A Development of Autonomous Navigation of Solar Panel Cleaning robots using IOT.

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Abstract - This project involves the development of autonomous robots designed to clean solar panels using IoT. The system utilizes IoT based integration for navigation and incorporates swarm intelligence with master and slave robots. The master robot is equipped with a vacuum pump, while the slave robot carries for cleaning the panels. The primary application of these robots is in desert environments. They are fully autonomous, relying on sensors for navigation collaborated to integrate IoT using swarm intelligence for overall control.

***Key Words*:** autonomous, swarm intelligence, vacuum pump, sensors, navigation.

1.INTRODUCTION

The introduction of solar panel cleaning robot is a bot which helps to increase the efficiency of the solar panel. The main factor that affects a PV (photovoltaic) panel's efficiency is dust, which can reduce its efficiency by up to 50%, depending on the environment this made us to make the cleaning robot [1]. There are many robots on this project but we are making our robot for the Desert Solar Farms cleaning. In this project we are using Internet of Things (IoT) to compile the working of both the robots which need the signal traction to connected and give real time information to the working robots and the monitoring person for completion of the task. The IoT is very useful where the slave and master robot are connected to each other with the Internet based microcontrollers in both the robots.

As in this paper the term swarm intelligence is described that is the group of multiple robots were we are making multiple robots. The multiple robots here specify as the Master robot and Slave robot. The master has the ESP-8266 Wi-Fi microcontroller for the integration of IoT, the master has the Ultra-sonic Sensor for field tracking. The Slave robot is the path follower of the master robot which helps the master robot where it sprays the solution and the viper is there at the end of slave robot to wipes the solution and spread it on the panel. The slave robot is integrated with the swarm intelligence on IoT where slave has the ESP-8266 Wi-Fi module which is integrated to ESP-8266 Wi-Fi the to get the instruction for working condition.

2. Solar Panel cleaning Robot Design -

The solar cleaning bot design is that as in this paper the Master & Slave robot are having separate design as per the specification of each. The Master is having the vacuum opening and the dirt bag caping for removeable dirt bag for removing it after filled. The slave robot is having the viper on the backside and the nozzle spray on the front side. The design of this both robots is compatible and precise as required for the solar panel cleaning which is as required weight on the solar panel. As Fig2.1 & Fig2.2 describes the Master robot and the Slave robot this robots are desgined on the CAD software with the dimensions as required for both robots.

