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Research Article

Online Failure Detection using Deep Learning in FPGA PCB Interface

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Abstract – This research paper is aimed to present a real-time failure detection technique while working with Field Programmable Gate Arrays (FPGA) and interfaced Printed Circuit Boards (PCBs). In this research, we explored the feasibility of currently available innovative Deep Learning (DL) algorithms to detect the defects in variety of PCBs. In our proposed technique, we trained the YOLOv5 (You Only Look Once) algorithm with a few hundreds of defective PCBs' images, which were obtained from Kaggle, an online community of data scientists and machine learning practitioners. The advantage of using YOLOv5 is that the detection is carried out in real-time. In the next phase, after training, the algorithm undergoes validation and testing, where we tested with different images. The obtained results are promising, as the Deep Learning process successfully detects the defects on the PCBs.

Keywords – Deep Learning, FPGA, PCB Defect Detection, YOLOv5, Kaggle

I. Introduction

Embedded Vision Systems (EVSs) need guided Machine Learning (ML) and Computer Vision (CV) acceleration. Systems on Chips (SoCs) with programmable logic are an essential element of real-time EVSs. Although introducing CV to EVSs' design can be a complex process. Hence, the design strategy of Field Programmable Gate Arrays (FPGAs) is changing, especially in the sphere of EVSs. In current scenario, the FPGAs industries [1-7] provide a fully integrated solution that engineer can modify and build upon. Software engineers can get started on complex Machine Learning (ML) based image-processing designs. The new design solutions utilize software-based systems with integrated hardware acceleration, allowing faster development but also requiring new design methods and tools [8-10].

Embedded Vision Systems' Printed Circuit Boards (PCBs) have become integral to all electronic devices due to the diverse specification needs Therefore, for universal success and acceptance of the of users' requirements. Integrated PCB design requires being defect free. Printed Circuit Boards are manufactured on large scale and could be prone to certain defects, over a period. Defects in PCBs such as shorts, spurs, mouse bites, and pinholes thus cause issues like current leakage and open circuits, which in turn quickly either degrading performance or rendering the defective

PCBs useless in respect to its application.

Different Fault-Tolerance (FT) techniques [11-14] are employed to ensure that defects are kept to a minimum and that to increase the reliability and dependability of applications on ICs [1-14]. However, inspecting and diagnosing defects manually is a challenging aspect. It is time-consuming, expensive, and subjective, as in any field, calling for automation. In addition, PCBs can be extremely detailed and technically demanding, cramming multiple critical components into a small package. Thus, considering requirement of ensuring reliability and constrained challenges, an automated solution for detecting and classifying defects in PCBs is in demand.

Artificial Intelligence (AI) is becoming increasingly popular with the success of Deep Learning (DL) in many industrial applications. Some of these have been solving image analysis and segmentation problems to classify images and discover anomalies. This research employs DL techniques to identify defects in the PCBs. The background, implementation details, results, and conclusions will be presented in this paper.

II. Related Work

Broadly, the PCB defect detection techniques can be grouped in three categories, as mentioned below:

- Image processing-based techniques,
- Machine learning based techniques, and
- Object detection techniques.

The first technique is based on a MATLAB image-processing technique to discover and classify 14 different types of defects (see Table 1) in PCB [15]. The authors in this work [15], used a defect-free PCB's template, which is used as a reference image to map with the defected PCB image and if any difference is found after subtraction then the inspected image is classified as defective. The technique primarily uses morphology to discover the differences by comparing every pixel value between two images. The difference between two images (x, y) and $h(x, y)$ is expressed as in Equation (1). Consideration of outputs $g(x, y)$ used are just in negative and positive pixel image, since zeros values of data do not affect the output of the operation.

$$(x, y) = (x, y) - h(x, y) \quad (1)$$

In another research based on morphological image segmentation approach, a unique methodology have been presented for detecting the defects in PCBs and classify them as per defects [16]. This approach is based on image segmentation algorithm together with image processing theories. Printed Circuit Board defects have been identified using its morphology that is based on the structure or form of objects. Morphological filtering simplifies a segmented image, making it easier to find objects of interest. This is accomplished by blasting out the item contour, filtering small holes, and removing small projections. Morphology is implemented using MATLAB software [17]. Another morphological technique involving image subtraction operation compares a conventional PCB image with a PCB image to be inspected and discovers the faulty region [18].

III. Methodology and Method

A dataset of PCB images has been used to train a deep neural network [19]. The dataset has 1386 images classified into six defects listed below:

- Missing hole,
- Mouse bite,
- Open circuit,
- Short,
- Spur and
- Spurious copper.

Each of these types of defects are represented by at least 115 images with different positions and angles to denote possible faults.

In this paper, we built a convolutional neural network that is trained on 692 labeled images classified into the above mentioned six classes. The images are obtained from Kaggle [20]. Subsequently, distinct sets of images are used for testing and validation. The distribution chosen for training, validation and testing sets is 70, 20 and 10 percents respectively.

A. *Kaggle*

Kaggle is a crowd-sourced platform to attract, nurture, train and challenge data scientists from all around the world to solve data science, machine learning and predictive analytics problems. It has over 536,000 active members from 194 countries and it receives close to 150,000 submissions per month [20].

