CLASSIFICATION OF DEFECT PHOTOVOLTAIC PANEL IMAGES USING DEEP LEARNING IN COMPUTER VISION

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MASTER OF SCIENCE
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ABSTRACT

As one of renewable energy sources, the uses of solar panels is seen to be more widespread nowadays along with the development of technology. Large-scale maintenance has long been seen as a great challenge and needs attention. Currently, electrical performance measurement or image processing is used to carry out condition monitoring of photovoltaic panels. This method has the limited ability to detect defects, is time-consuming and has the inability to determine the exact location of defects quickly. To overcome this challenge, deep learning techniques are used for detection in this classification tasks. This research is focused on classifying defect PV panels using Matrox Imaging Library software which are to be installed in computer vision applications. This application provides a deep learning algorithm that is able to classify images according to its respective group. The image data set has been carefully compiled and divided into training and development datasets during the training to ensure the highest accuracy for the prediction of the presence or absence of defects on PV panels. A statistical measure that is the average accuracy rate for the training model and the total prediction was implemented to evaluate the classification performance of the defect PV panel models. The results show a remarkable total model accuracy of 99.9% for each class and the prediction results confirms show that nearly 90% of PV panel defects are detected from the test dataset. Furthermore, a comparative analysis was conducted to benchmark the findings against other algorithms. The findings of this research demonstrate the effectiveness of deep learning algorithms and its compatibility in computer vision applications in use. By leveraging this technique, solar panel users can improve maintenance management, control quality and reduce financial losses by promptly identifying and addressing panel defects.

ABSTRAK

Sebagai salah satu sumber tenaga boleh diperbaharui, penggunaan panel solar dilihat semakin meluas pada masa kini seiring dengan perkembangan teknologi. Penyelenggaraan berskala besar telah lama dilihat sebagai satu cabaran dan memerlukan perhatian. Pada masa ini, pengukuran prestasi elektrik atau pemprosesan imej digunakan untuk menjalankan pemantauan keadaan panel fotovoltaik. Kaedah ini mempunyai keupayaan terhad untuk mengesan kecacatan di samping mengambil masa yang lama. Untuk mengatasi cabaran ini, teknik pembelajaran mendalam digunakan untuk pengesanan dalam tugas pengelasan. Penyelidikan ini tertumpu kepada pengklasifikasian panel PV yang cacat menggunakan perisian Perpustakaan Pengimejan Matrox untuk dipasang dalam aplikasi penglihatan komputer. Aplikasi ini menyediakan algoritma pembelajaran mendalam yang mampu mengklasifikasikan imej mengikut kumpulan masing-masing. Set data imej telah disusun dengan teliti dan dibahagikan kepada set data latihan dan set data pembangunan semasa latihan untuk memastikan ketepatan tertinggi untuk ramalan kehadiran kecacatan pada panel PV. Ukuran statistik iaitu purata ketepatan untuk latihan model dijalankan dan purata ramalan telah dilaksanakan untuk menilai prestasi klasifikasi model panel PV. Keputusan menunjukkan jumlah ketepatan model sebanyak 99.9% untuk setiap kelas dan keputusan ramalan menunjukkan bahawa hampir 90% daripada kecacatan panel PV dapat dikesan daripada set data ujian. Penemuan penyelidikan ini menunjukkan keberkesanan algoritma pembelajaran mendalam dan keserasiannya dalam aplikasi penglihatan mesin yang digunakan. Dengan memanfaatkan teknik ini, pengguna panel solar boleh meningkatkan pengurusan penyelenggaraan, mengawal kualiti dan mengurangkan kerugian kewangan dengan segera.

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APPROVAL

The Examination Committee has met on **13 October 2023** to conduct the final examination of **Nur Syahiera binti Othman** on his degree thesis entitled **Classification of Defect Photovoltaic Panel Images by Using Deep Learning in Computer Vision.**

The committee recommends that the student be awarded the of Master of Science (Computer Science).

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Title	: Classification of Defect Photovoltaic Panel Images Using Deep Learning in Computer Vision
Academic session	: 2023/2024

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LIST OF ABBREVIATIONS

NDUM	-	National Defence University of Malaysia
MIL	-	Matrox Imaging Library
PV	-	Photovoltaic Panel
IR	-	Infrared
JPEG	-	Joint Photographic Experts Group
ICNet	-	Image Cascade Network
CNNs	-	Convolutional Neural Networks
EL	-	Electroluminescence Image
SVM	-	Support Vector Machine
IR 4.0	-	Industrial Revolution

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CHAPTER 1

INTRODUCTION

1.1 Background

The idea of photovoltaic panels, often known as solar panels, is to capture solar energy and to use the photovoltaic effect to transform it into electricity. French physicist Alexandre-Edmond Becquerel initially found this phenomenon in 1839 when he noticed that certain materials generated a little electrical current when exposed to light (Catalbas et al., 2021). However, photovoltaic technology did not start to see widespread use until the middle of the 20th century(Tabassum et al., 2021).