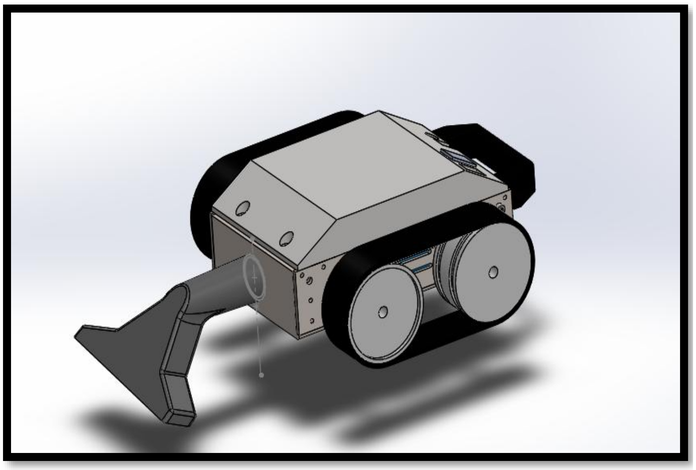

Fig - 1 - Master Robot

The master robot dimension are

lxb = 300mm x 200mm

h = 50mm

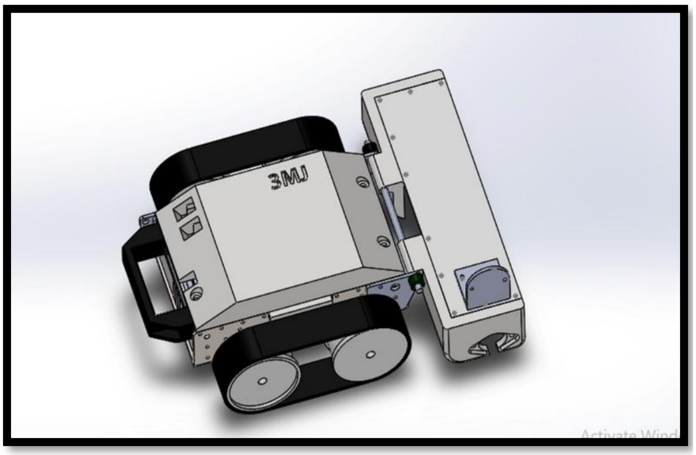

Fig – 2: Slave Robot

The Slave robot dimensions are

lxb = 240mm x180mm

h = 50mm

3. Hardware for Bots –

We have collected the required components for the bots designed to clean the solar panel. To enable interconnection between the two robots in this IoT-based project, we used a microcontroller. Specifically, we are using the ESP-8266 Node MCU, which is well-suited for this task as it includes a built-in Wi-Fi module for communication.

The figures below show the hardware circuits of both robots, each with its respective components. The Master and Slave robots are configured to perform different tasks accordingly.

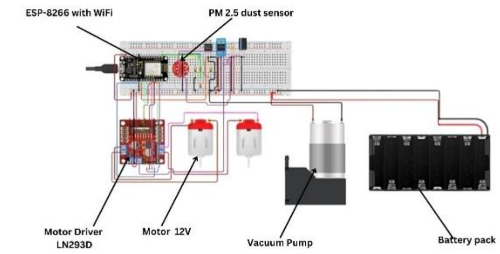

Fig – 3: Master bot Circuit.

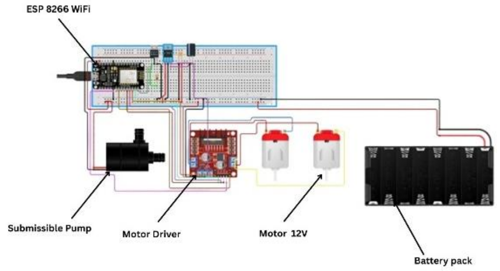

Fig – 4: Slave bot Circuit.

In the above circuit design, the Master and Slave bots are equipped with task-specific components. The Master bot is fitted with a vacuum pump for the suction of dust particles from the solar panel. The Slave bot is equipped with a submersible pump that sprinkles cleaning solution droplets onto the panel, along with an attached wiper to spread the solution evenly.

The motor and its driver, which control speed and turning—especially at the edges of the solar panel—have the following specifications: the motors are 12V high-torque DC motors suitable for inclined movement on the solar panel surface. The motor driver used is the L293D H-Bridge, which is highly compatible with a wide range of DC motors operating from 3V to 24V

4. GUI (Graphical User Interface) –

A GUI is a type of computer human interface on a computer [2]. In this project we are using GUI as the controller in the man who is performing the bots on the solar panel where in GUI the interface is user friendly and adaptable to person who can normally scroll mobile. The GUI has two options with it the manual and auto mode.

The GUI here as the axial control where it is shown on the screen also of the controlling person, the X, Y coordinates of the solar panel are structed and coded to the bots which will start at the initial condition of (0,0) of (X, Y) coordinates.

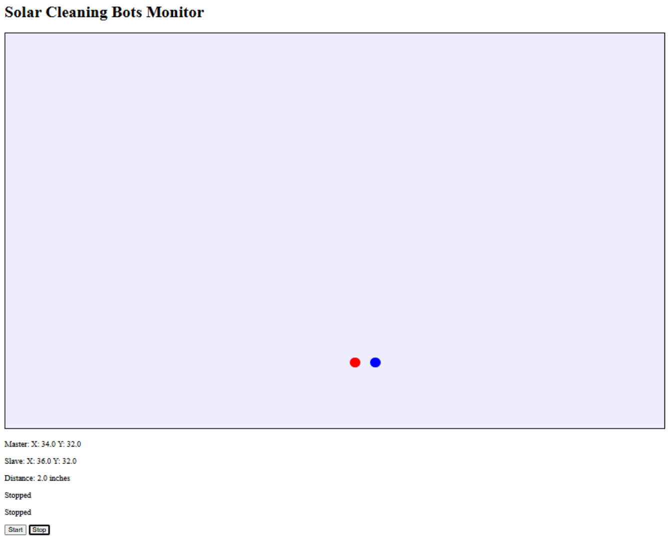

Fig – 5: GUI of bot.

