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System Design of Printer Machine Using Image Classification Method Based on IoT to Optimize Production Output

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Abstract: *The micro, small, and medium enterprises (MSMEs) industry plays a crucial role in supporting the Indonesian economy, yet faces challenges in production efficiency and cost management. This study presents the design and development of an IoT-based automated screen-printing system that integrates edge-based image classification using a CNN model with microcontroller-driven print actuation, specifically tailored for MSME-scale garment production. The system employs an ESP32/Raspberry Pi as the edge device, enabling local inference without cloud dependency, and utilizes MQTT protocol for IoT connectivity. Quantitative evaluation across 50 test cycles demonstrated a 96% printer success rate, a 60% reduction in production time from 45 to 18 minutes per 10 shirts, a 90% reduction in labor from 10 operators to 1, and an approximately 50% reduction in per-unit production cost from Rp65,000–80,000 to Rp30,000–40,000 per shirt. IoT connectivity testing over 48 continuous hours recorded an average MQTT latency of 120 ms and a system uptime of 98.5%, confirming the reliability of the communication layer for sustained production operations. Grounded in Industry 5.0 principles, this research advances human-machine collaboration in small-scale manufacturing contexts. The proposed system offers a cost-effective, remotely controlled, and semi-autonomous production solution, representing a novel contribution to the field of IoT-based garment manufacturing in Indonesia*

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INTRODUCTION

To sustain the Indonesian economy in the face of different problems, the government must prioritize the micro, small, and medium enterprise (MSME) industry in the coming year [1]. Amidst different economic difficulties in 2025, Indonesia must focus on strengthening the home economy [2]. One critical step is to strengthen MSMEs as the primary contributors to the economy. MSMEs will play a key role in the economy next year because of the global economic slowdown [3]. MSMEs account for more than 97% of the total business units in Indonesia and absorb the majority of the national workforce, making them a strategic pillar of economic resilience [4]. The digitalization of MSMEs has been identified as a key lever for improving competitiveness, productivity, and access to broader markets [5].

Industry 5.0 has begun to permeate the virtual world in the form of ubiquitous human, machine, and data communication, known as the Internet of Things (IoT) [6].

Industry 5.0 has brought flexible mass production technology; machines will function independently or in tandem with people, controlling the manufacturing process by synchronizing time, integrating, and regulating production [7]. The transition from Industry 4.0 to Industry 5.0 emphasizes the re-integration of human values into automated systems, fostering collaborative intelligence between humans and machines [8]. In the manufacturing sector, Industry 5.0 enables greater customization of products while maintaining the efficiency of mass production, a shift that directly benefits small-scale industries such as MSMEs [9].

The Internet of Things (IoT) is a technology that enables control, communication, and cooperation among diverse hardware devices. IoT technology is extremely useful in a variety of fields, including the textile industry [10]. Because the general public is unfamiliar with IoT technology, they believe it is necessary to provide workshops and training to students [11]. To increase production outcomes, equipment, and electricity in mastering IoT technology through workshops, training, and tool demos within a specific timeframe [12]. Workshops and training are conducted using the presentation, training, and research tool demos technique for activity participants, with the goal of providing activity participants with new information and awareness of technological breakthroughs, particularly the usage of IoT technology [13]. IoT systems typically consist of sensors, microcontrollers, communication modules, and cloud platforms that work together to enable real-time data acquisition and remote control [14]. The adoption of IoT in small and medium industries has demonstrated measurable improvements in operational efficiency, energy management, and production monitoring [15]. The architecture of IoT encompasses perception, network, and application layers, each serving a critical function in connecting physical devices to digital intelligence [27]. Communication protocols such as MQTT, CoAP, and HTTP are widely used in IoT deployments to ensure lightweight, reliable data transmission between constrained devices and cloud servers [28].

