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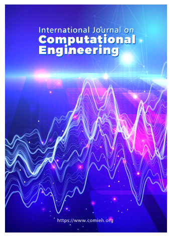

Product Design and Development Strategies for An Automated Printed Circuit Board (PCB) Defects Detection Systems

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Abstract— **Printed Circuit Board (PCB) defects, such as shorts, spurious copper, and missing holes, can severely impact the reliability and performance of electronic devices. In the industry, ensuring the quality of PCBs is crucial, yet conventional manual inspection techniques are time-consuming and prone to errors. This work aims to design and develop a low-cost, automated PCB defects detection system utilizing modern machine learning methods. The primary goal of the work is to create an efficient system that identifies PCB defects with high accuracy. Several conceptual designs were generated based on customer requirements. To refine these designs, quality functional deployment (QFD) and product design and development methodologies were applied. Using a Pugh chart, the best design was selected and further refined through concept scoring based on the highest scoring. Concept design 5 was selected as the best conceptual design. This approach provides a practical and economical solution for PCB defect detection, merging advanced object detection algorithms with accessible, cost-effective hardware. The prototype was fabricated and integrated, demonstrating that the system is highly accurate and efficient in identifying PCB flaws.**

Keywords— **Quality Functional Deployment (QFD), Printed Circuit Board (PCB) defects.**

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I. Introduction

Printed Circuit Boards (PCBs) are essential components in modern electronics, underpinning the functionality of a wide array of products, from consumer electronics to industrial machinery. Ensuring the quality and reliability of PCBs is paramount to maintaining the performance and longevity of these devices [1]. Historically, quality control in PCB production has relied heavily on visual inspection performed by trained personnel. While effective to some extent, this method is burdened with several significant limitations [2]. Firstly, manual inspection is subject to individualism, where human inspectors can suffer from fatigue and inconsistencies. These human factors introduce a higher risk of errors, potentially allowing defective PCBs to pass through the quality control process unnoticed. Secondly, manual inspection is inherently slow, which can bottleneck production lines and reduce overall productivity. As the complexity of PCB designs increases, the difficulty of manual inspection also scales, exacerbating these issues [3].

To mitigate these challenges, Automatic Optical Inspection (AOI) systems have been developed and adopted within the industry. AOI systems utilize advanced machine vision and image processing techniques to identify defects rapidly and accurately. These systems offer significant advantages over manual inspection, including improved consistency, speed, and the ability to handle complex PCB designs [4][5]. However, despite their effectiveness, AOI systems come with a substantial financial burden, particularly for small and medium-sized manufacturing companies. The high initial costs and maintenance expenses associated with AOI systems can be prohibitive, limiting their widespread adoption in smaller-scale operations [6].

The need for an affordable and reliable PCB defect detection system is clear. Small and medium-sized manufacturers require solutions that can bridge the gap between manual inspection and high-cost AOI systems, providing accurate defect detection without imposing significant financial strain. This work aims to address this need by designing and developing a low-cost, automated PCB defect detection system using readily available hardware and advanced machine learning techniques. This paper starts by describing methodology adopted in this work, followed by results found which are the House of Quality (HOQ), Conceptual Designs, Final concept design and the prototype.

II. Material and Method

Several studies have been conducted to identify the issues and problems associated with PCB defect detection systems in the manufacturing industry [7][8][9]. The primary concern identified was the inefficiency and high cost of existing systems[10]. For the literature review, information was gathered from various journals, articles, books, and websites. A market survey was conducted to review the products currently available in the market. In general, these products consist of a camera, frame, and monitor that work together to detect abnormalities during the inspection process. Four commonly used products in the industry were analyzed [11][12][13][14]. Using computer programming, these systems can efficiently display various types of faults on the monitor, providing a visual representation of the detected errors. Based on the survey findings, five (5) design proposals were developed in the form of sketches.