In the above figure, the interface is shown in Auto-Mode, where the Start and Stop buttons are displayed along with the initial conditions—Master and Slave bots in a stopped state and their (X, Y) coordinates.

The GUI also includes a monitoring screen that displays the initial and final states of the bots. The point shown in the figure represents the track movement position of both bots as they begin the cleaning task on the solar panel.

5. Calculations –

1. Total Load (Mass):
• Master Bot: 3.5 kg. (including the bot and the load)
• Slave Bot: 2 kg. (including the bot and the load)
2. Force Required to Move Up the Incline:

$$F = mg \times \sin(\theta)$$

where:
• m = 3.5 kg (Master) & 2 kg (Slave),
• g = 9.81 m/s^2 (gravitational acceleration),
• θ = 30∘ (incline angle).

$F = 3.5 \times 9.81 \times \sin(30) = 3.5 \times 9.81 \times 0.5 = 17.16$ N (Master)

At θ = 30

$F = 2 \times 9.81 \times \sin(30) = 2 \times 9.81 \times 0.5 = 9.81$ N (Slave)

Total Force Required for Master : 17.16 N
Total Force Required for Slave : 9.81 N

4. Belt Velocity:

$$V = \frac{\pi D n}{60} \Rightarrow \frac{3.14 \times 0.035 \times 200}{60}$$

$$V = 0.3665 \text{ m/s}$$

Where,
v = velocity
D = Wheel Diameter = 0.035 m
n = motor speed = 200 RPM

5.Tension difference:

$$T1 - T2 = \frac{P}{V} \Rightarrow T1 - T2 = \frac{10.25}{0.3665} = 27.96 \quad \ldots(i)$$

Angle of inclination (θ)	Force required for Slave (Fs)	Force required for Master (Fm)
15	5.07 N	8.88 N
20	6.71 N	11.74 N
25	8.29 N	14.51 N
30	9.81 N	17.16 N
35	11.25 N	19.69 N

Table -1: Force Calculation for inclination condition for bots.

6.Belt Drive:

$$\frac{T1}{T2} = e^{\mu\theta}$$

Where,
μ = Coefficient of Friction = 0.4
θ = angle of contact
$T1$ = Tension of tight side
$T2$ = Tension of Slack side

Angle of Contact (θ) :

$$\theta = \pi - 2\sin^{-1}\left(\frac{70-70}{2 \times 100}\right)$$

$$\boldsymbol{\theta = 3.14 \text{ rad}}$$

$$\frac{T1}{T2} = e^{0.4 \times 3.14}$$

$$\frac{T1}{T2} = 3.5113 \Rightarrow T1 = T2(3.5113) \quad \ldots(ii)$$

Substituting equation (ii) in (i)

$$T2(3.5113) - T2 = 27.96$$

$$T2(3.5113 - 1) = 27.96$$

$$T2 = \frac{27.96}{(3.5113 - 1)} = \underline{11.1336} \text{ N}$$

∴ T1 = 11.1336 x 3.5113 = 39.09 N

7.Initial Tension:

$$T0 = \frac{T1 + T2}{2}$$

$$T0 = \frac{11.13 + 39.09}{2} = \underline{25.11\ N}$$

8. Required Vacuum Suction Pressure :

Minimum vacuum pressure for lifting sand and dust.

We need to keep the feasible suction pressure to maintain stability during the cleaning operation

Pv ≥ pgh

Pv ≥ 2600 x 9.81 x 0.005

Pv ≥ 127.53 Pa

Where,

Pv = Required Vacuum pressure

p = 2600 kg/m^3 (maximum density of dry sand)

g = 9.81(gravity)

h = 5 mm = 0.005m (assumed hight of nozzle from floor)

So required vacuum pressure should be more than 127.53 Pa. To efficiently lift the sand and dust we consider 1500 Pa of vacuum pressure.

