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DEEP LEARNING ALGORITHM AND IOT BASED SYSTEM FOR PHOTOVOLTAIC (PV) MODULE DEFECT IMAGES CLASSIFICATION

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ABSTRACT

Renewable energy had become a critical alternative to traditional power sources due to the depletion of non-renewable resources in recent years. Solar energy offered significant advantages, including sustainability, environmental friendliness, and cost-effectiveness. Photovoltaic (PV) systems, which converted sunlight into electrical energy through PV modules, play a crucial role in solar power generation. However, maintaining the efficiency of PV modules was essential for long-term energy sustainability, as defects can significantly impact performance. Traditional inspection methods required extensive on-site assessments, making the process labour-intensive and inefficient. This study proposed an automated PV defect classification system using Convolutional Neural Network (CNN) with transfer learning, supported by an IoT-based monitoring platform. The total of 1,394 RGB type images were used in this research, undergoing image pre-processing that included data augmentation techniques such as resizing, rotation, and X-Y translation to enhance the dataset and improved model generalization during training and evaluation. The system employed CNN with two distinct transfer learning architectures, Series Networks which were AlexNet, VGG-16, and VGG-19 and Directed Acyclic Graph (DAG) Networks which were ResNet-18, ResNet-50, Inception-V3, and GoogLeNet. Series Networks, known for their simpler, layer-wise feature extraction, perform well in certain classification tasks, such as specificity and precision. Meanwhile, DAG Networks leveraged deeper architectures and residual connections, enhancing feature learning efficiency and classification accuracy. Experimental results revealed that ResNet-50, a DAG Network, outperforms other architectures by achieving the highest classification accuracy (98.96%) and F1-score (97.89%), largely due to its ability to retain critical features across multiple layers. This model particularly excelled in classifying the Cracks defect with perfect accuracy. In contrast, AlexNet, a Series Network, achieved the highest specificity (99.53%), also performing best in identifying Cracks. VGG-16 demonstrated superior precision (98.65%), with outstanding classification performance across Cracks, Delamination, and Encapsulation Discolouring classes. Meanwhile, VGG-19 excelled in sensitivity (98.10%), effectively identifying all true cases of Cracks and Delamination. These results highlighted the strength of Series Networks in handling structured, less complex classification tasks, while DAG architectures like ResNet-50 show superior performance in capturing deeper feature representations for high overall accuracy. The IoT integration, implemented via the ThingSpeak platform, enable remote visualization of classification performance metrics transmitted from MATLAB, with the system's effectiveness evaluated based on data transmission accuracy and the reliable display of results on the platform. This research demonstrated that while Series Networks offered efficiency in structured classification, DAG Networks provided superior deep feature extraction, making them more suitable for complex PV defect detection. The integration of deep learning with IoT enhanced result accessibility and supports more informed decision-making, potentially reducing manual inspection efforts in future implementations.

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TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Research Background

The use of renewable energy rather than fossil fuels for the production of electricity needed to be taken into consideration because of concerns about pollution that contributed to climate change. The escalating concerned surrounding the energy crisis and environmental pollution had brought increased focus on solar energy. This was primarily due to its clean, non-polluting nature and widespread availability [1]. The solar power system, a widely utilized form of renewable energy, comprised various components designed to efficiently harness solar energy. Photovoltaic (PV) panels were commonly employed to convert solar energy into a usable form for storage [2].

As seen by a significant capacity increased to 220 GW in 2022 [3], on-going research and cost reductions in solar PV energy systems had led to their broad use for distributed generation on both large and small scales. The increased in demand was ascribed to market-driven procurement and corporate power purchase agreements, particularly in the industrial domain, which was indicative of a wider movement towards the integration of sustainable energy. However, problems like the 25-year lifespan of PV modules, the vulnerability of partial shading-induced hot spots to power mismatches, and the environmental impact of PV waste containing heavy metals underscore the significance of automated methods for quickly detecting partial shading and resolving these issues, particularly in the context of large-scale systems where manual inspections were resource-intensive and impractical [4].

Defects such as partial shading, hotspots, and cracks can profoundly affected module efficiency [5]. A comprehensive study [6] had identified several common defects in PV modules, including cracks, snail trails, encapsulation discoloration, delamination, hotspots, degradation, and more. Failure to conduct regular inspections increases the probability of these defects occurring. To address these challenges, researchers had developed a promising solution that eliminated the need for human intervention by harnessing the power of computer intelligence. By leveraging Artificial Intelligence (AI), which simulated human thought processes, the PV industry can significantly enhance its monitoring of PV modules. AI's capacity to think like a human