A SURVEY ON SOLAR CELL; THE ROLE OF SOLAR CELL IN ROBOTICS AND ROBOTICS APPLICATION IN SOLAR CELL INDUSTRY

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Abstract. The solar cell technology has been massively developed and applied as a substitute to exhaustible or nonrenewal energy since 1767. The unlimited energy produced by solar cell can be very useful to robot application where battery life-time is an issue, such as in space or even for agricultural industry where the robot deployed a day long and long-life-self-rechargeable battery will be such an advantage. Indonesia as a country blessed with abundant sunlight should apply more solar cell technology in robotics application. The other side of this solar cell industry is that robotics technology is also applied in the making of solar cell. By employing robot instead of human, the fastness and accuracy of solar cell production are more guaranteed. Last but not least, the application of robot in solar cell is also the deployment of mobile robot to do maintenance in solar cell farm, such as for automatic cleaning of solar cell surface. This paper discusses the interesting relationship between the solar cell and robotics technology by reviewing the articles in solar cell technology related to robotics.

Keywords**:** Automation Technology, Robotics, Solar Cell, Survey Article.

I. INTRODUCTION

Sunlight has been utilized to support human daily life from long time ago, around 7th century BC where people used magnifying glass to concentrate sun's ray to make fire for cooking. This practice kept on continuing for centuries and other sunlight utilization was only limited to simple daily life activity, such as to lighten up a room.

The milestones of sunlight role in human life started in 1767 when Swiss scientist Horace de Saussure built the first sun collector, although this first solar cell application was only limited to domestic application. Even though in 1816, Robert Stirling registered a patent for his solar thermal electricity engine that can concentrate sun's ray thermal to produce electric power. But it was not until year 1839; Edmond Becquerel from France discovered the photovoltaic effect that became the basic concept of solar cell technology. Since then the solar cell technology improved very fast and many leading scientists took the role in developing this promising technology, such as Albert Einstein in 1905 published his paper on the photoelectric effect [1].

The application of solar cell in space was initiated by William Cherry, from U.S. Signal Corps Laboratories by approaching RCA Labs' Paul Rappaport and Joseph Loferski. But not until 1958, Vanguard I space satellite used a small solar cell to power its radio. This little small solar cell became the beginning of widely used solar cell in space. An architect named Frank Bridgers created the first commercial building that utilized solar cell as for water heating, however not until year 2000, solar cell became a mass production for everyone to enjoy and the house started to used its own electricity rather that depended on government electric supply [2].

This paper reviews and discusses the interesting relation between solar cell and robotics world by studying and citing the articles in solar cell and robotics application related papers. We would like to show that both improvements in these two fields will give a great contribution to better living and clean earth trough the renewable clean energy of solar cell and the automatic world provided by robotics.

II. THE ROLE OF SOLAR CELL IN ROBOTICS TECHNOLOGY

Robotics like many electronics devices require a large amount of power source, defending on the size and the length of its applications. The traditional way of powering robot is by installing battery or directly plugging to the electricity. The roboticists have to think and design another method of power source; instead of rely on traditional non-renewable energy. Solar power is one of renewable energies that have a bright future in robotics. Robots with continuous application would be greatly helped with the

continuous clean power source, and not to mention the solar technology is getting cheaper nowadays.

Everyday new idea of how to implement the solar panel on robot has been emerging out, for example in 2013, a team of professors and student at the University of Maryland had created the first robotics bird that flied with solar power. They called the robot "Robo Raven III" whose batteries were automatically charged by on board solar cells. The wings of the robots consisted of solar panels therefore as if the robot feeding itself.

