An Unveiling System to Clean Solar Panels with FPGA Based Robots

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Abstract

A new system has been proposed in this paper for cleaning the solar panels to improve the efficiency of solar energy. Solar energy is used to generate electricity which can be used for many appliances as it is directly available from sun. The solar PV modules are specially made in the outdoor environment where dust particles are common. The dust accumulates on to the solar panels through different sources and blocks the incident sunlight onto the module reducing transmittance; it results in reduction of power generation capacity of the module. As per analysis, the output power of the panel is reduced by 50% due to accumulated dust on panels for a period of one month. Labor based cleaning techniques are in lack of automation and expensive. This process consumes more time, water and energy usage. The proposed work is to improve the performance of solar grids by using cleaning methodology that includes simultaneous cleaning and wiping mechanisms. This design approach includes FPGA interfacing with IR sensors and motors to identify the accumulated dust particles on the path and perform cleaning-wiping mechanisms. A sprinkler followed by a wiper in the system performs panel-wise
cleaning in a simple and easy way. The solar panels are set with a four-bordered sliding frame that holds the entire FPGA setup. By programming this setup using Xilinx 2014.4, it cleans the panels and enhances efficiency of the grid with about 35% more energy output than the normal. **Key Words:** Solar photovoltaic (PV) panels, FPGA, Sensors

1 Introduction

Solar photovoltaic (PV) panels system subsists of solar cells for energy conversion from sun radiations into electricity, [1]. It is positioned in a open environment under the sun and connected to an inverter, to convert the DC energy received from sun into AC energy. Different types of PV cells are accessible, thick film silicon generally mono-crystalline silicon cells, multi crystalline silicon cells, and vague silicons [2]. Photovoltaic array installations found anywhere in world, like solar farms/parks with enormously high ratings. The life span of solar parks is up to 20 to 25 years, such panels require magnifying the power by producing potential in daily service [3].

The performance of solar PV panels will affect negatively due to accretion of dust particles on the surface, similarly as a cloudy day also affects their efficiency [4]. This shows the problem arises mainly in the dusty and arid environments. Thus, robotic cleaning solution is required to serve huge solar panels arrays around 22,000 panels [5].

Regular cleaning of the solar panels increases the efficiency. Several methods are use to clean the panels, Manual cleaning techniques are generally used, which requires labor to clean manually by using of bucket, sponge, mop, non-scratching brush and wiper etc. It is difficult to clean by standing on ladder and climbing on roof, It is expensive in terms of cost and labors [6]. Authors in [7] have been developed autonomous navigation algorithms for floor cleaning using FPGAs. Path planning for autonomous navigation and sensing mechanisms using FPGAs are developed by authors in [8,9,10].
2 LITERATURE SURVEY

Ridha Azaiz et al introduces [11] Solar brush, to clean solar panels in a non-wet environment by using tracks made up of suction cups, the movement of cups over the panels making feasible to cross space up to 30mm and functioning on surfaces tilted up to 35 degrees. Various kinds of brushes integrated in front of the robot and also rechargeable battery is used to generate power. The advantage is small in size, Autonomous in nature and this robot require operator and safety rope to work on tilted panels, expensive and batteries should be reloaded. In sandy and dry environment, Ecoppia E4 [12] autonomous robot consist of Microfiber brushes which is used to sweep dust on enormous rows of solar panels. The sliding movement of brush depends upon gravity and generates airflow to sweep the dust. During night, robot utilize battery and onboard solar panel to store energy which allows cleaning the dust, this type of robot is used only large arrays and lot of construction is needed. Wash Panel [13] company produces robots which clean the PV panels by moving a brush horizontally over a row of solar panels. The length of the brush is 1 to 16 meters and comprise a 12V battery which is deployed automatically. To wet the panels, water tube is appended to it, this robot is used to clean one row of panel at a time and it is a custom made product.

To clean the solar panels in dried area sprinkler [14] systems are used which gives same effect as rainfall and relatively low cost. The disadvantages is huge water is required to clean the panels several times in a day. Because of this the system becomes trickier for the sprinkler to eliminate soiling when it is affected from dust.

