Module

The Infrared Obstruction Sensor Module is an integrated IR transmitter and receiver that uses IR energy to detect any obstacles in front of the sensor module. The IR transmitter sends an infrared signal that is broken off by the receiver, which records the signal and detects the object when the surface is absorbent.

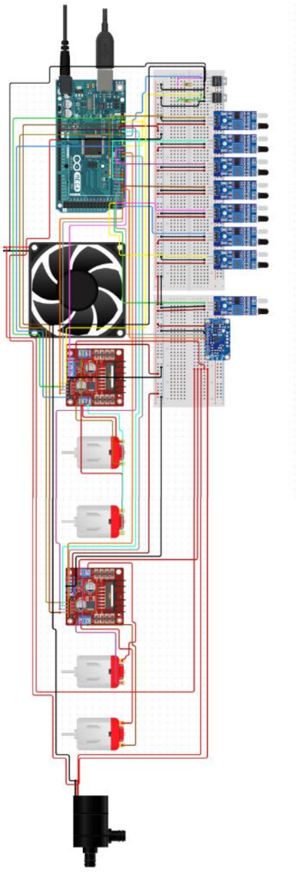


Fig. 7 Robot electric circuit diagram

4. Power supply

DC rechargeable batteries will be used. They will be defined subsequently based on the required nominal voltage and capacity (the average current and minimum working time).

5. Geared DC motor with encoder

DC motors are electrical machines that convert direct current electrical power into mechanical power and are based on magnetic field forces. They have a gear assembly attached to them, which helps in raising torque and decreasing speed. Motor Encoder is an electromechanical device that generates an electrical signal that can be used to regulate speed and/or position. Closed-loop feedback or closed-loop control systems use encoders or other sensors to regulate specified parameters.

6. Motor driver

L298N Motor Driver is a high-power motor driver module for DC and Stepper Motors, with an IC and 78M05 5V regulator, capable of controlling up to four DC motors or two DC motors with directional and speed control.

7. 5V Brushless DC Cooling Fan

The ability to circulate cold air into an enclosure or over a high-heat component, such as a regulator, motor driver, or processor, can significantly affect the component's performance and lifespan. The ability to cool an element directly depends on the air itself.

8. Water Pump

This Micro Submersible Water Pump DC 3V-5V uses a water suction mechanism to drain and release water through its intake and exit.

C. Mechanical Design

The robot’s mechanical design is assembled on the two main chassis as shown in Figure 8. It contains different components, and they are:

1. 2 levels of aluminum plate.
2. Tank tracks wheels.
3. Water tank.
4. 2 Roller brushes.
5. 3D printed cover.
6. 2 Caster wheels.

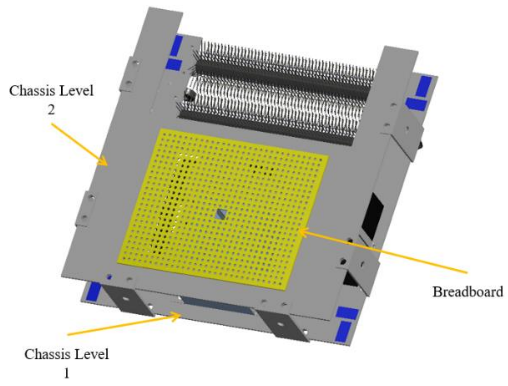


Fig. 8 The internal main chassis assembly of UTU

D. Mathematical Modeling

1. Driving Motor Calculation

The motors are going to be chosen according to some specifications of the robot design, such as weight, wheel diameter, number of motors, etc. after completing the mechanical design of the robot we will calculate the specification of the motor by using the equations below.