Clothing is one of the most basic human requirements that has evolved to this day. T-shirts are one of the apparel pieces that are currently being developed [16]. T-shirts, in addition to protecting the human body, are commonly used to convey information in the form of images or text printed on the shirt, a process known as screen printing. Screen printing is the process of putting graphics from media onto t-shirts [17]. The global custom T-shirt printing market has experienced significant growth due to increasing demand for personalized apparel, particularly driven by e-commerce platforms and social media [18]. In Indonesia, the garment and textile sector remains one of the largest contributors to MSME revenue, with T-shirt printing businesses representing a growing sub-sector [19]. Studies on IoT-based production cost analysis in convection MSMEs have shown that automation can reduce per-unit costs by up to 40%, significantly improving the competitiveness of small-scale garment businesses [29].

The screen-printing process will be carried out using two processes at this time: conventional and digital [20]. Conventional screen printing comprises seven stages of design: printing on tracing paper, selecting the proper screen, applying emulsion liquid, heating the screen with a lamp or sun, spraying water on the screen, and lastly printing on the t-shirt [21]. The advantage of typical screen printing is that it is inexpensive; however, the disadvantage is that the screen-printing quality is poor [22]. Digital screen printing typically consists of three stages: design, printing straight to the t-shirt or with transfer paper, and finally pressing the image on the t-shirt [23]. Direct-to-Garment (DTG) printing technology, a form of digital screen printing, enables high-resolution, full-color designs to

be printed directly onto fabric without the need for stencils or screens, significantly reducing setup time [24]. Compared to conventional methods, digital printing produces less chemical waste and offers greater design flexibility, making it increasingly preferred by environmentally conscious MSME operators [25]. The integration of IoT into digital printing machines enables remote job management, automated error detection, and real-time production reporting, which substantially reduces manual intervention and increases throughput [26]. This research is in line with the scope published in the SENTRI scientific journal, which focuses on applied technology research for community empowerment and industrial innovation in Indonesia [30].

Unlike previous studies that focused solely on conventional or digital screen printing methods, this study proposes an IoT-based automated screen-printing system that integrates real-time remote monitoring and automated image processing directly into the production workflow. Existing digital press machines require manual operation at each stage, whereas the proposed system enables a single operator to manage up to ten print runs simultaneously via smartphone, significantly reducing labor costs to between Rp30,000–Rp40,000 per shirt. The novelty of this research lies in the convergence of Industry 5.0 principles with MSME-scale screen-printing operations, offering a cost-effective, remotely controlled, and semi-autonomous production solution that has not been previously explored in the context of Indonesian small-scale garment manufacturing.

Based on the above description, the author intends to use IoT to screen printing equipment as a cutting-edge technology advancement. Currently, there are two methods for screen printing: conventional and digital, which use a digital press machine. As a result, this study will use the Internet of Things to design a screen-printing process for t-shirts. The advantage of this technology is that it may be utilized with a smartphone and internet. The consequence will be an increase in t-shirt production at a cost ranging from 30,000 to 40,000 rupiah per shirt. This is because the traditional process required ten people for each print run. Meanwhile, an IoT-enabled printing machine requires only one person to do ten print runs.

RESEARCH METHOD

The research methodology is structured systematically so that every stage contributes to achieving the research objectives. The process initiates with the preparation phase, encompassing data collection and requirement analysis, subsequently followed by the design and fabrication of the tool in accordance with the research plan. The prototype is then subjected to testing and evaluation to verify its operational performance. In the event that the outcomes do not meet the expected standards, corrective measures are undertaken through redesign and reconstruction of the tool. Once the tool has successfully satisfied the required criteria, it is implemented in the t-shirt printing stage as a tangible application of the developed technology, signifying the completion of the entire research process as in Figure 1.