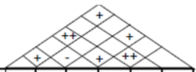
These designs were developed in response to user specifications. Several factors determining the design that satisfied the user's requirements were identified during the evaluation of the design concepts. Concept screening was performed to select the most relevant requirements, and concept scoring was used to narrow down the number of concepts under consideration. The concept with the highest rating was selected through this process. Finally, the chosen design concept was fabricated, and the system was integrated.

III. Results and Discussion

A. Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a structured methodology used in product development and quality management to translate customer requirements (what the customer wants) into specific technical requirements (how to achieve it) for each stage of product development and production [15][16]. It is a way to ensure that the voice of the customer is systematically incorporated into the design and manufacturing process, leading to products that meet or exceed customer expectations. Based on the customers' needs or requirements, the design of the automated defects detection system was produced. The House of Quality (HOQ) is shown in Table I, and its legend is in Table II. Based on the survey of the customers, the most important requirement rating is manufacturing cost. This would lead to a low-cost product that is affordable for industry use. Manufacturing cost and types of controllers to be used have a strong correlation, as indicated by the HOQ. In terms of relative importance weight, it also shows the highest value compared to other design targets. Thus, an affordable controller such as the Raspberry Pi 4 is selected as the target specification, as it is known to be an affordable controller for this detection system.

TABLE I
HOUSE OF QUALITY FOR DEFECTS DETECTION SYSTEM



		Customer importance	Manufacturing cost	User nterface	Camera resolution	Type of micro controller	Open source software	Display monitor
Customer requirement	Good image resolution	6			●			○
	Good accuracy	7			○	●		○
	Versatility	3		□			●	
	Reliability	4			○	●	○	
	Low processing time	5				●	●	
	Low cost	8	●	□	○			□
	Easy maintenance	1					●	
	Easy to handle	2		○			●	
	Importance weight		72	17	111	144	171	47
	Relative importance weight		13	3	20	26	30	8.4
		Target specification	Custom components	Open source	Arducam IMX219 Camera	Raspbery PI 4	YOLO v5,Python	7" inch LCD screen, HDMI

TABLE II
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Legend	
Strong relationship (9)	●
Medium relationship (3)	○
Weak relationship (1)	□
Strong positive correlation	(++)
Positive correlation	(+)
Strong negative correlation	(--)
Negative	(-)

B. Design Concept

Fig. 1 - 5 show four design concepts generated in this work. The first design concept Fig. 1 was generated with the feature to move the camera along one axis. This feature allows the product to adapt to different sizes of PCBs. Meanwhile, design concept 2 (Fig. 2) includes the feature of inspecting the PCB in a closed area. This would enable the product to control the lighting and adjust the brightness in a fixed environment. Design concept 3 (Fig. 3) is more or less similar to design concept 1, but in this case, the platform where the PCB is fixed can move along one axis instead of the camera as in design concept 1. This also allows defects in all areas of the PCB to be detected. Design concept 4 is the datum product, as shown in Fig. 4. Design concept 5 (Fig. 5) has the feature to adjust the height of the camera at z-axis.