Jalbertet. al. [3] designed a solar-powered autonomous underwater vehicle in 2003. The project was conducted by Falmouth Scientific, Inc. (FSI) in cooperation with the Autonomous Undersea System Institute (AUSI) and Technology System Inc. (TSI) to develop a long-time deployment and station-keeping duties. They developed a vehicle that allowed solar cell on-station recharging system. The Solar Powered Autonomous Underwater Vehicle II (SAUV II) was designed for long-continuous deployment therefore a self-recharging system was required. It would come to surface to recharge and to communicate via Iridium satellite or RF communication data to upload the collected data and also allowed reprogramming of mission profiles. The SAUV II battery system provides a total capacity of about 1500 whrs. This high rechargeable battery made the application of SAUV II for long-continuous time was possible with solar panel recharging at sea and gas gauge monitoring of battery system. The control software implemented PID control loop which operating in several modes. There were two Li-Ion battery packs connected in parallel as a single battery, 1056 each. The system was also included battery management, safety circuitry charge equalization, charger and solar panel interface and provision for gas gauge monitoring of battery capacity. The energy management microprocessor interfaces with the battery system. To ensure the system was working well, SAUV II had a reliable navigation system that could navigate the vehicle from one location to another without the assistance of the mission manager [3].

Still from 2003, Hollaret. al. [4] created a 10.2 mg silicon two-legged micro-robot powered by solar. This is the first reported autonomous solar power legged micro-robot. This robot consisted of three chips, one for robot's motor and legs, one for solar cells and high voltage buffer and the other one is for CMOS circuitry for sequencing the leg. The solar cell installed in this robot generated over 100μW of power under solar illumination. This robot could be a pioneer for a swarm ant-robots powered by solar [4].

Lever et. al. [5] introduced the Cool Robot in 2006, a four-wheeled drive solar-power autonomous vehicle to support summertime science campaign in Antarctica and Greenland. The robot drove continuously at 0.78 m/s^2 and its demand power of 160 W was given by solar power. The Cool Robot had a five-sided box of solar panels, 54-cell each side, surrounded the chassis and produced about 240 W of electricity when the sun is 15^O above the horizon. The power was not only derived directly from the sun rays but also from the reflected light from the snowfield. The Cool Robot successfully deployed at summer camp over snow in Antarctica [5].

In 2008, Takahashi et. al[6], designed a hybrid robotic wheelchair with photovoltaic solar cell and fuel cell that was presented in international conference of control, automation and system in Korea. The hybrid wheelchair was powered by three energy sources, a battery, a photovoltaic solar cell, and a hydrogen fuel cell. Each of those sources has its own advantages, for photovoltaic solar cell, it used as energy alternative of fossil fuel. A cascade connection of two solar panels of 17.4 V and 43 W is used to cultivate the solar energy, and it used DC-DC converter to reduce up to 24V. This wheelchair was designed to be able to automatically change its energy sources based on optimal condition. However, the usage of three energy source in one wheelchair might be too much and too heavy for it, but the idea is that we can have three different sources and not only dependent on electricity [6].

Anderson et. al. [7], in 2011, developed DEG (Dielectric Elastomer Generator) that was used with SPC (Self-Priming Circuit) to supply an artificial muscle system. The SPC can be started using a solar cell array. This study used a series of 12 photovoltaic cells (Sanyo AM-1437 amorphous solar cell) for the initial charge about 30 V [7].

From the list of solar power robots, we can see that the application of solar cell in robotics promise a bright future, moreover for the robots that are applied around the clock.

III. Robotics Application In Solar CellIndustry

The demand for solar panels is getting higher and for that we need a system with accuracy and continuously working without fatigue. Robotics is the answer for that. By applying robots in solar cell industry, the production is getting higher with better quality.

As the solar cell manufacturing automation demand is getting higher and robotics technology is part of the production system, it is crucial to consider the condition and the types of the robots give the best match for this industry. There are some factors need to be considered such as the kinematics, dynamics, control system, and sensors to create an almost ideal robots.

The robots employment in solar cell industry is also significantly reduces the cost production of solar cell, because more cells can be produced in shorter time rather than employing manual worker, for example Momo, the robot developed by German engineer Bernd Brodbeck and KeinerMaschinenbau, a manufacturer of automated industrial system. Momo can easily pickup large solar cells and put them on mounting racks, thanks to id 3D camera, it has good eyes. However, we believe although many works can be easily adapted and done by the robots, this industry still needs lots of human labour due to not all the processes can be done by the robots, such on quality control or design.

