IRACST – International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501

Vol.14, No 3 Sep 2024

Solar Cell Surface Defect Detection Based on Optimized YOLOv6

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ABSTRACT—

An approach to defect detection in solar cells is proposed, considering the characteristics of complex pictures of solar cells, such as large-scale changes, shifting defect form, and an improved YOLO v5 algorithm. By introducing deformable fourier into the CSP module, an adaptive training measure and sensory field size are realized. Incorporating the ECA-Net attention system enhances the model's capacity for feature extraction. Finally, fine-tuning the model network topology and including one small defect prediction head enhance the accuracy of target detection at various sizes. The CIOU function for loss, the K-mean++ cluster anchor box methodology, and Mosaic or Mistake fusion data enhancement approaches are used in this work to considerably optimize and improve the YOLO v5 method. With an area of 89.64% in the technique that was developed on a solar cell EL image dataset, the improved YOLO v5 method beats the original method by 7.85%, according to the experimental findings. It can also achieve an average rate of 36.24 frames per second, which enhances its ability to detect flaws in solar cells while meeting real-time demands.

INTRODUCTION

People are under pressure from pollution and the problem of conventional energy, thus they are concentrating on locating and using other sources of energy. Solar power, one of the new energy sources that is growing the fastest, has become more popular due to its numerous advantages, which include low cost, high reliability, and safety. Even though solar panels are crucial for producing photovoltaic power, the fragile silicon crystal plates that go into making them are prone to defects that can lower the quality of powered by sunlight power generation and even put people's lives and property in danger if improper handling occurs during the manufacturing and installation process. Thus, it is critical to look into methods for identifying flaws in solar cells.

Electroluminescence (EL) imaging is achieved by stimulating the photovoltaic module with a forward bias current. The stimulated solar cell produces infrared light, which is detected by an optical GaAs camera or a silicon-based charge-coupled sensor (CCD). Electroluminescence imaging offers several advantages over conventional imaging techniques since it is non-invasive and requires no touch. For instance, it may identify process flaws that would normally go unnoticed, including tiny fractures or finger disruptions. It may also avoid image blurring brought on by the spread of heat laterally. Due to its exceptional performance, electroluminescence imaging has become the dominant approach for identifying flaws in solar cells.

In the past, each solar cell had to be physically inspected by maintenance and operational engineers using their own equipment. Because of this method's labor-intensiveness, inefficiency, and excessive reliance on their own knowledge, the findings cannot be trusted. Researchers have proposed using traditional computer vision techniques, which depend on human extraction of features and classifiers, as a reliable and automated way to identify problems in images. Tsai et al. proposed using Fourier reconstruction approach to detect defects in polysilicon solar cells. By setting the frequency part of lines and strips errors to zero, this method removes the potential for inaccuracies in EL images. Dement et al. devised a classification identification method that effectively identifies photoluminescence (PL) and IR (infrared) images of silicon small-grain wafers by combining location descriptors with support vector machines. However, human-operated descriptor the extraction procedure, which is used in traditional computer vision, is intrinsically unstable, requires a great deal of parameter tuning, and is not very good at generalization.

In recent years, deep learning models based on convex neural nets have found widespread use in a variety of fields, including target identification, photo classification, and semantic segmentation. In complicated backdrops, solar cell detection is susceptible to interference, and photographs of real settings are not meant for the most convolutional neural networks. Thus, there are issues with using developed neural networks models to quickly detect surface flaws in solar cells EL images. Micro defect features such as fractures

& fingers disruption tend to disappear from solar cells that show form variation in the same fault grouping as the network development and down sampling procedure progresses. The aforementioned problems make it difficult to find flaws in solar cells. Systems for detecting solar cell faults relying on deep learning face all of the above difficulties. Because of this, R-CNN series—including R-FCN—are often used as two-order detection methods in the early stages of research, predicated on the idea of candidate regions. These algorithms have a slow detection speed, but they have excellent detection accuracy. Using first-order detection models provided by the YOLO series algorithms, scientists are working nonstop to increase target detection speed and accuracy. Consequently, the effect of detection is increasing every day.

