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RESEARCH ARTICLE

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Deep learning-based automatic detection of multitype defects in photovoltaic modules and application in real production line

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Abstract

Automatic defect detection in electroluminescence (EL) images of photovoltaic (PV) modules in production line remains as a challenge to replace time-consuming and expensive human inspection and improve capacity. This paper presents a deep learning-based automatic detection of multitype defects to fulfill inspection requirements of production line. At first, a database composed of 5983 labeled EL images of defective PV modules is built, and 19 types of identified defects are introduced. Next, a convolutional neural network is trained on top-14 defects, and the best model is selected and tested, achieving 70.2% mAP_{50} (mean average precision with at least 50% localization accuracy). Then, through analyzing an object detection-based confusion matrix, recognition bias and detection compensation in missed defects that restrain the best model's mAP_{50} are discovered to be harmless to normal/defective module classification in real production line. Finally, after setting specific screen criteria for different types of defects, normal/defective module classification is conducted on additionally collected 4791 EL images of PV modules on 3 days, and the best model achieves balanced scores of 95.1%, 96.0%, and 97.3%, respectively. As a result, this method surely has a highly promising potential to be adopted in real production line.

KEYWORDS

automatic defect detection, convolutional neural network, deep learning, electroluminescence, photovoltaic module

1 | INTRODUCTION

Renewable energies have become an irreversible trend for future power supply. Besides wind and water energy, another one of the most important and promising technologies is solar energy, which supplies around 2% of the world's total energy demand today and is a proven technology to be deployed to a multi-terawatt scale by 2030.[1] A photovoltaic (PV) cell is the basic unit of converting solar energy to electricity, and a number of them are concatenated to form a PV module through some processing stages in production line. During the solar cell production and processing stages, various defects like weak soldering, finger interruption, and crack can be generated due to incorrect manipulations such as deficient soldering, screen printing error, and collision. Among all the types of these defects, part of them hinder the current flow, decrease the module power, and even damage the whole module while others may not infect the module efficiency but the quality grade. In this context, all of them should be inspected carefully in the production process to ensure the efficiency, security, and quality of the PV modules.

One of the most commonly used approaches to detect defects in PV modules is electroluminescence (EL) imaging due to its high resolution to characterize different types of defects.[2,3] But manually inspecting EL images requires well-trained professionals to keep staring at the screen all the time as the line moves. It is not only time-consuming but also expensive and the inspection accuracy may fluctuate due to the boring and mechanical repetition of the