2. Motor Torque

The required torques that will be applied on the actuators can be calculated as the follow

$$\tau_{robot}\,(N\text{-}m) = F_{robot} \cdot r \;\dots\dots\dots\; eq.1$$

F_{robot} is the total force needed by the robot
r is the radius of the drive wheel

$$F_{robot}\,(N) = F_{total} / N \cdot \eta \;\dots\dots\dots\; eq.2$$

N is the number of used motors while η is the efficiency of the motor

$$F_{total}\,(N) = F_a + F_H + F_R \;\dots\dots\dots\; eq.3$$

the acceleration force $F_a = m \cdot a,$

the Downhill-slope force $F_H = F_G \cdot sin\alpha,$

the friction force $F_R = \mu \cdot F_G \cdot cos\alpha.$

the gravitational force $F_G = g \cdot m.$

m is the mass of the robot,

α the angle of the slope,

μ the friction coefficient,

g the gravitational acceleration constant of $9.81 m/s^2$, a is the acceleration of the robot

3. Angular Velocity

$$\omega\,(rad/s) = v/r \dots\dots\dots\; eq.4$$

V is the velocity of the robot (m/s)
r the radius of the wheel (m).
To get the angular velocity in RPM, it needs to be multiplied by $60/2\pi$.

4. Power

$$P\,(W) = \omega \cdot \tau \dots\dots\dots\; eq.5$$

with the angular velocity in radians per second.

E. Mobile Application

It is challenging to monitor and control the robot directly because there are no standard positions for the solar panels, they may be high on the roof-to at the edges of a building or any other place that is hard reach. So, the mobile app is used to monitor the status of the robot if there is an accident and can control the robot's Start/Stop. We will make use of some IOT applications such as Blynk and RemoteXY. The mobile app prototype is shown in Figure 9.

Fig. 9 Mobile App Prototype

F. Working Algorithm

For this robot, we used a technique close to bubble band technique which defines a “bubble” containing the maximum available free space around the robot, which can be traveled in any direction without collision. The shape and size of the bubble are determined by a simplified model of the robot’s geometry, and by the range information provided by the sensors.

According to that, we used 8 IR sensors facing downward at the edges of the robot and distributed on the corners called a, b, c, and d. each corner has two sides called 1 and 2 as shown in Figure 10

These sensors will detect the absence of the solar panel (panel edges or holes), and with the use of a 9 DOF, with three rotation angles Roll, Pitch, and Yaw shown in Figure 11, we can navigate the robot through the whole panels.

Fig. 10 UTU IR Sensors

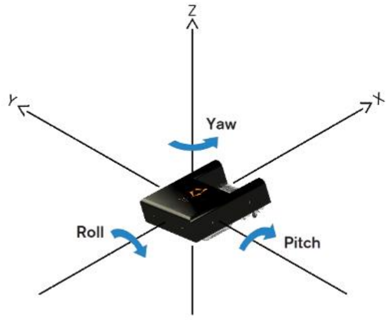


Fig. 10 UTU rotation axes

The full working algorithm is shown in the flow chart presented in Figure 12.