B. *YOLOv5*

The acronym YOLO is abbreviated for You Only Look Once. YOLO is an object detection algorithm that divides images into a grid system. Each cell in the grid is responsible for detecting objects within itself. In our work we used YOLO v5 for the object detection purpose as it is one of the best deep learning algorithms that is publicly available since the end of 2020 [21]. The key advantages of this algorithm are that it is faster than previous versions and that it is more accurate. We apply this technique to a relatively new domain viz. PCB quality check. Visually detecting the flaws in PCBs is a skilled labor-intensive task as there are a variety of problems. Scrutinizing a board's working condition involves testing tools such as multi-meter, thermal cameras, magnifying glass, and oscilloscope. If the appropriate defects are not detected in a timely manner, the whole PCB may be damaged. Our algorithm could predict most of the defects as shown in the results section. The application of such a system is convenient as users need to just upload an image of PCB and the algorithm detects if there is any defect in the image.

C. *Deep Learning Approach*

Deep learning [22] is considered as one of the powerful advances in machine learning research field and is used to simulate and develop the human brain concept and then interpret and analyze data such as image, voice and text [23, 24]. The success reason of traditional machine learning depends upon the handcrafted feature representation performance. Through this process, the aim of machine learning approaches is only to optimize learning weights and ultimately to achieve the optimal learning outcomes [25]. Different from the traditional machine learning methods, deep learning automatically tries to get the work of data representation and feature extraction completed [26, 27]. The classification and labelling images accuracy using deep learning outperforms any other traditional algorithms and get remarkable results that cannot be obtained using humans. Google nowadays uses DL to manage and control the energy at data centers of the company. More than 40 percent of their need of the energy is reduced for cooling. In turns, hundreds of millions of dollars are saved for the company and achieved more than 15 percent in power reduction. Robust and open-source software packages have been widely spread due to the advances in practical applications of deep learning. In addition, it urges the people to push the development forward.

D. *Convolutional Network*

Convolutional Neural Network (CNN) is a neural network type that has the capability to identify characteristics of the nature (features) of the input image. This method serves to extract the raw image into a classified image. The layer that is used to serve for extracting the image features is called a convolutional layer [28]. Convolution Neural Network has four layer architectures [29]. Namely, these layers are as mentioned below:

- Convolutional layer,
- Activation function,
- Pooling, and
- Fully connected layer

The Convolutional Neural Network power comes from the deep architecture, which extracts a set of discriminating feature representations at different levels of abstraction. Recently, it has been widely used in classification and recognition due to its remarkable performance [30, 31]. Its ability to learn rich image features is the main reason of its success. However, to train a deep CNN network needs plenty of labeled datasets for pre-training and optimize its hyper-parameters [32]. Convolutional Neural Networks are category of deep neural networks used especially in computer vision area such as image classification [33, 34].

IV. Experiments and Results

As introduced earlier, the dataset contains images of PCBs released by the Open Lab on Human Robot Interaction of Peking University. The dataset is synthetic as it is edited with Photoshop. It has different images classified based on the defects. Center the following figures show some samples from the dataset, such as a missing hole is shown in Figure 1.

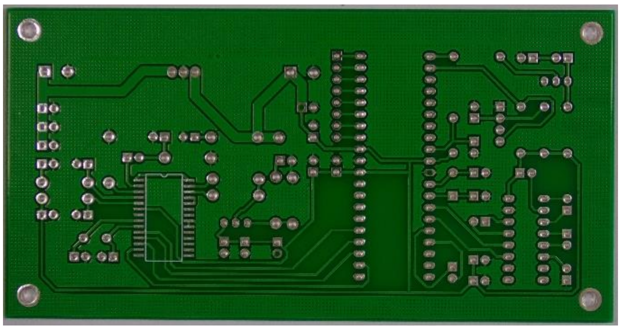


Fig. 1. PCB image with missing hole

The dataset also include a set of rotated images to enable the learning algorithm to demonstrate tolerance. The image rotation is performed randomly using a Python code that adjusts the position of image center when rotation is performed. An example of rotated image is shown in Figure 2, while Figure 3 depicts a raw image with another defect viz. spurious copper.