When solar cells were used to power satellites and spacecraft during the space race in the 1950s and 1960s (Ren et al., 2023) the development of the contemporary solar panel accelerated. It has become a key component of the global transition towards renewable energy sources as a result of developments in materials science and engineering over time, which have produced extremely efficient and economically feasible solar panels. These panels currently have a major impact on cutting carbon emissions, improving energy independence, and advancing sustainable development across the globe.

Moreover, these flaws are not only superficial problems; they may risk the panels' structural stability, raising the possibility of electrical hazards and posing a greater risk to safety during severe weather. Stakeholders in the solar sector can maintain quality standards, reduce warranty obligations, and protect the dependability and safety of PV systems by giving priority to the identification and classification of scratches and cracks.

To ensure its consistent and ideal energy production, photovoltaic (PV) panels must be maintained (Bosman et al., 2020). There are a few types of defects that may cause PV panels to be less effective. Some of the common issues is the occurrence of cracks and fractures in the PV panel’s cells or modules, which can be brought on by mechanical stress, temperature fluctuations, or external impacts (IEEE Antennas and Propagation Society., 2010).

Besides that, there are also various classifications of defect based on publicly available dataset to verify the model’s validity and was named the PV Multi-Defect dataset (https://github.com/CCNUZFW/PV-Multi-Defect)(L. Li et al., 2023). From all of these types of defects, in this research the focus will only focus on the scratch and crack types of defects. It is reasonable to limit attention to scratch and crack faults in PV panels due to their widespread occurrence and substantial influence on both performance and safety.

These flaws seriously jeopardise the efficiency of energy generation and can arise from a number of PV panel lifecycle stages, including manufacture, shipping, and installation. Small scratches or hairline cracks can interfere with the absorption of sunlight and interfere with electrical conductivity, which can result in significant losses in energy production.

Furthermore, proactive maintenance serves as a critical defence against degradation and defects. Through consistent inspections and prompt resolution of these concerns, potential problems can be addressed before they escalate. This preventive approach not only sustains the panels' performance but also extends its operational lifespan, safeguarding the longevity of the solar energy system(Bosman et al., 2020).

Ultimately, the practice of maintaining PV panels contributes to the longevity and return on investment of solar energy systems. Regular upkeep ensures that panels continue generating clean electricity efficiently over the course of many years. By preserving optimal functionality and addressing any emerging defects, system owners can unlock the full potential of their solar installations, not only in terms of financial gains but also in their commitment to sustainable energy production and environmental stewardship.

Due to developments in machine learning algorithms and imaging technology, it is now possible to create automated inspection systems that can precisely spot scratches, cracks and another type of defect in photovoltaic panels. By utilising these technologies, PV system performance can be optimised, downtime can be reduced, and proactive maintenance techniques can be implemented. Computers can comprehend and analyse images with the use of sophisticated software such as CNN and ICNet for classification purposes.

For applications such as robotics and self-driving automobiles, ICNet is very helpful as it can quickly and effectively detect distinct components of an image. Convolutional neural networks, or CNNs, on the other hand, are like extremely intelligent tools that can identify a variety of objects in photos, such traffic signs and animals. Many technologies, including facial recognition and medical imaging, rely on computers' ability to see and comprehend the world around them.

Additionally, by identifying and classifying flaws early on in the manufacturing process, firms can lower the risk of performance degradation and warranty claims by implementing quality assurance methods during production. In the end, the solar sector can maximise the long-term profitability of renewable energy infrastructure while improving the efficiency, dependability, and safety of PV installations by resolving these fundamental faults.

1.2 Problem Statement

Early PV panel defect detection is very crucial thus, by maintaining the panels' performance in functioning properly and producing energy effectively, it helps to identify flaws before it turns into significant difficulties. Rapid problem-solving increases savings and reduces downtime while ensuring the longevity of the panels.

In the study by Balasubramani et al., (2020) IR images were employed to detect defect PV panels by the FLIRT420bx® thermal imager and results were used to validate the research outcomes. In Gurras et al., (2021) study on the automatic identification and characterization of flaws in PV modules, IR images from UAV flights were integrated with digital image processing techniques. Automated thermal drone inspection offers intriguing possibilities for structural health monitoring and nondestructive testing to prevent PV module failures

Imperfections like as cracks, delamination, and hotspots can severely reduce PV system performance and efficiency. Researchers want to improve the efficiency and reliability of defect identification processes that have historically relied on manual inspection by utilising image processing techniques. These methods typically include taking high-resolution photos of PV panels, pre-processing the images to remove noise and improve features, extracting useful information or features from the images, and using machine learning algorithms to classify defects.

This brings hope that the discovery will equip solar energy specialists with effective tools for swiftly and precisely identifying problems, allowing for timely maintenance and boosting the overall performance and longevity of PV systems.