A handful of considerations have to take in selecting the correct robot for your photovoltaic industry. The first and most important is what kind of payload required for your robot. The thought has to start from how the product being handled and the type of end effector of robot manipulator. The roboticists also have to evaluate the motion requirement of the robot in production system, for example a simple

motion of picking and placing, how the robots interfere each other, the type of links and all other things that might come into contact with the photovoltaic cell. The robots will works around the clock producing the products, therefore the robot designers also have to design how repeatable, accurate, the robot be and where the robots will be placed in manufacture plant.

Yuexinet. al. [8] designed a robot to manufacture space solar cell array. The application of robot would enhance the development of space industry more than only employing manual worker. The robot consisted of the mechanism of dispensing and auto-laydown, a pneumatic system, and a control system. The researchers derived the prediction model for adhesive dispensing therefore the problems resulting from manual work such as control of adhesive section could be avoided thoroughly [8].

Park et. al. [9] modelled a beam type solar robot to handle solar cell substrate. This research objective was to decrease the deflection and the vibration of the robot end-effector in the substrate handling technology. The proposed method gave good result in both simulation and experiment [9].

Cho et. al. [10] modelled a large scale solar cell handing robot with belt driven flexible arms. The full model of large scale solar cell panel handling with a flexible fork model and belt drive system had been designed where the parameters have been adjusted to match the simulation result with experimental results. The researchers was successfully reproduced the vibratory behaviour similar to the actual system [10].

Chaïbet. al. [11] employed a robot manipulator to adjust the orientation and positioning of solar panel. By employing a robot manipulator instead of manual work, the amount of collected sun rays was increased. The robot was designed and a controller was model to get best outcome. The sun position at anytime and anywhere were predicted by MATLAB software. The result of the experiment was validated by comparing them with data obtained by PVSYST software. Four situation tests have been performed: panel tilted at 0°, panel tilted at 30 one axis tracking and finally the two axes tracking cases with a robot controlling a solar PV panel. The application has been done for Algiers. A gain about 34% in terms of solar energy yield compared to fixed panel case has been obtained [11].

Cammarata[12] also created an optimized design of a large-workspace 2-DOF parallel robot for solar tracking system. The researcher proposed a parallel kinematic machine of type U-2PUS that was optimized to get a large workspace to follow sun motion all year long. In this study, the singularity avoidance and link/join collision was only discussed to get an optimized system that could operate at latitudes among 0^{O} and 50^{O}. On top of that the design consideration and vibration analysis were also discussed. To evaluate the system performance, an energy assessment with respect to other solutions based on fixed solar panels was also included [12].

Testing the product is also one of most important step in production. Al. Mashhadanyet. al. [13] simulated a design of pneumatic arm robot for solar cell tester system by utilizing PLC controller. A virtual reality model was built to simulate the system and considered the real world's constraint. This system used two photoelectric sensors to detect both the testing process and the robot motion. The simulation results showed an accurate trajectory of the robot and the good performance was obtained [13].

Robots are also taken a very crucial rule in maintenance of installed solar panel. Periodic cleaning is very important to ensure the sustainability of the solar panel. The power output generated by photovoltaic panels is known to suffer power efficiency loses over time due to the accumulation of dust and other dirt on the surface of the panels. And as the growth of solar cell panel use increased and so did the need for maintenance and cleaning. For limited numbers of solar panels, human labours might be able to do it, however in the large areas of solar cell farm, the application of robotics will be the most appropriate. Below are the examples of robot that applied as the automatic cleaner of solar panel surfaces.

Anderson et. al. [14] presented the first robotized cleaning device for photovoltaic panels, and they called the robot, the PVCleaner Robot V1.0. The robot consisted of a cleaning head that moved over the panels, and robot's auxiliary equipment for power and water supply. The cleaning head was driven vertically by cables and horizontally by pair of motorized drive trolleys which ride along the top and bottom edges of the array panels. The drive system consisted of top and bottom trolleys with 12 V DC motor to provide lateral motion and four inductive proximity sensors on the trolley frame to detect the edge of the panel and slow the motion for crossing the gap or stop when reaching the end of arrays. This was a big step to the automation of photovoltaic panels maintenance system [14].