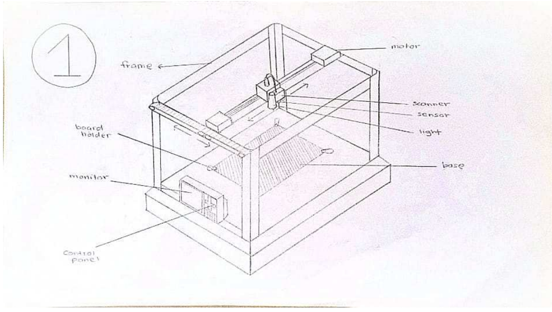

Fig. 1 Concept design 1

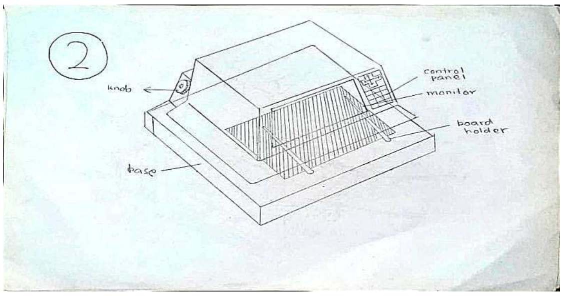

Fig. 2 Concept design 2

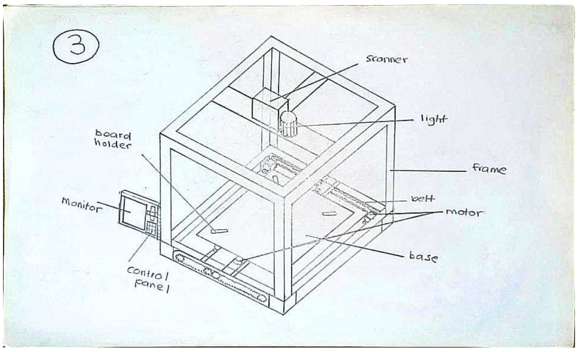

Fig. 3 Concept design 3

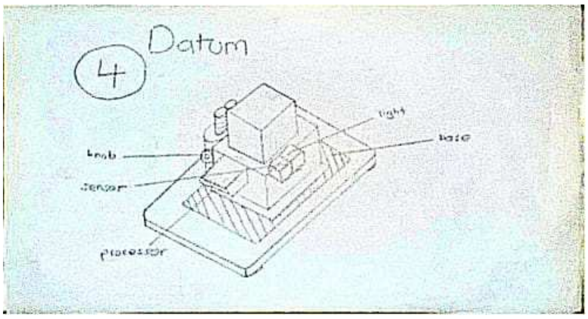

Fig. 4 Concept design 4

C. Final Design Concept and Prototype

The main aim of this work is to select the best concept design based on the concept scoring method. Thus, a method known as the Pugh chart (Table III) scoring method was used to select the best design. Based on this method, concept design 5 achieved the top ranking compared to other concept designs. Thus, concept design 5 was selected as the best final design for this product. The CAD design for this product is shown in Fig 6. The prototype of this product includes several main components such as a frame structure (aluminum profile), LCD screen, camera, Raspberry Pi 4, and acrylic plates as the base (Fig. 7). Additionally, other components are fabricated using a 3D printing machine (Fused Deposition Modeling). The dataset used in this work is from [17].

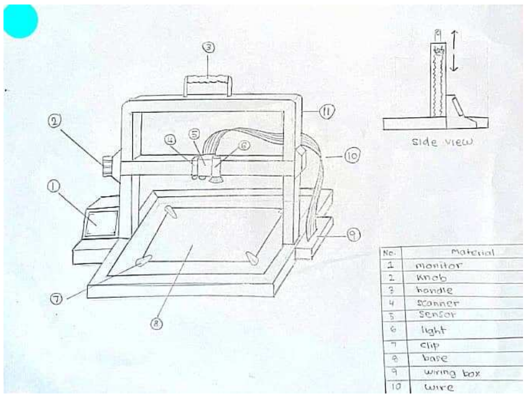

Fig. 5 Concept design 5

TABLE III
PUGH CHART

Selection criteria	Design Concept				
	Datum (4)	1	2	3	5
1. Able to detect defects accurately.		+	-	+	+
2. Low cost.		-	+	-	+
3. Processing time / speed.		-	-	-	-
4. Good image resolution.		+	+	+	+
5. Versatility.		+	-	-	+
6. Reliability.		-	-	+	+
7. Easy for maintenance.		-	S	-	-
8. Easy to use.		-	-	-	-
SUM of +		3	2	3	5
SUM S		0	1	0	0
SUM of -		5	5	5	5
Net Score	0	-2	-2	-2	0
Rank	2	3	4	3	1
Continue?	NO	NO	NO	NO	YES

To precisely identify these defects, this work uses a custom PCB defect dataset annotated using a program named "Roboflow." A YOLOv5 model is trained on Google Colab. The system then combines an Arducam Camera Module IMX219 with a Raspberry Pi 4 to take high-resolution pictures of PCBs, which are instantly inspected for flaws. The integrated system can detect defects on PCBs, as shown in Fig. 8.