Besides, solar panels promote the use of clean energy and prevents energy from being squandered, thus detecting flaws early keeps solar panels operating well overall, saves money, and benefits the environment. Over time, many defect PV classifications have been done using deep learning techniques. According to (Han et al., 2021), they the suggested a method of acquiring thermal images and pinpoints the solar panel problem using an unmanned aerial vehicle (UAV) integrated with a thermal camera and GPS. The issue was discovered using a modified version of the deep learning model of You Only Look Once (YOLOv3-tiny), which is then communicated via Long Term Evolution (LTE) to a distant server for visualization.

Next, is, in (Tang et al., (2020) classification of faulty PV modules using a small sample size in Electroluminescence (EL) images. In this study, an efficient data augmentation technique that can produce high-resolution EL images for deep learning-based approach were utilized and a CNN-based defect classification model was also given. With the dataset produced by the combined data augmentation technique, the classification model is trained. Other than that, according to (Zyout & Qatawneh, (2020) implementing a deep convolutional neural network to automatically analyse and detect defects on the solar panels' surface, instead of creating and optimising the entire deep CNN from scratch due to the limited amount of data available for training and validation, a transfer of learning using AlexNet was used.

The core of this research lies in the fusion of deep learning techniques and the implementation of computer vision for the precise classification of defects in images of photovoltaic (PV) panels (Ren et al., 2022). This integrated approach seeks to capitalize on the strengths of both advanced methodologies, a trained model with deep learning algorithms such as convolutional neural networks (CNNs) extracting intricate patterns from images, and computer vision providing the automated visual analysis necessary for informed decision-making.

By seamlessly combining these technologies, the goal is to revolutionize the defect detection process, ensuring the accurate identification of various types of flaws within PV panels. The combination of deep learning and computer vision is critical in the context of the Industrial Revolution 4.0 (IR 4.0). This technology can be incorporated into machine tools that are currently created, dependent on the nature of the machining, to make it more intelligent than before and enable it to be Industrial

Revolution 4.0 compliant by incorporating the perception and decision-making cognitive abilities (Penumuru et al., 2020a).

The rapidity of computer vision systems in capturing and processing visual data is harmoniously complemented by deep learning algorithms' proficiency in analysing this data for defect identification. This combination enables real-time information, enabling quick and accurate automated judgements. To achieve predictive, proactive, and efficient production processes, it is essential to integrate these technologies as the manufacturing landscape shifts towards intelligent, data-driven practices.

1.3 Research Questions

Based on the problem statements above, these are the research questions to be answered which are:

(a) How can we differentiate the type of defects in PV Panel Images?

(b) How can we get the model to classify defect and good PV panel images?

(c) How can we classify defect or good PV panel image?

1.4 Research Objectives

The objectives of the research are:

(a) To identify the type of defects PV panel images.

(b) To classify the images that represent defect or good PV panels by using classifiers.

(c) To validate classification models using deep learning techniques.

1.5 Scope

The scope of this research is designed in regards to the use of deep learning technique in Matrox Imaging Library software for computer vision application as one of the growing technologies worldwide and specifically in IR 4.0. The classification of defect PV panels in the earlier stage may help in many ways regarding financial planning and time consumption. It is highly related with the quality check of the PV panel once it is completely built up.

This research utilized 1400 images, with 700 images for defect and 700 images for good PV panels. Whereas, 100 mix images consist good and defect PV panel are for testing datasets. All the image dataset had been verified and validated by experts from Control Easy Technology Sdn Bhd. Two classifiers' contexts in training dataset were compared in this research to find the most accurate training model to detect the defect PV panel. All tests were run on a Matrox Imaging Library (MIL) software equipped with an Intel Core i7 processor, 16 Gb of RAM and employed C/C++ API to implement deep learning algorithm.

1.6 Organization of Thesis

The various chapters in this thesis are organized as follows, Chapter 1 describes the background of this research, problem statements, research questions, objectives of this research and scope of this research.

Chapter 2 presents the literature review on the general overview of PV panels, the types of defect PV panel, deep learning techniques, Matrox Imaging Library and the computer vision application. Other than that, it also highlights the specialty of using deep learning techniques in MIL software as the main core in this study.

Chapter 3 explain the few activities conducted in this research to get the optimum results. There is data acquisition consisting of data searching and data conversion. This is followed by the data augmentation process, to ensure that the data is the best fit in a MIL workspace. It will also explain about the function of MIL and the training methods that will be used to classify PV panels.

Chapter 4 discusses previous experiments done during this research, the comparison of average trained model in accuracy and the average test model that can detect the defect and good PV panel images in testing dataset images. This chapter describes how experiments were done with discussions on the choice of applied models followed by the evaluation of the test result. Lastly, the chapter describes the analysis of results of these experiments for further study.

Chapter 5 presents a review of the thesis, the summary, contributions, and several possible areas that have potential for future work.

1.7 Conclusion

In this concluding chapter, this research is focuses on the classification of defects in PV Panels by using the MIL deep learning techniques that were built inside to the extent to be used in any computer vision application respectively. The main purpose of this chapter is to give a brief understanding of the problem statement, research questions and research objectives for the whole of this thesis. Three research objectives were proposed in order to answer the research questions of this study.