Design of vision based AI solar panel surface defect detection module

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Abstract : The solar energy market continues to grow as the demand for renewable energy increases. In recent years, growing number of solar power plants and panel installations has paved the way for new businesses and technology, especially in the area of operations and management(O&M). For example, solar panel cleaning robots are commonly used to provide an automated, cost-efficient means of panel surface maintenance, which in return can maintain their energy extraction efficiency and protect the panels from climactic conditions such as mud, rain, and snow. This paper explores a modular defect detection machine that can be attached to an existing solar panel cleaning robot to inspect the surface quality of install solar panels while cleaning them. The defect detection module bases its detection on the integration of machine vision and artificial intelligence(AI), as well as real-time embedded system. The modular design allows solar power plant O&M practitioners to quickly deploy the system to check the conditions of panel surfaces. In addition, the real-time AI image detection algorithm can notify the workers of hazardous surface conditions, such as critical surface cracks that can potentially cause further damages due to the rotating brushes on the robot.

Keywords : Embedded AI, Machine Learning, Defect Detection, Real-time AI, O&M, Photovoltaics

Ⅰ.Introduction

Growing environmental concerns has made governments and policy makers to resort to a sustainable, renewable source of energy, such as solar power, to meet the increasing energy demand. The global solar power capacity has increased to a total of 627GW in 2019, which is a phenomenal growth compared 2009's global total of 23GW[3]. In line with this trend, solar panel installation operations and maintenance(O&M) market has also increased in its size and experienced technological advancements to effectively maintain solar energy extraction and automate O&M tasks that requires professional maintenance practitioners.

1. Solar Panel Cleaning Robots

One of the most highlighted technologies related to solar power installation O&M is an automated solar panel cleaning robot. These robots generally consists of a mobile robot that can moves within an array of panels to clean the surfaces via rotating brush mechanism[1]. In such mechanism, a guide rail is fixed to the edge of photovoltaic(PV) panels and the panel cleaning robot moves along the rail in a linear motion while brushing through the surface to rid of dust, snow, and bird

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droppings that affect the panel efficiency.

2. Effect of Panel Surface Defects

In addition to the physical conditions imposed by the environment surrounding the PV installation sites, surface defects such as damages and cracks can also affect the panel efficiency in extracting solar radiation[6]. These defects makes the panels more difficult to capture solar radiation and can eventually lead to thermal hotspots which denote the panel's inability to convert solar radiation into electricity. Most solar panel cleaning robots in operations today are not capable of detecting such surface defects, and can sometimes lead to catastrophic failure if and when the cleaning brushes and water leaks into the damaged panels.

3. Solar Panel Inspection Methods

Common PV panel inspection techniques employed today are I-V measurements, electroluminescence, visual inspection, and thermal thermography[7]. I-V measurements are used to draw an I-V curve of a solar panel, and it provides an analysis of the efficiency of the inspected panel. However, such technique does not give any information about the defect, like its location and type. Electroluminescence(EL) inspection, on the other hand, provides images of the inspected panels under short-wave infrared light, which can reveal defects that are not recognizable by the naked eye, such as micro-cracks. EL inspections are usually carried out during panel production process, and are limited in that it cannot be performed on PV plants under operation.

For PV modules, that are under operation, visual and thermal inspection are used to inspect the surface quality of individual panels. At a PV plant sites, where large numbers of PV panel arrays are installed, visual and thermal cameras are attached to a drone which is flown over the panel arrays to capture panel surface images and extract panel thermography. The comparison of the visual and thermographic images let the O&M practitioners know which panel in a PV plant is defective, as well as the type and exact location of the defect.

Ⅱ. Solar Panel Surface Defect Detection Module

1. Design

The Defect Detection Module(DDM) consists of one machine vision camera, one thermal camera, battery, and an embedded board for image acquisition and detection. The CAD design of DDM is presented in Figure 1.

In Figure 1, the board case (1) encloses embedded boards, battery, and other required electrical components like cables. The camera mount arm (3) is designed so that the height of the cameras (2) relative to the panel can be adjusted, thus the module can be implemented in different variations of solar panel cleaning robot. In case the module is used in a wet or dusty environment, the casing is sealed tight and the camera connectors are fed into the board case via a waterproof flex cable. Cameras and their case (3) are oriented 45° to the panel, in order for the wide angle cameras to capture the maximum area of panel array underneath the module.