A YOLO family of algorithms, which combine target localization and classification using an anchor box, is an example of an a first-order detection technique. The acronym YO series of algorithm has been devised and published in three versions by the YOLO research team: YOLO v1, YOLO v2, and YOLO v3. The YOLO v3 represents a notable increase in the YOLO algorithms' speed and performance. The Yolo v4 and v5 algorithms are two further iterations that have been made available by different research teams. Since the YOLO v5 recognition model is entirely written in Python (Porch) and is faster and smaller than the four previous model iterations, everyone in the object recognition field is gushing about it. It is important to note that scholars from other areas have improved the originally created YOLO v5 paradigm based on the characteristics of their detection targets, making the updated YOLO v5 approach exceptional in many research domains. Li et al. improved the YOLO v5 target detection for infrared photographs by developing a detection model that reduced system factors while maintaining detection accuracy. This was achieved by adding the cross-stage-partial-connections (CSP) part and introducing an enhanced attention course in the residual module. Luo et al. proposed an improved YOLO v5-based plane target recognition method by combining centering and size calibration, optimizing the cross-Entropy loss function, and adding the Sandglass unit into the remaining module. The precision and speed of detection are greatly increased by this method. Zhu et al.'s TPH-YOLO v5 model incorporated an attention mechanism, replaced the initial prediction's forehead with an A transformer prediction head, and raised the number of prediction heads from two to five. Consequently, the enhanced model outperformed the original by 7% in terms of detection performance. In order to address the class imbalance in the dataset during training and enhance the classification performance of the YOLO stands v5 detection model, Kim et al. proposed a hybrid data enhancement approach that integrated online copying and pasting with other methods. Using a network of Siam cell for binary at neck classification, Misedit et al. built a lightweight YOLOv5 monitoring model that could detect visited networks and loop closures. First-order identification YOLO v5 is a crucial tool for identifying targets given its low hardware needs, robust immediate analysis capabilities, and possible mobility to portable devices for real-time monitoring, as shown above and presented. Based on this, the study offers an updated version of the YOLO v5 model which takes into consideration cracks, black the core, and finger discontinuity—three different kinds of surface flaws in solar cells. To capture errors of varying sizes and forms more effectively, the CSP module of the enhanced YOLO v5 network integrates deformable convolution. To improve detection quality via cross-channel interaction, the ECA-Net attention component is introduced to the Neck section. In order to achieve four-scale feature defect identification and increase the accuracy of micro defect detection, the prediction head is added and the model architecture is optimized simultaneously. The updated model put forward in this paper's experimental findings, which include ablation tests and a review of conventional techniques, objectively evaluate the enhanced detection advantage. The findings show that the modified model ensures real-time detection while improving the accuracy of solar cell fault detection.

RELATED WORK

Sustainable development and renewable energy: an essential overview

To solve the current environmental issues, longer-term sustainable development programs are required. Renewable energy appears to be one of the greatest and most effective solutions available. Renewable energy sources and sustainable development go hand in hand because of this. The projected growth in consumption of energy and the ensuing environmental impacts are extensively examined in this research, with a focus on acid rain, stratospheric ozone depletion, and the effect of greenhouse gases. Possible solutions to current environmental challenges are also presented, in addition to alternative energy technologies. The relationship between renewable energy and sustainable development is thoroughly explained in the article along with several examples from actual projects. This article examines a number of subjects, including sustainable development, renewable energy, and environmental preservation, from both the current and the future perspectives. The present study's conclusions and recommendations should be useful to energy industry researchers, engineers, and policymakers.

Improving the efficiency of solar panels: a thorough analysis

As an alternate energy source for creating clean, eco-friendly power, solar panels have grown in popularity lately. An adverse effect of rising ambient temperature is a reduction in photovoltaic efficiency. The amount of energy produced decreases by 0.33 percent for each degree Celsius exceeding STC. The output of the solar panel may not be sufficient to power the load as a consequence. It ought to be noted that adding a second solar panel to compensate for the lower output power would not be feasible in certain applications, such as autonomous electric vehicles. By using the cooling techniques, this intense heat might be reduced. There have been applications for both passive and active cooling systems. This article offers an overview of the research on enhancing the efficiency of solar panels via the combination of TEG and other cooling methods.