9. Stability Check:

We need to keep the feasible suction pressure to maintain stability during the cleaning operation

Suction force (Fs) = Pv x Area of Nozzle

= 1500 x (0.06 x 0.21)

Fs = 18.9 N

10.Feasibility check to ensure the stability during the cleaning process:

Fr ≥ Fs

23.79 N ≥ 18.9 N

S0, Suction pressure is feasible enough to maintain the stability during the cleaning process.

11.Water pump Calculation:

i) Pressure drop at pump outlet:

ΔP = pgh

ΔP = 1000 x 9.81 x 0.03

ΔP = 0.294 KPa

Where,

P = Pressure

p = 1000 kg/m^3 = density of water

g = 9.81 = gravity

h = 0.06m x sin30 = pipe height (Lsin30)

14. Friction Force on viper:

- Wiper material: Rubber
- Weight of Wiper: 40-50gm

Ff = μN(Wg)

= 0.8 x 0.05 x 9.81

Ff = 0.39 N

Ff < Fs

∴ The required force of slave bot is much higher than viper's friction force, it could not oppose the motion of bot.

6. Swarm Intelligence –

Swarm intelligence is the main factor in this paper where the group of robots are integrated with each other. In this paper the group of robots is the Master & the Slave Robot. Swarm robotics is a part of multi-robotics where n number of robots coordinate and communicate with each other in a distributed and decentralized way to accomplish a common goal [3]. The Wi-Fi communication is the base of swarm intelligence where the controllers used in robots are prebuild with Wi-Fi module. The swarm intelligence here we are using IoT where each robot needs the node where the master node needs to replace node using, For displaying the intelligence behaviour among the swarm, a microprocessor for computing and processing the data is needed as a communication device that will establish communication and transfer the data [4].

As on solar panel cleaning is the working of robots, we are using two robots they need to integrate in swarm is established using the MAC address [4]. There are many types of Swarm Intelligence algorithm to apply in IoT such as Particle Swarm Optimization, Ant Colony Optimization, Cuckoo Search, Firefly Algorithm, Bat Algorithm, Artificial Bee Colony Algorithm [5]. We are using the algorithm for swarm intelligence is the Particle Swarm Optimization (PSO) is the algorithm based on the behaviour of birds like flock of birds, the algorithm was proposed by the Eberhart and Kennedy 1995 [6].

The Particle Swarm Optimization (PSO) algorithm with ROS2 in this paper will control the integration between the two robots. The algorithm in this paper will perform to optimize each position of the master and slave robot, where the master and slave are the particles as per PSO. The PSO will help for the position control of the robots (*x*,*y*). In the project we are using Lead Follower Approach (LFA) this helps the integration in between the master & slave to work in lead and follow to complete the solar panel cleaning task. Using Leader Follower Approach (LFA), one robot acts as a leader whose motion defines the path of the entire group. All follower robots will use the defined path to attain a certain goal or to achieve a defined task. Follower robots should position themselves in accordance with the position and orientation of the leader. The leader moves along an assigned trajectory and the followers maintains the desired distance and orientation with respect to the leader robot [7].

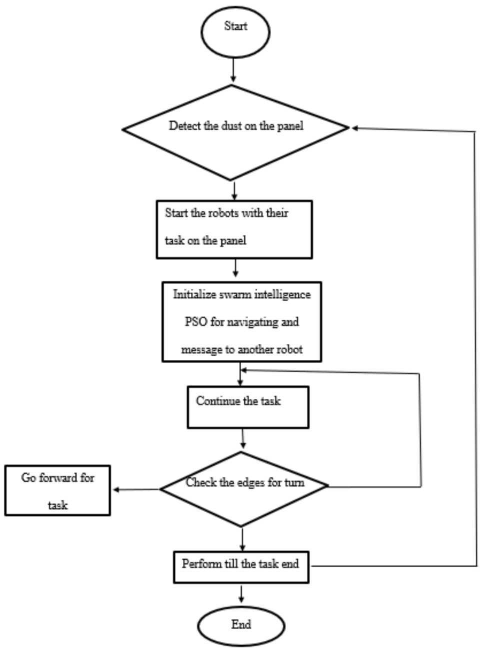

Fig -6: Flow chart of Algorithm.

