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XAI Weld: An Interpretable Deep Learning Framework for Defect Localization in Welding using Grad CAM

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ABSTRACT

In the Industry 4.0 era, automated quality inspection is critical to the productivity of manufacturing, but the black box behaviour of deep learning models is a barrier to trust in industry. This paper presents an interpretable approach to defect detection and localization in shielded metal arc welding (SMAW). Based on a new dataset of more than 50 high resolution images from a collegiate engineering workshop, we address the challenge of data scarcity with cutting edge augmentation and transfer learning. A Deep Convolutional Neural Network (DCNN) was developed to classify defects such as porosity, cracks, and lack of fusion. To make the model interpretable, the idea incorporated gradient weighted class Activation Mapping (Grad CAM), which allowed the model to possess Explainable AI (XAI) capabilities. This approach generates visual heatmaps to show the exact pixel regions that contribute to the defective outputs. By validating the outputs against the existing literature on automated subassembly inspection, this paper shows that high precision defect detection is possible even with localized workshop data. The proposed system fills the gap between the complexity of AI models and their implementation on the shop floor. The proposed system allows manual welders to make decisions based on the visual feedback provided by the system.

Keywords: DCNN, XAI, Grad CAM, Defect Localization, Transfer Learning.

1. INTRODUCTION

In the present manufacturing scenario, Industry 4.0 has brought a major change in the manufacturing sector by introducing artificial intelligence (AI) into the manufacturing sector. Among the most difficult and important areas of automation is quality inspection. The main aim of this process is to reduce human errors and increase efficiency. Welding is a major part of structural manufacturing, but the traditional manual welding process is often susceptible to errors such as porosity, longitudinal cracks, and lack of fusion. Deep Learning (DL) has achieved immense success in classifying welding defects from images, but the black box problem related to these models is a challenge. Traditional neural networks can give a result for classification, but they cannot give an explanation for why a certain classification was done. This is a major challenge in using AI in manufacturing, as the manufacturing floor managers and manual welders need tangible evidence about the correctness of the AI model before accepting the classification results. This paper proposes to solve this problem by developing XAI Weld, a framework that not only classifies welding defects but also gives visual explanations for the classification results using Gradient Weighted Class Activation Mapping (Grad CAM). By focusing on interpretability, this study proposes to develop a harmonious relationship between AI and human abilities, rather than replacing them. The need for automated quality inspection has increased with the advent of Industry 4.0.In the conventional Shielded Metal Arc Welding (SMAW) process, quality inspection is performed by the trained eye of a skilled technician, which is susceptible to human error. As a result, there has been a paradigm shift in research towards Deep Learning (DL), where CNNs have shown a significantly better ability to detect structural irregularities than human inspection.

However, there is a trust gap. Most state of the art models are Black Boxes. They give a binary result (Pass/Fail) but lack any spatial information. A human welder must know the precise coordinates of porosity or cracks to do rework. While models such as YOLO perform well on clean data, they fail miserably in the gritty, real world environments of localized workshops with metallic reflections and unregularized lighting. The aim of this research is to fill this gap by incorporating Grad CAM into a localized DCNN system. With the ability to give visual heatmaps of defect coordinates, this system will make AI from a black box judge to a team player, giving welders human interpretable results.

The main objective of this research work is to develop a transparent and human in the loop diagnostic system that enables the transition of automated inspection from binary classification to spatial interpretation. The objectives of this research work are as follows: