Design of a Pneumatic Robotic Arm for Solar Cell Tester System by Using PLC Controller

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Abstract

Solar cell testers sort photovoltaic cells according to their electrical performance, tested under simulated sunlight. A variety of testers exist, but they all face a common challenge of handling cells that are very small and thin, which makes it difficult to transport the cells from the conveyer to the storage box. This paper presents a new design for a handling robot with vacuum end-effectors, which uses a PLC controller to govern the movement of the cells and the testing process. The design applies to solar cell testers for monocrystalline, polycrystalline, cadmium telluride (CdTe), and copper indium diselenide (CIS) cells. Each cell is tested for efficiency and categorized accordingly into four groups (A to D). A Virtual Reality (VR) model was built to simulate the system, keeping in mind real world constraints. Two photoelectric sensors were used to make detections for both the testing process and the robot movement. The PLC controller guides the trajectory of the robot according to the results of the efficiency testing. It was seen that the system worked very well, with the testing process and the robot movement interacting smoothly. The robot trajectory was seen to be highly accurate, and the pick and place operations were done with great precision.

Keywords: *Handling robot, Solar cell tester, Virtual reality, photoelectric sensor.*

1. Introduction

The testing of solar cells both in the laboratory and for commercial uses, solar simulators are used. The simulators employ a single light such as that from a xenon arc lamp to produce a beam of collimated light that matches a reference solar spectrum. Despite some advantageous features for simulating a solar spectrum, the beam from a xenon arc lamp cannot be directly used. This is firstly because a considerable spectral range, especially between 0.8m and 1.2m, is covered in the emission lines of the lamp output. Secondly, the richness of the Ultraviolet (UV) region in the lamp output is an issue. To get around this problem, there are proprietary notch filters that decrease IR and UV components of the output, which is why many types of optical filters are required to obtain a useful spectrum. A water cavity is sometimes used to enhance spectral matching. Still, a number of disadvantages of the xenon lamp remain [1- 6]:

(i) The wavelength of the peak of the solar spectrum and the xenon spectrum do not coincide.
(ii) Intense emission lines remain in the output.
(iii) The liquid water cavity's absorption spectrum and that of the water vapor are not the same.

A cheap alternative to generating solar electric power are Silicon-Film solar cells. The production systems of Silicon-Film use a continuous in-line process to produce polycrystalline silicon sheets. The Apex sheet growth process has continuously progressed and after five design generations, one sheet can give an annual yield of over 15 MW of 200-mm wide polycrystalline silicon sheet, which is used to make large-area APx-8 solar cells. These cells generate over 4 W each and have edge dimensions of 208mm x 208mm. Parallel process systems are often used to increase the volume of solar cells manufactured. However, with modern large-area Apex sheet generation approaches and the development of solar cell process tools, single-thread process systems can be used to design large volume production lines for solar cells [7-11].

The greatest verified efficiencies for a number of photovoltaic cell and module technologies is regularly recorded in many references. The information has helped researchers stay aware of the state of the art and to document their own independent findings in a standardized manner. All results have to be verified by a recognized test center before they are included in the tables [12-16].

There are three significant areas relevant to each photovoltaic device: designed illumination area, aperture area and total area. The efficiencies of the 'active area' are excluded. Depending on the type of device, a particular

minimum area is an important parameter (800 cm^2 for modules, over 0.05 cm^2 for concentrator cells and 1 cm^2 for one-sun cells). Cells and modules can be made from a variety of semiconductors. Also, each semiconductor can be further categorized into different types (such as thin film, crystalline and polycrystalline). By provides spectral information with plotting the external quantum efficiency (EQE) against the wavelength, with normalization done to the peak measured value [16-19].
Recent years have seen a dramatic increase in the solar industry, due to which solar cell and module test solutions are widely sought after. The solar cell modules are generally of two types: comprehensive turnkey solutions and test-system building blocks that must be assembled. The former are easy to set up but expensive. Furthermore, the technology used in the turn-key solution is likely to become outdated quickly, thus requiring an upgrade. With building blocks though, the system is more reasonably priced and is easily modified when required. If there is a need to upgrade to a higher current range or accuracy, only one relevant block would need to be replaced. Also, sets of blocks that are useful for a variety of platforms can be standardized and reused [20,21].
Many automotive facilities are used in the solar cell manufacturing process for mass production. In thin film solar cell production especially, a key task is to handle large size solar cell substrates like the LCD production system. Robots like the serial manipulator, beam type and link type robot can be used to handle the large substrate. A variety of handling robots have been developed over the years for the manufacturing line for solar cells. With an increase in the size of the substrate, vibration control and dynamic analysis assumes greater importance. Since the weight of the solar cell substrate is at least three times more than the LCD glass substrate, the position control needs to be precise, especially considering the vibration of the substrate and forks. The motion analysis of the beam type handling robot using Matlab/ SimMechanics was performed by the authors in a previous research [22 - 24].
In this paper, the design and analysis of a handling robot to transfer solar cells from the surface of the conveyer to four main boxes is proposed, with special consideration of the percentage of efficiency. The paper is divided as follows: Section I is the introduction. Section II explains the problem formulation. Section V presents the design of a prototype by VR. Section IV describes the design of the controller. Section V explains the simulation of design with VR and finally conclusion.

2. Problem formulation

A solar cell tester designed previously at University Malaya's Power Energy Dedicated Advanced Centre (UMPEDAC) was used in this work. The structure of the tester is illustrated in Fig. 1. The tester moves the cells upon the conveyer till it enters the texting box. The entry is detected by a photoelectric sensor, after which the tester box commences work. Each solar cell undergoes a testing process of 2.5 sec duration. Based on the test results, the solar cells are divided into four groups.

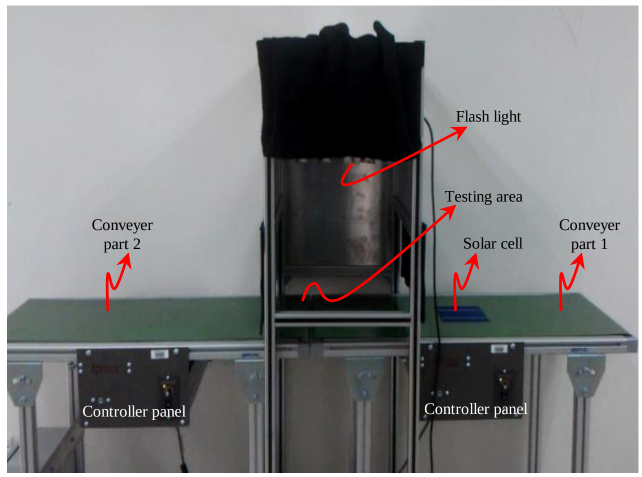

Fig. 1. Real solar cell tester

The tester calculates efficiency values of the solar cells in series, which are used to determine the appropriate box the cells are to be placed in. The robot design thus has two main objectives: to pick the solar cells from the conveyer and place them in the suitable box corresponding to the efficiency value.

3. Design Robot Arm

The robot is designed in two main phases. In the first phase, the robot is designed in a VR environment and the controller performance is tested in simulation. VRLM software was used for the design.The 'classical objects' feature in the software was used to create the preliminary design. The objects were then redrawn using the indexed-face option to obtain the advanced design. Fig. 2 illustrates the design of the robot arm in VR.
To design and simulate the movement of the robot, a trajectory was set for the robot after a number of trials. The trajectory advances in three stages (Fig. 3): first, the cell is handled and moved vertically up to a specified point; second, the cell is moved horizontally to a certain point and finally the cell is lowered vertically to box A, B, C or

D. The robot needs to complete this trajectory in 30 sec. Due to the thin construction of the solar cell and light weight (20 gm), it is quite difficult to pick the cells from the conveyer.

To ensure that each part of the robot was best suited to its job, a number of robot designs were tested in simulation. For picking the cells from the conveyer (which requires accurately capturing them through the conveyer trajectory) and placing the cells in the appropriate box, the vacuum technique was used. Two vacuum grippers were used for this purpose, as is shown in Fig. 3.

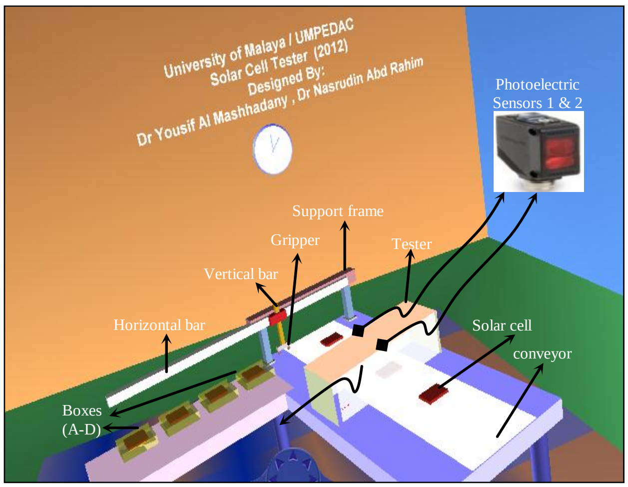

Fig.2. Design robot arm in VR environment

Fig. 3. Suction grippers of robot

For high speed up-down vertical movement, the electric cylinder DNCE with a mechanical linear axis and piston rod was selected (Fig. 4). The cylinder has low weight and fast response. The drive component consists of an electrically driven spindle, which converts the rotary motion of the motor into the linear motion of the piston rod. The mechanical interfaces are largely compatible with the standard cylinder DNC.

The power electronics with positioning controller were designed as an external field device (IP54). Speed, power and position can be set independently of each other and up to 31 travel profiles can be stored. The positioning controller is suitable for stand-alone operation or can be externally controlled via an I/O interface or fieldbus. The movement of the robot in horizontal direction is achieved using the electric toothed belt axis, drive axis (for applications with external guide or for easy handling tasks), plain-bearing guide, toothed belt covered by a steel band and a flexible motor mounting on all 4 sides of the axis. The arrangement provides high feed forces, with speeds up to 5 m/s and acceleration of 50 m/s^2. It also features space-saving position sensing with proximity sensors in the profile slot suitable for electric axis EGC with a recirculating ball bearing guide (Fig.5). All the different parts are assembled virtually and reconstructed in one frame to achieve the complete robot shown in Fig. 6.