Jawale et al [15] introduces human movable automatic cleaning system called Bot cleaning for solar panels arrays with the help of microcontroller board, cleaning can done by moving Bot from horizontal to vertical on the glass surfaces. Shahzada Pamil Ali et al [16] developed four stage automatic dry cleaning systems which is an electromechanical device. The system consist of compressed air spray, foam roller and poly wool synthetic cluster. Initially it checks the level of humidity, if satisfies then it starts working. It is specially meant for dried areas. Nasir k. Memom

Et al [17] used Robot control operating system (ROS) and Virtual Robot Experimentation Platform (V-REP) to model automatic
vehicle to clean the solar panels. The proposed work is designed using FPGA based robot for implementation of Autonomous hardware system to clean the solar panels. This system enhances the efficiency and life span of the solar panels. It will be useful especially in solar panel commissions over larger areas where manual cleaning is difficult.

3 PROPOSED ALGORITHM

A. Control Unit
The proposed system subsists of three units i.e. Input unit, Control unit and Output unit. The input unit collects data from the external environment and gives it to the control unit for further processing. The collected information is analyzed through processing module which includes positional information, edge detection and decision making algorithm. The analyzed information from the processing module and then it is given to the navigation module for the mobility of robot. The output unit includes actuators which moves the robot in the desired direction based on processed data, from control unit.

![Figure: 3.1 Block Diagram of Control Unit](image)

In this system, IR sensors are used to detect the positional information of robot on the solar panels. The output of the sensors is processed to control unit along with the clock signal. The data from sensors is given to the processing module which consists of three blocks. The processing module identifies the exact positional information of the robot using a predefined algorithm, which is programmed to the controller. The edge detection algorithm in the
controller detects the edges on the solar panel array. This information is used by the decision making module for the movement of robot. The Navigation module gives the instructions to the robot for moving either in forward or backward motion based on the signal received from decision making module. The execution module i.e., a motor driver acts as an interface between the controller and the actuators. Based on the signals received from the execution unit, motors drive accordingly for cleaning of panels. These motors are responsible for the movement and accurate cleaning of the entire Solar panel array.

B. Process Flow

Control unit works as heart of the system which includes FPGA, it synchronize between sensor information and motors. The consequence of data movements through different sub-units inside the control unit are well explained in flow chart. The operation of control unit i.e., the process flow is as shown in Figure 3.2.

![Flow Chart of Control unit](image)

Figure: 3.2 Flow Chart of Control unit

Initially, the robot is present at the docking station. The positional information of robot on the solar panel array is collected through IR sensors. The IR sensors detect the panel and send the information to the decision making module. Based on the processed
signals, the navigation module tells the robot to move either in forward or backward direction.

- **Forward Movement**: The Robot moves in the forward direction until it reaches the other edge of the solar panel array.
- **Backward Movement**: The Robot moves in the backward direction when an edge is detected by the IR sensors. The backward movement continues till the robot reaches the docking station.
- **When robot reaches the docking station, the process gets stopped.** If the robot does not reach the docking station, it goes back to the navigation module where the process continues as far as the above procedure is concerned.

### C. State diagram

The state diagram consists of four states:

- **IDLE**: In this state, the Robot will not move in any direction. It will stay, until there is any change in the control variables such as enable and reset.
- **FORWARD**: In the forward state, the Robot checks all the control variables such as values from IR sensors enable and reset. It moves in the forward direction until an edge is detected.
- **REVERSE**: When the robot reaches the other end of the panel, it has to trace back to its initial docking position for charging the Robot. The robot moves in the backward direction until it is in the Reverse state.

![State diagram of Control unit](image)

- **STOP**: After cleaning the entire solar panel array, it reaches the docking station where it has to be charged. When Enable pin is switched off, it goes back to the idle state.
• **ENABLE:** Enable acts as a normal switch which is used to Start and Stop the process flow.
• **RESET:** It is used to reset the entire process flow by telling the processor to start the process from Idle state, no matter in which state it was at that point of clock cycle.

### 4 HARDWARE DESIGN FOR PROPOSED ALGORITHM USING FPGA

The robot consists of an iron frame sliding over a channel attached at the border of the solar panel to clean every angle and corner of it. The iron frame is selected for its stability in holding the brushes and motors; it has an advantage over plastic and fiber that are light weighted to hold the vehicle. Also, due to its strength, brushes are stabilized with perfect placement and rotation, which helps in cleaning the panel effectively.