Methods for identifying crystalline silicon defects and impurities for use in solar cells

Grain boundaries, dislocations, and transitional metals are examples of imperfections and imperfections that lower the efficiency of multicrystalline solar power cells. In several instances, the defects' weight density varies across grains. Redirecting the low open circuit voltage generated by "bad grain" with short minority carriers diffusing length away toward "good grains" with longer minority carriers diffusion length lowers the overall efficiency of the cell. Clusters of transitional metals are more common in "bad grains" than in "good grains," and guttering is ineffective in enhancing the areas with short diffusion lengths. In photovoltaic materials research, identifying the defects with the longest lifetime is the primary objective. The knowledge on lifetime-limiting flaws in solar cells is summarized in this article along with recent developments in the field, including a fluorescence X-ray microprobe and X-ray absorption spectro microscopy, as well as advantages and disadvantages of more conventional analytical methods.

A Look at Solar Cell Defects: How They Affect Control and Detection

The efficiency of commercial solar cells is greatly impacted by any flaws or contaminants in the substrates utilized to create them.

Defects that cause the semiconductor's band gap to reach deep levels of energy lower the quantum efficiency and transport lifetime of solar cells. Utilizing electrical characterisation techniques is essential to comprehending defects in their entirety. These methods will provide specifics about the flaws, such as their concentration, distribution, or physical origins. This page contains a full description of every experimental technique we have available. However, the productivity of triple connection solar panels may be greatly enhanced by an intermediate band that forms in the semiconductor's midcap. Deep level faults may produce the intermediate band if their concentration is high enough. This article also provides experimental evidence for the formation of an intermediate band.

Impact of flaws on solar cell properties

The bulk of industrial silicone solar cells have current-voltage (I-V) characteristics that differ greatly from the exponential behavior expected by textbook knowledge. Hence, for a given material quality, the recombination current may be substantially larger than expected and often shows an ideality factor exceeding two throughout a wide bias range, none of which can be explained by conventional theory. Ohmic shunts may also exist in other situations even after the cell's borders have been totally sealed up. Conventional expectations of saturation are not met: qualities are global or super-linear with inverse bias even in the absence of such shunts. As expected, breakdown, especially with mult-crystalline cells, usually happens below -15 V or even less rather than at -50 V with an opposite bias. The primary causes of these differences are persistent cellular anomalies. This paper gives new insights on recombination with linked defect levels and summarizes the existing knowledge of how these poor I-V characteristics of silicone solar cells have come to be.

Procedures for manufacturing and inspecting solar cell modules

A multitude of solar power generating facilities of all sizes have proliferated in response to the growing demand for energy derived from renewable sources. Large-scale facilities spread over a wide range of terrain need accurate and fast monitoring technology to guarantee steady electricity production and maintenance. With the utilization of orthographic temperature images obtained by unmanned aerial vehicles (UAVs) fitted with optical and infrared sensors for temperature, this study aimed to give a technique for analyzing solar cells in both their normal and failing states. The following are the results of the study: Using optical and warm infrared sensors at different resolutions in tandem may provide accurate spatial data, which enables orthographic pictures to be created from infrared thermal images. Through examination of the solar panel's and cell's typical temperature swings, it was discovered that the aberrant course and cell showed a greater change in temperature than the normal module or cell. Furthermore, the temperature variance throughout the region made it possible to precisely identify the unusual heat produced by the irregularly charged panels and cell. We conclude that the obtained UAV-based infrared heat sensor may be utilized for safe monitoring and examination of the rapidly growing solar power producing facility, as well as a method of solar module inspection.

METHODOLOGY

1.Calculate metrics This module must be used to calculate metrics.

2.Training faster RCNN algorithm: We trained the RCNN using this module.