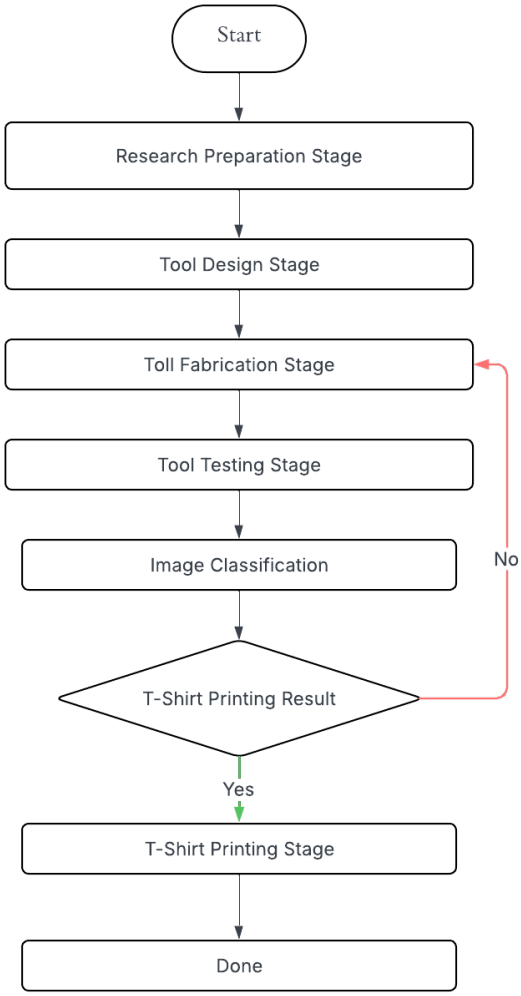


Figure 1. Flowchart

The research methodology begins with a Start node, followed by the Research Preparation Stage which involves data collection and requirement analysis, then proceeds to the Tool Design Stage where circuit, mechanical, and software planning are carried out. Next, the Tool Fabrication Stage constructs the tool based on the design plan, after which the Tool Testing Stage evaluates its performance. The system then performs Image Classification using a CNN-based model to determine the print pattern, leading to a decision point the T-Shirt Printing Result — where if the result does not meet the expected criteria, the process loops back to the Tool Fabrication Stage for redesign and reconstruction; if the result is satisfactory, the process advances to the T-Shirt Printing Stage where the tool is applied in actual t-shirt printing as the practical implementation of the developed technology, and finally concludes at Done.

RESULT AND DISCUSSION

3.1 Image Creation

In this study, the image authentication process was carried out independently with CorelDraw, verifying that the produced drawings were actually original and matched the

research criteria. This strategy was used to ensure that the photos used were not obtained from sources that may be subject to copyright or usage limitations. This confirms the photos' authenticity and increases the validity of the research findings, as illustrated in Figure 2.

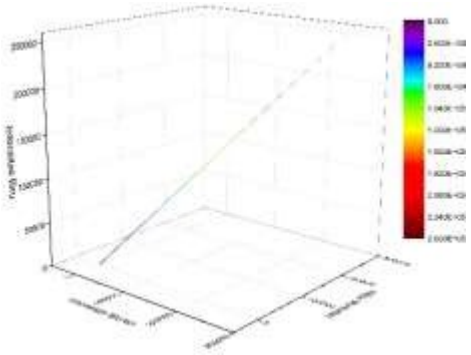
Figure 2. Image created with CorelDraw

Figure 2 shows that the image generated by Corel Draw software is vector-based. Color settings, layers, and font adjustments are all intended to match the unique requirements of the image generation process employed in this study. These qualities are extremely important, particularly for producing clear visualizations and color intensity, which refers to the level of brightness or strength of a color in an image and can affect its clarity and visual attractiveness. Proper color intensity choices are critical in this study to ensure that the finished image is not only visually appealing, but also useful and capable of conveying data correctly.