![Figure: 4.1 Hardware Module of the robot](image)

The hardware design consists of following three systems. They are Cleaning system, Driving System and Control System.

**A. Cleaning System**

Cleaning system has the component like sprinkler, brushes and wiper which deal with cleaning aspects of the solar panel array.

**i. Water Sprinkler**

The water is poured into the bottle tube of the sprinkler; then water is split into small water drops through the holes of the tube, which fall on the surface of the panel. It is shown in the below Figure 4.2
ii. Brush
Plastic brush is used with high density of smooth bristles to clean the dust and to remove even fine particles on the panel. It is shown in below Figure 4.3

iii. Wiper
The wiper is used to clear off the water and the dust cleared by the brushes and is attached at the rear end of the robot.  

B. Driving System
Driving system helps the robot to move in forward and backward direction.

i. Channel
The steel channel is preferred for the wheels of the robot to slide on them and to have a good grip for the wheels and also to bear the weight of the frame perfectly. The channel is presented in the below Figure 4.4.
ii. DC Motors
The geared DC motors are used for the rotation of wheels and helps in increasing torque. For brushes, motors are used with 300 rpm for fine and rapid cleaning.

iii. Motor Driver
A motor driver is used to convert low-current control signal to a higher-current control signal which help to drive a motor.

![Motor Driving circuit](image)

Figure 4.5: Motor Driving circuit

C. Control system

The function of the control system is to give commands to the motors of wheels and brushes. It is the central intelligence which holds the algorithm developed for the robot. The IR Sensor is placed vertical slide facing the solar panel. If there is no acknowledged signal or delay in signal, it means that are on the edge of the array and need to travel back to the docking station. Driving system helps the robot to move in forward and backward direction.

![IR sensor](image)

Figure 4.6: IR sensor

5 Results

A. Simulation Results
The proposed algorithm is verified in a feasible manner as shown in the below simulation Figure. The simulation result describes the movement of the DC Motor and the IR Sensors which helps to design hardware prototype of Automatic solar panel Cleaning Robot.
In the above simulation results, it shows the state transformation and movement of robots in all conditions. At 6.223ns, the sensor information is 01 which indicates the position of robot is at edge of solar panel and it takes the appropriate sliding to right direction and moves backward direction.

B. Hardware result

The robot travels according to the sensor inputs form IR sensors as shown in Figure 5.2. The robot initially starts at the docking station where the front and back IR sensors read value 0, meaning the robot is out of the solar panel.

When the robot starts from the docking station and enters the solar panel and moves in forward direction i.e., the back and front sensors read 0 and 1 respectively. It means the robot entered the area of solar panel. In its journey, the back and front sensors will read 1 and 1 when the robot is completely on the panel as shown in Figure 5.3. The robot continues to move in the forward direction.
The robot moves forward till an edge is detected i.e., back sensor = 1 and front sensor = 0 which is shown in Figure 5.3. When these values are read, the robot starts moving in backward direction towards the docking station.

When the robot reaches the docking station again, the task is completed. The robot does the cleaning during its journey on the solar panel.

6 FPGA IMPLEMENTATION

The FPGA Robot is developed with IR sensors, DC motors with driving circuits. The VLSI design to clean solar panel algorithm has been coded in Xilinx 2014.4. The design was implemented on XC3S500E Xilinx FPGA board. It consumes less power for computation than a PC/Laptop.
7 CONCLUSION AND FUTURE WORK

The proposed design methodology includes FPGA interfacing with IR sensors and motors in order to identify the accumulated dust particles on the path and perform cleaning-wiping mechanisms. A sprinkler followed by a wiper in the system performs panel-wise cleaning in a simple and easy way. The solar panels are set with a four-bordered sliding frame that holds the entire FPGA setup. By programming this setup using software tools, it cleans the panels and increases the efficiency of the grid with about 35% more energy output than the normal. Also, the proposed system is of low cost with high efficiency.

The future scope is to enhance the degrees of freedom and stability for the robot so that it can clean more effectively. The robot shall be connected to Internet of Things (IoT) for its operation from the control room/anywhere. The whole objective is to make sure that, at any point of given time window, the robot should make sure no dust is present.

References


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