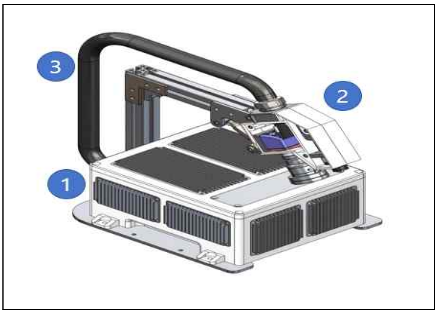

Fig. 1. CAD model of Defect Detection Module

2. Real-Time Artificial Intelligence

To achieve real-time detection of defects using artificial intelligence, an open source neural network framework called Darknet is used. Within the framework, YOLOv3 is utilized to realize real-time image detection of surface defects[5]. YOLOv3 predicts an objectness score for each bounding box using logistic regression. It is extremely fast in detecting objects in an image, hence it is commonly used in applications of real-time object detection, given its high frames per second rate than other detectors like Faster R-CNN and RetinaNet.

However, since the DDM can only accommodate an embedded board and a limited power supply, a variation of the YOLOv3 architecture suitable for embedded environment called Tiny YOLOv3 is used as the defect detector.

3. Vision Sensors and Embedded System

The vision sensors required to detect panel surface defects have to acquire the panel images in two spectral ranges: visible radiation and long-wave infrared radiation. The prior is used to acquire images in the visible light, which will allow the DDM to detect surface defects that can be observed under a naked eye. On the other hand, the latter allows the DDM to acquire thermal information of the panels under observation, so as to detect panel hotspots. Comparison of the two images in a different spectrum provides a meaningful analysis of the detected defect. For example, if a crack is detected using the visible camera, the thermal camera can judge whether or not the observed crack influences the power generation of the solar panel.

Furthermore, both vision sensors are required to have an FPS of at least 60. Because the DDM is to be mounted on a mobile robot that moves linearly along an array of PV panels, the cameras have to be able to acquire the panel images at a faster rate than the speed of the robot, so as to not cause any blurs in the acquired images[4].

In order to accommodate real-time inference speed with Tiny Yolov3, an embedded board capable of achieving more than 25FPS is needed. Therefore, NVIDIA Jetson AGX Xavier, an embedded AI computing platform, is selected to perform defect detection, as the device can achieve an FPS of 30FPS or higher when implementing Tiny Yolov3[2]. The AI embedded board also operated under 30W, which is suitable for the application of DDM.

III. System Implementation

1. Sensor Configuration

The sensors used in DDM consists of a machine vision camera and a thermal camera. Matrix Vision mvBlueFOX3-2016c is selected as it has a maximum FPS of 223, and Theia Technologies MY125M ultra wide angle is attached to the vision camera, allowing the camera to have 125° of diagonal field of view(FOV). FLIR Boson 320 is selected as the thermal camera as it has a baseline frame rate of 60FPS and a lens of 92° FOV.

Table 1. Vision Sensor Configuration

Vision Sensor	Lens Type
mvBlueFOX3-2016C	MY125M (125° FOV)
FLIR Boson 320	92° FOV

2. Implementation of Defect Detection Module on Commercial Solar Panel Cleaning Robot

In order to test the validity of the proposed system, the developed defect detection module is attached to a commercially available social panel cleaning robot. The robot used for this experiment is Ecosense ES-SRS robot, which is currently operating in a South Korean solar power plant installation, Korea East-West Power. The robot with the DDM is setup in an indoor testing environment. The Darknet YOLOv3 model is pre-trained using a set of 100 images containing damaged and cracked panels, and for the experiment, two panel out of the four panels installed in the testing environment is purposely damaged.

Figure 2 demonstrates the result of YOLOv3 model detecting two separate damages within the damaged panel. The resulting FPS of using custom Tiny YOLOv3 model is 32FPS. The damage of the panel on the left of Figure 2 resulted in an accuracy of 100% while the other resulted in 78%.

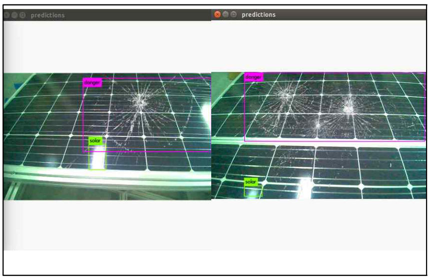

Fig. 2. Defect Detection Module's Result of Crack Prediction

IV. Conclusion and Future Work

The proposed defect detection module for solar panel cleaning robot consists of an AI based embedded system that can detect solar panel surface defects. The experimental results demonstrate the validity of DDM. The position and orientation of the vision sensors sufficiently captured an array of panels, and the sensor specification was sufficient to acquire clean cut images without any blurs. Furthermore, the module was able to detect the two damages on the panels while the robot was in motion and in the process of cleaning the panel. The discrepancy between the two damages in Figure 2 is due to the lack of AI model's accuracy; the training set used on the data was limited as it is especially difficult to obtain more sample size for panel crack images.

For future work, larger sample size for different surface defects, such as delamination, bubbles, and micro-cracks should be implemented to provide a more accurate AI model. The real-time YOLO network used in this paper is limited to detecting damages and macro-cracks that can potentially disrupt the cleaning robot's O&M process. In addition, a user friendly UI can be developed to provide insights into the details of the defects, such as its position on the panel.

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