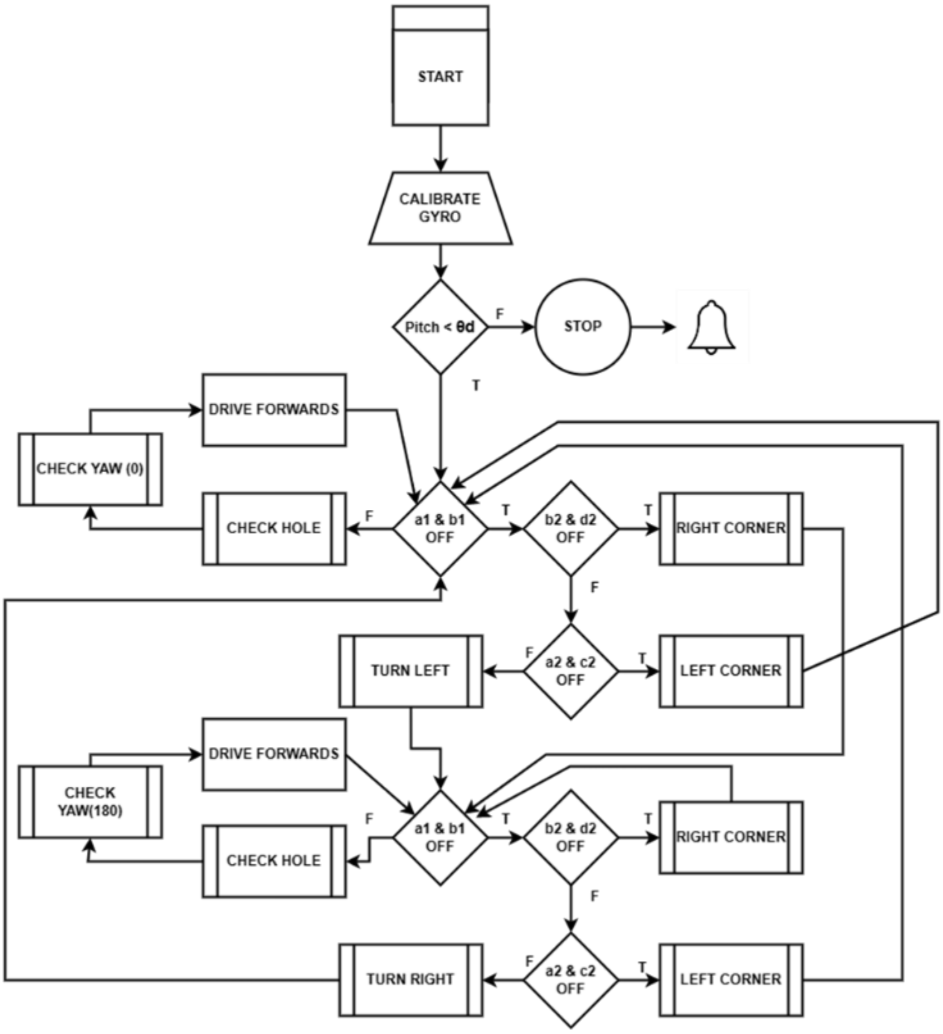
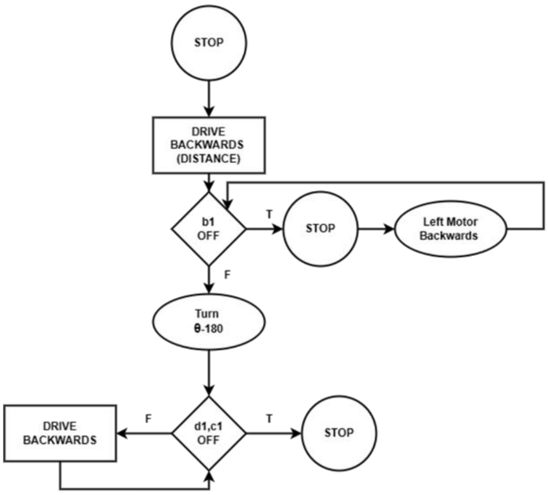
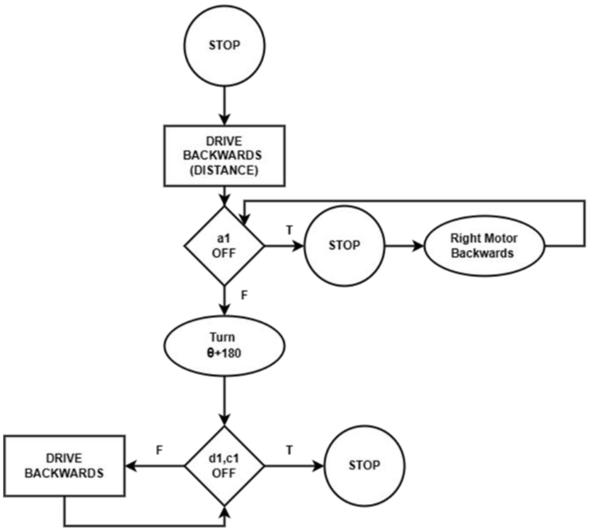


Fig. 11 MAIN ALGORITHM (continue)