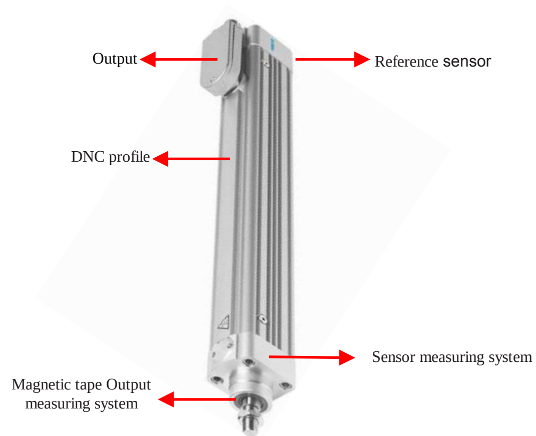

Fig. 4. The electric cylinder DNCE is a mechanical linear axis with piston

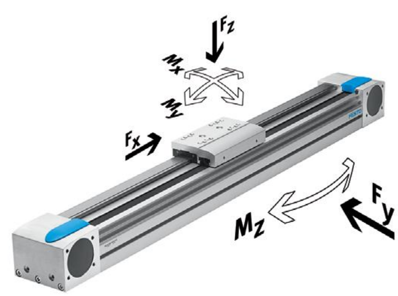

Fig. 5. Electric toothed belt axis

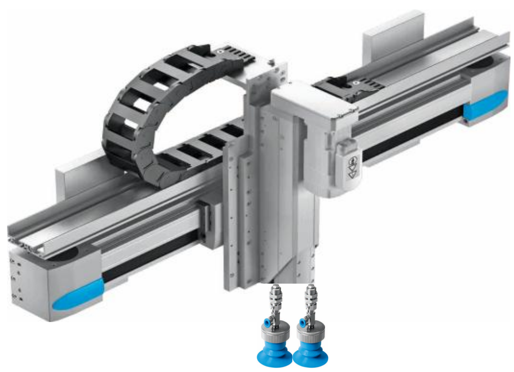

Fig. 6. The overall form of robot design.

Program interfaces made by Festo were used to select the suitable parts of the robot. In the program, application parameters such as mounting position, mass, stroke and precision are input and the required process time is specified. The drive technology can also be preselected. The required solution package is selected, which are sorted by motor and axis technology, component utilization, cycle time or price. The program also provides detailed results such as motor characteristic curve, dynamic characteristic values, system data, product data, and parts list.

4. Controller Design and simulation of solar cell tester

The solar cell tester consists of three main parts: the tester, conveyer and handling robot. Each part requires its own control strategy. The controller has to both determine the working of each part in stand-alone mode and also govern the interaction of the different parts of the tester. Taking the environment of the tester into consideration and the variety of signals that need to handled, a PLC controller was seen as a suitable option to create the controller. Two photoelectric sensors are used; one detects the entry of the solar cell into the testing area (which turns on the tester flash) and the other to detect the movement of the robot to start the handling operation. The duration of robot operation for each cell, from picking the cell and returning to the initial position, is 10 sec. The time for testing each cell and obtaining the efficiency value is 10 sec. The rate of testing for the system is thus 360 cells/hour.

The block diagram of the testing process is shown in Fig.7. The block diagram used for VR simulation is shown in Fig.8. The diagram shows the blocks used for implementing all the steps of the tester: movement of the cells on the conveyer, working of the flash lamp, measurement of efficiency and the handling operation of the robot (vertical and horizontal movements, capture and release of solar cells at the right locations).

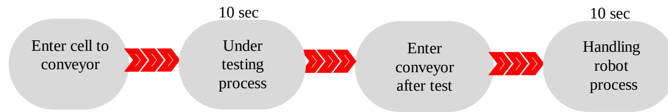

Fig. 7. Block diagram of testing process.

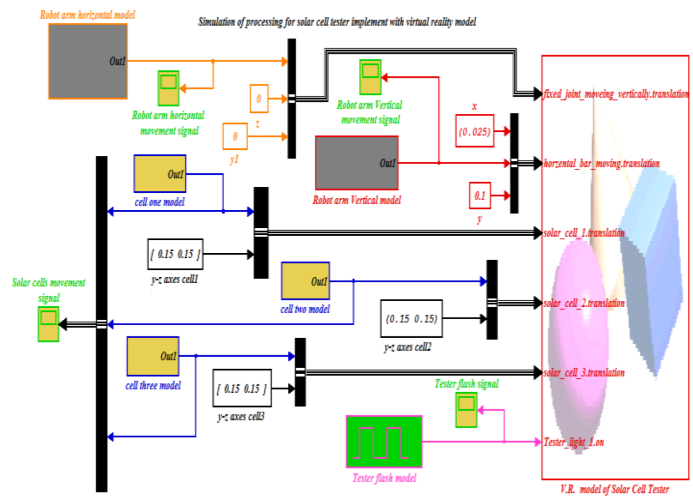

Fig. 8. Simulation of solar cell tester in V. R. environment

5. Simulation Result

The simulation of the design was achieved by using Matlab Ver. 2012a with VR environment to implement the movement of system by interfacing with Matlab/Simulink. Fig.9 presents the simulation results by using oscilloscope display of the control signal for each part of the solar cell tester.