IV. CONCLUSION

Sunlight has been utilized to support human daily life from around 7th century BC where people used magnifying glass to concentrate sun's ray to make fire for cooking. In 1839, Edmond Becquerel from discovered the photovoltaic effect that became the basic concept of solar cell technology. Since then the solar cell technology improved very fast and many leading scientists took the role in developing this promising technology. Robotics like many electronic devices requires a large amount of power source. The traditional way of powering a robot is replaced with clean renewable source, solar power. And as the demand for solar panels is getting higher, therefore a system with high accuracy and continuously working is needed. Robotics is the answer for that. By applying robot in solar cell industry, the production is getting higher with better quality. This paper reviews and discusses the interesting relations between solar cell and robotics world, by studying the articles in solar cell and robotics related application. This paper also shows that the improvement in these two fields will give a great contribution to each other and in the end will help to create better living and clean earth through the renewable energy of solar cell and the automatic world provided by robotics.

REFERENCES

[1] A.Einstein, Concerning an heuristic point of view toward the emission and transformation of light,*Annalen der Physic 17*, pp. 132-148, 1905.

[2] U.S. Department of Energy, "The history of solar", *Office of Energy Efficiency ¥& Renewable Energy*, accessed August 9, 2015.

[3] J.Jalbert, J.Baker, J. Duchesney, P.Pietryka, W.Dalton, D.R.Blidberg, S.Chappell, R.Nitzel, and K. Holappa, A Solar-Powered Autonomous Underwater Vehicle, *OCEANS 2003. Proceedings*, Vol. 2, pp. 1132-1140, 2003.

[4] S.Hollar, A.Flynn, C.Bellew, and K. S. J.Pister, Solar Powered 10 mg robot, *IEEE The Sixteenth Annual International Conference on Micro Electro Mechanical Systems*, 2003.

[5] J.H.Lever, A.Streeter, and L. R. Ray, Performance of a Solar-Powered Robot for Polar Instrument Network, *In Proceedings 2006 IEEE International Conference on Robotics and Automation*, 2006.

[6] Y.Takahashi, S.Matsuo, and K.Kawakami, Hybrid Robotic Wheelchair with Photovoltaic Solar Cell and Fuel Cell, *International Conference on Control, Automation and Systems*, pp. 1636-1648, 2008.

[7] I. A. Anderson, I. A.Ieropoulos, T.McKay, B.O'Brien, and C.Melhuish, Power for Robotic Artificial Muscles, *IEEE/ASME Transaction on Mechatronics*, Vol. 16, pp. 107-111, 2011.

[8] W.Yuexin, F.Zhuang, Z.Yanzheng, and Z.Hui, A Novel Robot of Manufacturing Space Solar Cell, *Advanced Robotic System International*, pp. 46-50, 2007.

[9] D. I.Park, C.Park, Y.Yoo, J.Park, S.Lee, and D.Kim, Modeling of Beam Type Solar Cell Substrate Handling Robot, *International Conference on Ubiquitous Robot and Ambient Intelligence (URAI)*, pp. 561-562, 2012.

[10] E. Y. Cho, J.Kim, and S.Rhim, Modeling of Large Scale Solar Cell Handling Robot with Belt-driven Flexible Arms, *Theoretical ¥& Applied Mechanics Letters*, Vol 3, 2013.

[11] A. Chaïb, M. Kesraoui, and E. Kechadi, PV Panel Positioning using a Robot Manipulator, *2015 3rd International Renewable and Sustainable Energy (IRSEC)*, 2015.

[12] A.Cammarata, Optimized Design of a Large-Workspace 2-DOF Parallel Robot for Solar Tracking System, *Mechanism and Machine Theory*, Vol. 83, pp/ 175-186, 2015.

[13] Y.Al Mashhadany, and N.Abd Rahim, Design of a Pneumatic Robotic Arm for Solar Cell Tester System by Using PLC Controller, *IJCSI International Journal of Computer*, Vol. 10, pp. 658-663, 2013.

[14] M.Anderson, A.Grandy, J.Hastie, A.Sweezey, R.Ranky, C.Mavroidis, and Y. P.Markopoulos, Robotic Device for Cleaning Photovoltaic Panel Arrays.