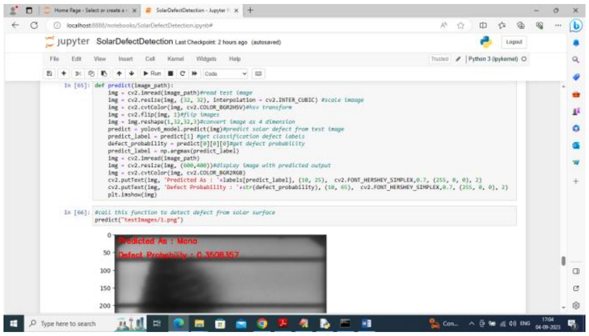
3.Training existing FRCNN: We trained a genetic elm known as GA-KELM using this module.

4. Training yolov5 algorithm: This module was used to train the Yolov5 algorithm.

5. Training yolov6 algorithm: With this module, the yolov6 algorithms was learned.

6. All algorithm performance graph Thisgraphs showing each algorithm's performance were created using the module.

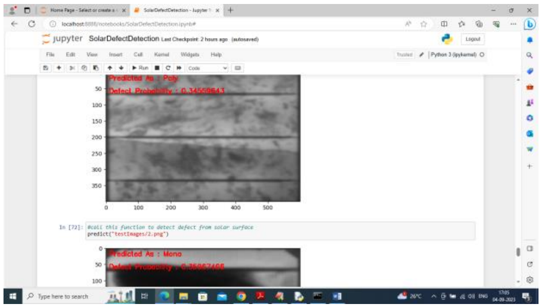
RESULT AND DISCUSSION



```
In [65]: def predict(image_path):
             img = cv2.imread(image_path)#read test image
             img = cv2.resize(img, (32, 32), interpolation = cv2.INTER_CUBIC) #scale image
             img = cv2.cvtColor(img, cv2.COLOR_BGR2HSV)#hsv transform
             img = cv2.flip(img, 1)#flip images
             img = img.reshape(1,32,32,3)#convert image as 4 dimension
             predict = yolov6_model.predict(img)#predict solar defect from test image
             predict_label = predict[1] #get classification defect labels
             defect_probability = predict[0][0][0]#get defect probability
             predict_label = np.argmax(predict_label)
             img = cv2.imread(image_path)
             img = cv2.resize(img, (600,400))#display image with predicted output
             img = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
             cv2.putText(img, 'Predicted As : '+labels[predict_label], (10, 25),  cv2.FONT_HERSHEY_SIMPLEX,0.7, (255, 0, 0), 2)
             cv2.putText(img, 'Defect Probability : '+str(defect_probability), (10, 65),  cv2.FONT_HERSHEY_SIMPLEX,0.7, (255, 0, 0), 2)
             plt.imshow(img)

In [66]: #call this function to detect defect from solar surface
         predict("testImages/1.png")
```

The red text in the picture indicates the name of the defect, "MONO," and the likelihood of the defect is 0.35%. The prediction function is defined in the above screen using the Yolov6 extension model.



```
In [72]: #call this function to detect defect from solar surface
         predict("testImages/2.png")
```

The kind of flaw and the likelihood of its detection for additional photos may be seen in the screen above.

CONCLUSION

This work suggests an altered YOLO v5 detecting model to account for solar cell defective characteristics, which includes a prediction head, an enhanced network framework, an ECA-Net attentiveness mechanism, a deformable convolutional CSP component, and additional features. Because of its improved feature extraction capabilities, the model can identify flaws at various sizes. This paper's optimization and improvement attempts include the use of the K-means++ cluster anchor box strategy, multi-model integration techniques, and model enhancement utilizing mosaic and Confusion scale merging data. The results of ablation and test comparisons show that the improved target detection model achieves a frame rate of 36.24 frames per second, a considerable improvement in accuracy to 89.64%, and surpasses the previous identification model's map by 7.85%. The next stage to lowering the model's level of complexity and attaining high detection speed is processing the identification model's net trimming and purification to get a lighter refining of the model.

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