ENHANCED IMAGE CLASSIFICATION FOR DEFECT DETECTION ON SOLAR PHOTOVOLTAIC MODULES

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ASIA e UNIVERSITY

2023

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A Thesis Submitted to Asia e University in
Fulfilment of the Requirements for the
Degree of Doctor of Philosophy

October 2023

ABSTRACT

Solar photovoltaic modules are a technology that utilizes solar energy. Solar photovoltaic modules have many advantages, such as clean electric energy without pollution, very simple to channelling energy, and the most important is that it does not produce greenhouse gas emissions and can be built in remote areas because it doesn't require energy transmission. In actuality, solar photovoltaic module systems are minimal maintenance and do not require any moving parts, but they still have more chances to get various defects by the environment or human beings. Once PV modules are electrically linked, the performance of the entire system might be impacted by any problem between them. Error-prone areas may be difficult to locate or recognise in a big solar photovoltaic module. A solar photovoltaic modules system can hide it until the whole system collapse or breakdown. On the surface of the photovoltaic modules, solar cell defects are identified based on cell shapes and textures. However, high similarity of characteristics among the shapes and textures has been a major challenge in defect classification process. The objective of this research was to develop and analyse feature extraction used for classification techniques for defect detection of solar photovoltaic modules surfaces. Methodologically, the entire study used a quantitative experiment technique. This research uses the Gaussian Naïve Bayes Algorithm using a ratio of training data and testing data of 70:30 resulting in an accuracy value of 46%. The second algorithm uses K-Nearest Neighbour using a ratio of training data and testing data of 95:05 resulting in an accuracy value of 62%. Both methods combine Statistical Feature Extraction and GLCM. Statistical tools provide quantitative information about the intensity distribution of pixels in an image, capturing important statistical properties such as mean, standard deviation, skewness and kurtosis. GLCM, on the other hand, analyses the spatial relationship between pixel pairs and extracts texture features such as contrast, correlation, energy and homogeneity. The accuracy value shows that the KNN algorithm is better when compared to the Naïve Bayes algorithm. Using the same data, these results are compared again using Convolutional Neural Network. The architecture used uses Le Net which is then modified into 3 2D layers and 1 Maxpooling screen. Experiments also compare the size of the image as input, using relu activation and adam optimization. The experiment results in the highest accuracy value at a ratio of 70:30 for training data and test data, which is 68%.

Keywords: Enhancing, Naïve Bayes, K-Nearest neighbour, Convolutional Neural Network, feature extraction

APPROVAL

This is to certify that this thesis conforms to acceptable of scholarly presentation and is fully adequate, in quality and scope, for the fulfilment of the requirements for the degree of Doctor of Philosophy

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DECLARATION

I hereby declare that the thesis submitted in fulfilment of the PhD degree is my own work and that all contributions from any other persons or sources are properly and duly cited. I further declare that the material has not been submitted either in whole or in part, for a degree at this or any other university. In making this declaration, I understand and acknowledge any breaches in this declaration constitute academic misconduct, which may result in my expulsion from the program and/or exclusion from the award of the degree.

Name: Ninuk Wiliani

Signature of Candidate: **Date**: 4 October 2023

ACKNOWLEDGEMENTS

I would Thank to God for his mercy to this day in launching all the affairs in completing my education this year. My deepest gratitude to Dr Titik Khawa Abdul Rahman for her great patience and guidance in this research. Without your help and guidance, I would not have been able to complete this research properly. I am very grateful for the time you took to guide me.

I would also like to thank Associate Professor Dr Suzaimah Ramli for her willingness to guide and continue to encourage me until this research was completed. Your support and encouragement provided additional motivation that means a lot to me. I would also like to thank my parents and those who have always provided the greatest support for me, my beloved children’s, Rana Kamilah Arif, Abiyyu Muhammad Arif, and Adzraa Luthfiyah Arif. Their presence has given me infinite strength and inspiration on this journey.

Thank you also to several other people who have provided support, although I cannot mention them one by one. Every contribution and assistance provided is greatly appreciated and has had a positive impact on this research, also like to thank my institution for supporting my educational activities.

Finally, thank you to all those who have been involved and contributed to this research. All the help and support provided has played an important role in the success of my research, and may all the kindness that has been given to me also be returned to all of you.