The operation of the cell testing system commences with the movement of the solar cell upon the conveyer. Scope (a) in Fig.9 shows the movement signal for three cells. As is evident from the signal, the sequence repeats after every 50 sec. After 10 sec, the first cell arrives at the tester and the flash tester turns on and off for 5 seconds each. The sequence is then repeated for the second cell (as is clear from the tester flash signal in scope (b) of Fig.9). After 25 sec, the first cell arrives at the capture point to be picked by the gripper of the robot. The down-up signal for the gripper is shown in scope (c) in Fig.9. The horizontal movement of the robot depends on the efficiency of the cell calculated by the tester. Depending on the box number that the cell is to be placed in, the amplitude of the horizontal movement signal (scope (d) of Fig.9) is limited. The duration of one cycle, from passing the entry point to being placed in a box is 50 sec. The output of the virtual model that simulates the movement is shown in Fig. 10.

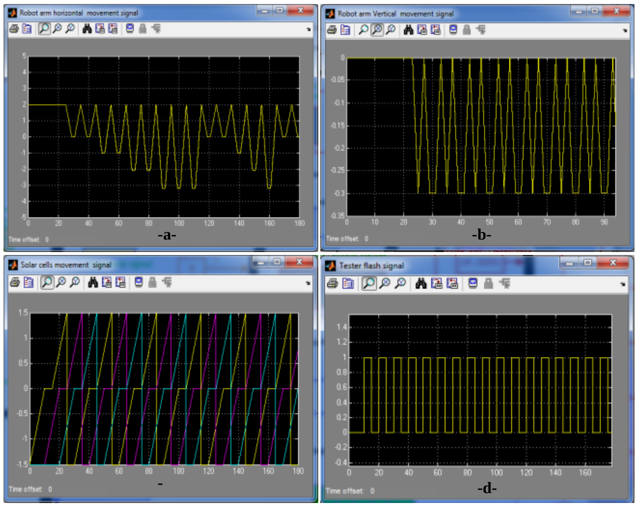

Fig. 9. (a) Robot arm horizontal movement signal. (b) Robot arm vertical movement signal. (c) Solar cells movement signal. (d) Tester flash signal.

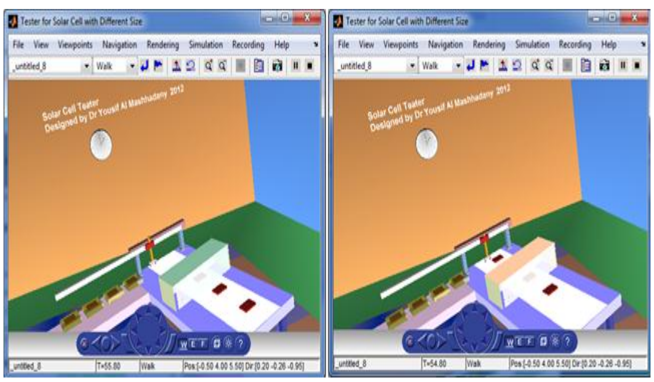

Fig. 10. Implement solar cell tester in V.R. model.

6. Conclusion

In this work, the design of a handling robot with vacuum end-effectors was created to sort solar cells according to their electrical performance. A PLC was used as the controller. The motion of the robot and the testing process were controlled based on detections by photoelectric sensors. The cells were allotted to suitable boxes based on their efficiencies. A highly accurate robot trajectory was obtained, coupled with very accurate position control for placing the cells inside the boxes. Excellent performance is obtained in the simulation of the tester in a V. R. model. The photoelectric sensors were seen to be very effective for detection of cell entry and robot movement. Future works can investigate other designs for the robot and look into different methods of controlling the robot trajectory.

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