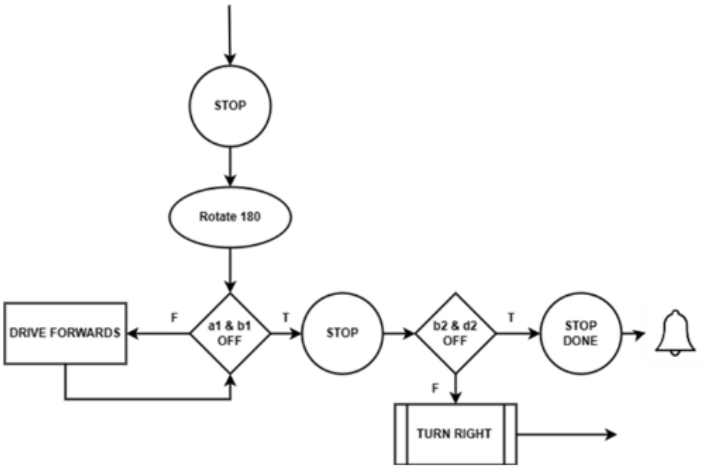
TURN LEFT

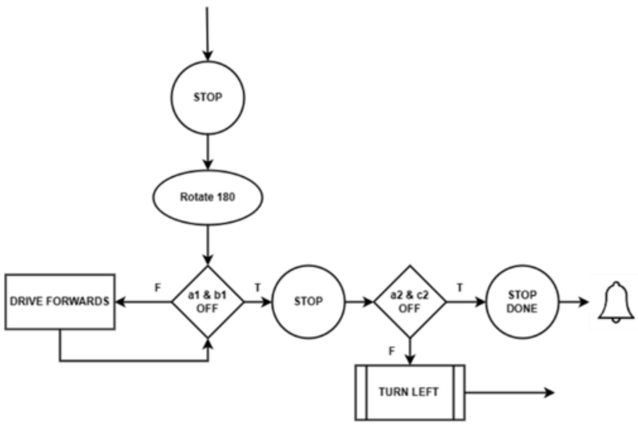


TURN RIGHT



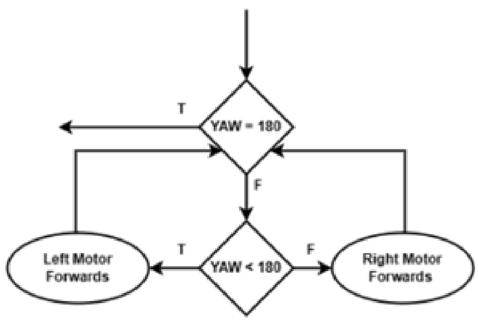
RIGHT CORNER

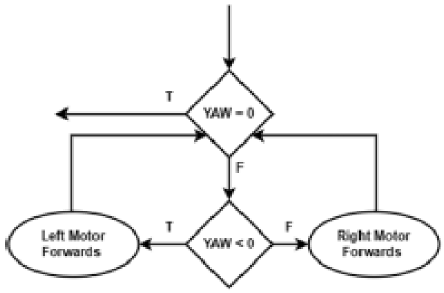




LEFT CORNER

CHECK YAW





CHECK HOLE

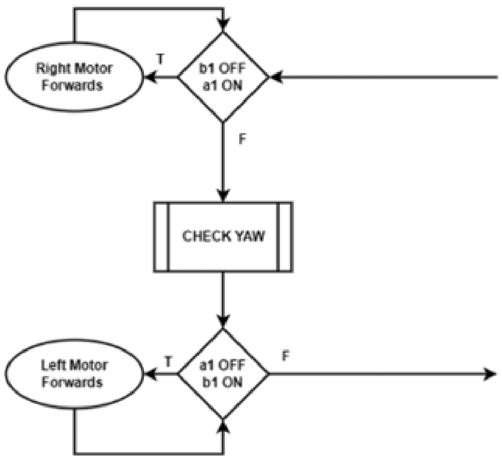


Fig. 11 MAIN ALGORITHM (continue)

IV. Recommendation

The robot can have image processing added for more advanced cleaning so that it can identify the type of dirt present and do specific tasks in response to the findings, in addition, to scanning the whole panels' area for more accurate navigation. Furthermore, the mobile application can also become more effective by extending and improving its monitoring and control features.

V. Discussion

The algorithm mentioned has to be tested, thus we will model the system and run a virtual simulation using MATLAB Simulink to validate that our computation and design are completely functional. After we finish assembling the robot, we may utilize it with the aid of certain programs to collect data on the effect of cleaning the solar panel on its power generation here in Mosul.

Acknowledgments

This project paper was created in the mechatronics department at the college of engineering in the university of Mosul.

References

[1] Abhilash, B.; Panchal, A.K. Self-cleaning and tracking solar photovoltaic panel for improving efficiency. In Proceedings of the IEEE—2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics, IEEE—AEEICB 2016, Chennai, India, 27–28 February 2016; pp. 1–4.

[2] Barker, A.J.; Douglas, T.A.; Alberts, E.M.; IreshFernando, P.A.; George, G.W.; Maakestad, J.B.; Moores, L.C.; Saari, S.P. Influence of chemical coatings on solar panel performance and snow accumulation. Cold Reg. Sci. Technol. 2022, 201, 103598.

[3] Anilkumar, G.; Naveen, K.; Kumar, M.T.V.S.H.K.P.; Kumar, G.V.B.; Palanisamy, K.; Patil, A.; Sachan, D. Design and development of wireless networking for solar PV panel cleaning robots. IOP Conf. Series Mater. Sci. Eng. 2020, 937, 012024.

[4] Khadka, N.; Bista, A.; Adhikari, B.; Shrestha, A.; Bista, D. Smart solar photovoltaic panel cleaning system. IOP Conf. Series Earth Environ. Sci. 2020, 463, 012121.

[5] Skilancer Solar - Automated Solar Panel Cleaning [Online]. Available: https://www.skilancersolar.com/

[6] F1A | SolarCleano [Online]. Avilable: https://solarcleano.com/

[7] HELIOS – an automated cleaning service for solar panels – ART Robotics [Online]. Available: https://art-robotics.com

[8] Olorunfemi, B.O.; Ogbolumani, O.A.; Nwulu, N. Solar Panels Dirt Monitoring, and Cleaning for Performance Improvement: A Systematic Review on Smart Systems. Sustainability 2022, 14, 10920.

[9] Smith, M.K.; Wamser, C.C.; James, K.E.; Moody, S.; Sailor, D.J.; Rosenstiel, T.N. Effects of Natural and Manual Cleaning on Photovoltaic Output. J. Sol. Energy Eng. 2013, 135, 1–4.

[10] Optimal Cleaning Strategy of Large-Scale Solar PV Arrays Considering Non-Uniform Dust Deposition. 2020.

[11] Parrott, B.; Aramco, S. Automated, Robotic Dry-Cleaning of Solar Panels in Thuwal, Saudi Arabia using a Silicone Rubber Brush Photocatalytic Water Splitting Device For Solar Power Generation View project Robotic Dust Mitigation in Saudi Arabia View project. 2018.

[12] Mondal, A.K.; Bansal, K. A brief history and future aspects in automatic cleaning systems for solar photovoltaic panels. Adv. Robot. 2015, 29, 515–524.

[13] Dahlioui, D.; Alaoui, S.M.; Laarabi, B.Waterless cleaning technique for photovoltaic panels on dual-axis tracker. Res. Sq. 2022, in press.

[14] Thongsuwan,W.; Sroila,W.; Kumpika, T.; Kantarak, E.; Singjai, P. Antireflective, photocatalytic, and superhydrophilic coating prepared by facile sparking process for photovoltaic panels. Sci. Rep. 2022, 12, 1–15.

[15] Williams, R.B.; Tanimoto, R.; Simonyan, A.; Fuerstenau, S. Vibration Characterization of Self-Cleaning Solar Panels with Piezoceramic Actuation. In Collection of Technical Papers—AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference; American Institute of Aeronautics and Astronautics Inc. (AIAA): Reston, VA, USA, 2007; Volume 1, pp.512–520.

[16] Li, D.; King, M.; Dooner, M.; Guo, S.; Wang, J. Study on the cleaning and cooling of solar photovoltaic panels using compressed airflow. Sol. Energy 2021, 221, 433–444.

[17] Ronnaronglit, N.; Maneerat, N. A Cleaning Robot for Solar Panels. In Proceedings of the 5th International Conference on Engineering, Applied Sciences and Technology, ICEAST 2019, Luang Prabang, Laos, 2–5 July 2019.

[18] Ali, A.H.; Kazmi, S.M.H.; Poonja, H.A.; Khan, H.; Shirazi, M.A.; Uddin, R. Motor Parametric Calculations for Robot Locomotion. Eng. Proc. 2022, 20, 8.

[19] A. Younis, M. Onsa, A brief summary of cleaning operations and their effect on the photovoltaic performance in Africa and the Middle East, Energy Reports, Volume 8, 2022, Pages 2334-2347.