The above flowchart represents both robots where the Leader-Follower Approach (LFA) is implemented, and tasks are performed accordingly. The Master and Slave robots are integrated with a Wi-Fi module to enable signal transmission, determining whether to move or stay idle.The start signal is sent through the GUI, where the "Start" prompt initiates the process and the "Stop" prompt halts it, returning the bots to their initial condition.

The "Update Position" function helps track the (X, Y) coordinates of the solar panel for detection. Edge detection is used by the Master to send a signal to the Slave to stop at the initial stage. At this point, the Master rotates while the Slave remains on hold. Once the Master completes the straight-line motion or turn, the Slave then begins its movement, turning at the edge detected earlier by the Master. The PSO will help for the position control of the robots (*x*,*y*). This can give the distance of the current position between two robots and also which area is remaining to clean the solar panel [8].

6. Testing Result –

Sr. No.	Testing Description	Required Result	Optimized Result
1.	Sprinkle Pressure of solution by Slave Bot.	0.294 KPa	0.276 KPa
2.	Suction Pressure of Master Bot.	>127.53 Pa	258 Pa
3.	Different Angle Test for Inclination of Solar Panel		
1.	15˚	5-8.8 N	5-7.3 N
2.	20˚	6.71-11.74 N	6.5-11.7 N
3.	25˚	8.29-14.51 N	8.29-14.5N
4.	30˚	9.81-17.16 N	9.9-17.1 N
5.	35˚	11.25-19.69	11.4-19.5 N

Table -2: Results & Validation Standard.

7. CONCLUSIONS

In this paper we have explained the solar panel cleaning robot in IoT for autonomous navigation. This paper is the human robot interaction where we made the robot which are now in the need to clean the energy generation plants. The robots are efficient to perform the solar panel cleaning autonomously with swarm intelligence to control the multiple robots. The operation of robots to clean the solar panel in autonomous mode is simulated in the IoT for achieving the required target by the robots.

REFERENCES

1. Shankar, S. S., Bande, M. B., Gore, S. A., & Sharma, M. O. (2019). Literature Review on Solar Panel Cleaning System. *International Journal of Research in Advent Technology*, Special Issue, Convergence 2019
2. https://faculty.ist.psu.edu/jjansen/academic/pubs/chi.html
3. Machaiah M.D, Akshay S (2019) IOT Based Human Search and Rescue Robot using Swarm Robotics. International Journal of Engineering and Advanced Technology (IJEAT), Volume-8 Issue-5.
4. Ayush K Agrawal & Jayendra Kumar (2024), Optimizing Master-Slave Communication in Collaborative Robotics Using IoT-Enabled Robot

Interaction, Indian Journal of Pure & Applied Physics, Vol 62.

5. Nguyen, L. V. (2024). Swarm Intelligence-Based Multi-Robotics: A Comprehensive Review. *Applied Mathematics*, 4(4), 1192-1210. https://doi.org/10.3390/appliedmath4040064
6. Quazi, I. A., & Chakraborty, P. (2022). Process Parameter Optimization in Friction Stir Spot Welding of High-Density Polyethylene Sheets Using GA, PSO, and ABC Algorithm. In *Recent Advances in Materials Technologies* (pp. 193-213). DOI: 10.1007/978-981-19-3895-5_15.
7. B Madhevan, M Sreekumar"

Indian Institute of Information Technology Design and Manufacturing (IIITD&M) Kancheepuram. Off Vandalur Kelambakkam Road. Melakottaiyur, Chennai-600127, INDIA

8. Wang, D., Tan, D., & Liu, L. (2017). Particle swarm optimization algorithm: an overview. *Soft Computing*, 21(2), 357-367. https://doi.org/10.1007/s00500-016-2474-6.