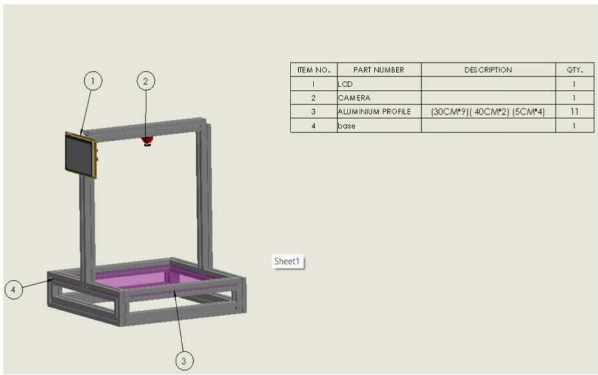

Fig. 6 Final design concept

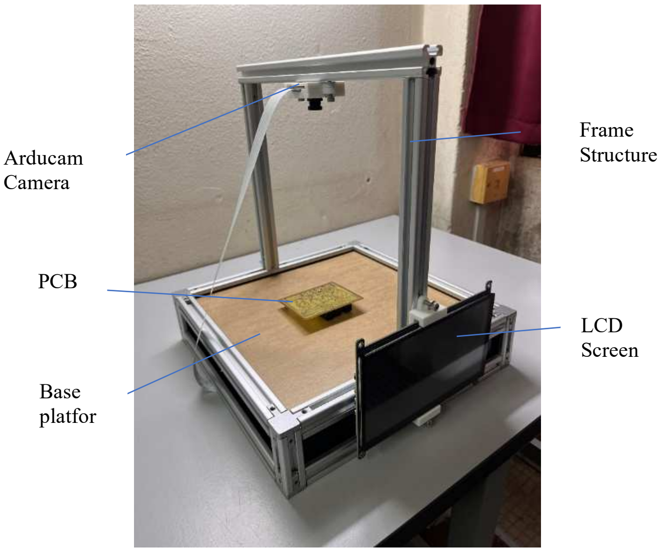

Fig. 7 Prototype of Defects Detection System

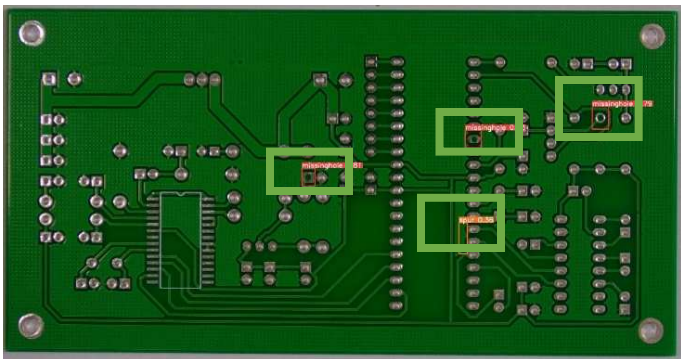

Fig. 8 Final design concept

IV. Conclusion

This study explored the fundamental design elements of an automatic defect detection system. Through the application of product design and development methodologies, particularly Quality Function Deployment (QFD), key design criteria were quantified in alignment with customer requirements. These criteria included reduced manufacturing costs, high accuracy, and good image resolution. Using the concept scoring matrix as a criteria-based decision-making tool, the research identified the most viable alternatives and solutions. Consequently, the study successfully developed a prototype that is less complex, cost-effective to manufacture, and maintains a high level of accuracy.

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