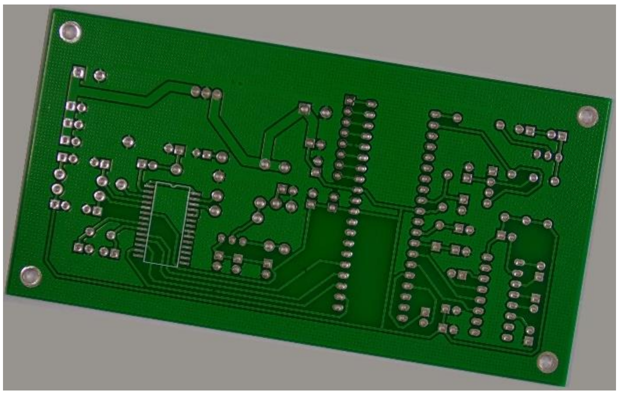


Fig. 2. Rotated image of PCB

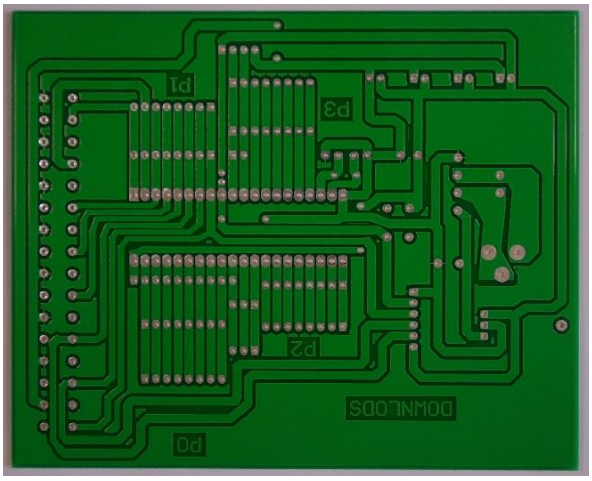


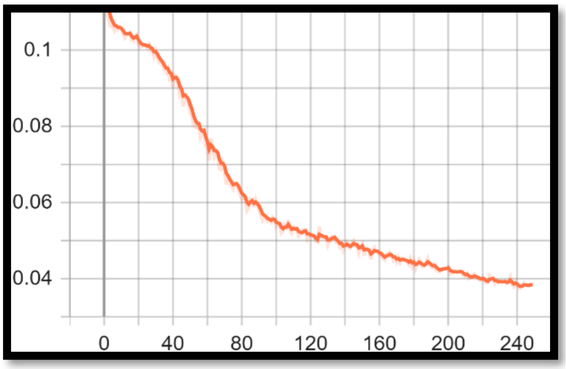
Fig. 3. PCB image with spurious copper

Roboflow is used to pre-process and organize the dataset. A screenshot of this is shown in Figure 4. YOLOv5 belongs to a family of object detection architectures that are pre-trained and open-source based on PyTorch and TensorFlow. Google Colab is the environment employed to conduct the experiments.

Fig. 4. Screenshot of distribution

The system instantly identifies the defects on PCB by drawing a bounding box around each defect. The accuracy is assessed based on the number of such boxes drawn automatically to the actual defects. TensorBoard is the visualization toolkit that has been used to depict the following charts.

Figure 5 plots the loss of fitting the bounding boxes. It shows that the error decreases over a period with an increase in the number of images. The chart



in Figure 6 shows that the classification error decreases. As the training sample size increases, the rate of misclassification is reduced.

Fig. 5. Missing the bounding boxes around defects in the images

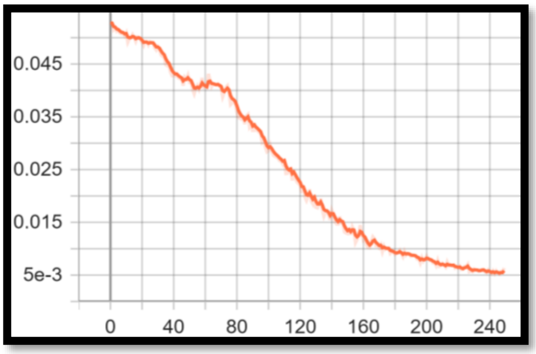
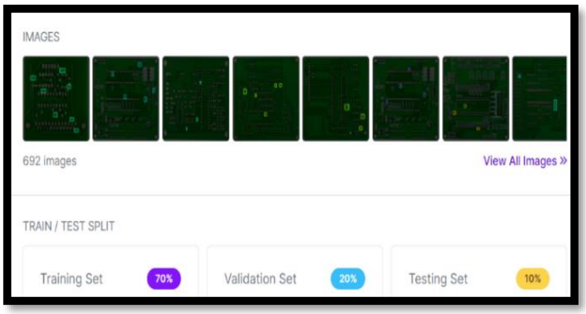


Fig. 6. Classification of error



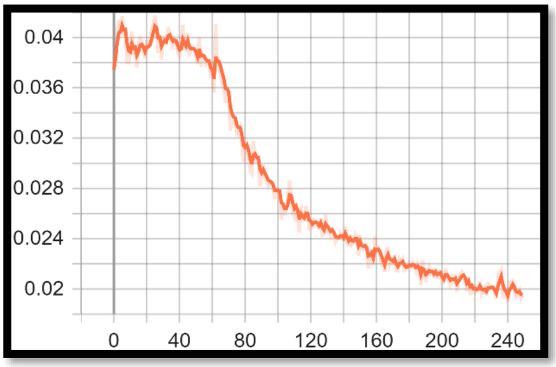


Fig. 7. Object loss in learning process

V. CONCLUSION

This paper presented an innovative application of Computer Vision to detect the flaws in PCBs. A Deep Learning model was built based on variety of training samples from Kaggle. The system was able to identify the defects precisely. The advantage of using YOLOv5 is that the detection is carried out in real-time. Hence, it can instantaneously spot the defects by drawing a bounding box around the defective part. Moreover, the accuracy of the learning model encourages to further explore Embedded Vision Systems.

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