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PV	Photo Voltaic
KNN	K- Nearest Neighbour
CNN	Convolutional Neural Network
GLCM	Grey Level Cooccurrence Matrix
DC	Direct Current
AC	Alternating Current
GA	Genetic Algorithms
DIP	Digital Image Processing
DE	Differential Evolution
PSO	Particle Swarm Optimization
HSA	Harmony Search Algorithms
ANN	Artificial Neural Networks
BA	Bat Algorithms
FA	Firefly Algorithm
ACO	Ant Colony Optimization
NSO	Negative Selection Algorithm
CSO	Cuckoo search algorithm
BDE	Beta Differential Evolution
SVM	Support Vector Machine
ROC	Receiving Operating Characteristics
PCA	Principal Component Analysis
ICA	Independent Component Analysis
AI	Artificial Intelligent
RGB	Red Green Blue

STD	Standard Deviation (STD)
ASM	Angular Second Moment
KNN	K-Nearest Neighbour
MAPE	Mean Absolute Percentage Error
mAP	Mean Average Precision
AP	Average Precision

CHAPTER 1

INTRODUCTION

Presenting the study findings on the design and development of solar photovoltaic module fault detection is the primary goal of this thesis. Defect detection systems for solar PV modules have been widely applied to identify installation errors (Naveen & Sugumaran, 2021). Some of these studies convey that solar photovoltaic modules defects depend on many parameters consisting of installation methods such as voltage, current, power and series resistance; in addition, there are many environmental factors such as temperature and environmental conditions and maintenance methods.

Defects on the surface of solar photovoltaic modules have been well studied and classified according to their origin, nature and effect on solar photovoltaic modules performance. The most common types are scratches (Chen et al., 2020), edge-dipped panels leaving small invisible holes (Buerhop et al., 2017), micro-cracks that are not immediately visible (Mahdavipour, 2017), chemical residues left behind during the maintenance process to clean the panel surface (Li et al., 2019).

The main focus of this research is to investigate the use of intelligent image processing techniques for defect classification in solar photovoltaic modules. To achieve this goal, several different methods were tested and compared to determine the most effective approach. In this chapter, the results of these experiments are presented and discussed in detail.

Overall, the results of this study demonstrate the feasibility of using feature extraction for defect classification in solar photovoltaic modules. Choosing the correct method and carefully optimising various parameters makes it possible to achieve a high level of accuracy in classifying different defect types. These results have important implications for developing algorithms used and data implemented for more efficient and effective maintenance procedures for solar photovoltaic modules and demonstrate that image feature extraction techniques have a potentially important role in this field.

1.0 Background of the Study

The world still has to rely on petroleum as the primary buffer for energy needs. Meanwhile, this energy source is becoming increasingly scarce and expensive. The need for electrical energy continues to increase beyond expectations. This is due to the increase in all life activities that use electricity. Therefore, there is a need for energy derived from nature to be an alternative energy known as renewable energy that is environmentally friendly and contributes to addressing global warming and reducing carbon dioxide emissions.

The sun is the primary energy source that emits the most significant energy to the earth. Under normal conditions, the earth's surface can receive solar energy of around 1000 watt/m^2 (Mokhtari, & Kimour, 2019). The solar energy that can reach the earth's surface is about 207.898 MW (4,80 kWh/m^2/day). Less than 30% of this energy is reflected in the atmosphere (Purwoto et al., 2018). Utilising energy from the sun would be very beneficial (Siregar & Wardana, 2017).

Solar photovoltaic modules *are* a technology that utilizes solar energy. Solar photovoltaic modules have many advantages, such as clean electric energy without pollution, being accessible to move, being very simple to channelling energy, and, most importantly, not producing greenhouse gas emissions. It can be built in remote areas because it does not require energy transmission.

The fact is that solar photovoltaic modules systems have no moving parts and generally require low maintenance. However, they still have more chances to experience various failures in the solar photovoltaic modules array, battery cables, and power conditioning unit. It is difficult to completely shut down solar photovoltaic modules in the event of a malfunction because the modules are energised by sunlight during the day. Solar photovoltaic modules are modular technology power plants that can be made by connecting many solar photovoltaic modules in series and parallel. Once the solar photovoltaic modules are electrically connected, any fault between them can affect the entire performance of the system. It can be complicated to correctly identify or detect faults in a large solar photovoltaic modules array. A faulty solar photovoltaic modules system can go unidentified because it is hidden until the entire system collapses or breaks down (Khan et al., 2017).

Figure 1.1: Fire hazard in 383 kW PV arrays in Bakersfield, California in 2009

Source: (Khan et al., 2017)

Several hazards have been reported in Sudanese solar photovoltaic modules stacking due to undetected faults. Figure 1.1 shows a fire hazard on a 383 kW PV module in Bakersfield, California, 2009. Another fire hazard occurred at a 1 MW PV power plant in Mount Holly, California, in 2011, shown in Figure 1.2. In both cases, unknown faults in the system caused the fire and shut down the system completely. This fire hazard points out the weaknesses in conventional fault detection and protection schemes in solar photovoltaic modules arrays and reveals the urgent need for better ways to prevent such problems. Failure-free, excellent efficiency, fast,