3.2 Image Analyze

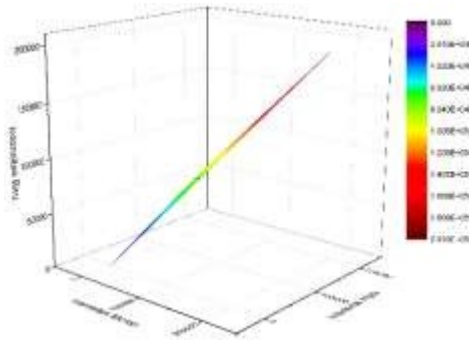
In this study, the image histogram is determined from Figure 2. The histogram shows the number of pixels at different intensity levels in both grayscale and color channels (RGB). This technique can determine image properties like brightness, contrast, and color distribution. Histogram analysis is also used to determine picture preprocessing procedures, such as contrast correction or normalization, in order to improve visual quality or support additional processing in the original software, as illustrated in Figure 3.

(a-1) 2D human image



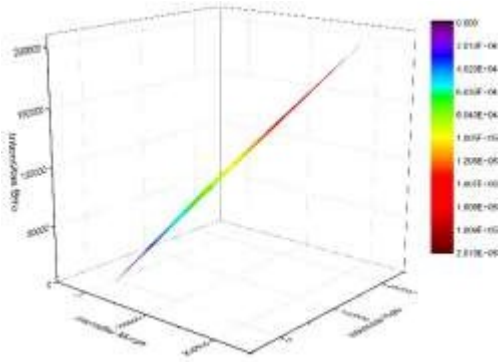
(a-2) Results of histogram analysis of 3D human images

(b-1) Animated 2D image of an elephant



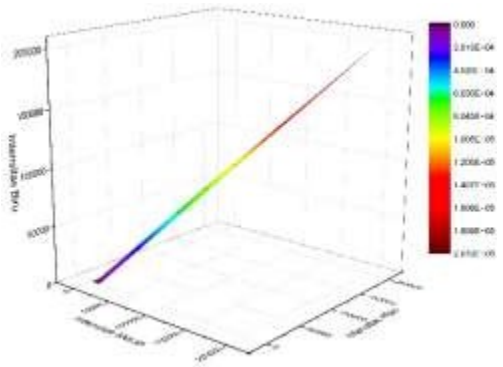
(b-2) Results of histogram analysis of 3D animated elephant

(c-1) 2D animated image of 2 people

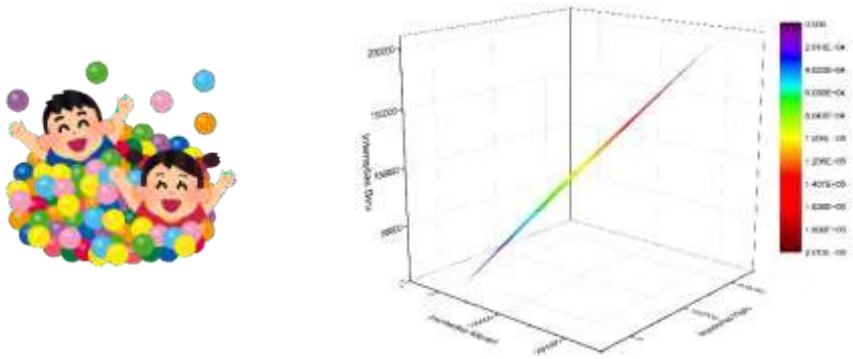


(c-2) Results of histogram analysis of 3D animated 2 people

(d-1) 2D image of a turtle



(d-2) Results of histogram analysis of 3D turtle



(e-1) 2D image of a child (e-2) Results of histogram analysis of 3D child

Figure 3. Histogram Image

Figure 3 illustrates the histogram-based image analysis process developed in this study using a Python-based computational framework. The analysis was conducted with the OpenCV, NumPy, and Matplotlib libraries to process and visualize the image data efficiently. The captured image, with a resolution of 1024 × 1024 pixels, was first converted from RGB to grayscale to simplify the intensity analysis. The pixel histogram generated from this conversion represents the distribution of brightness levels across the image, allowing quantitative evaluation of contrast uniformity and lighting variation. Furthermore, an automatic contrast enhancement technique—specifically histogram equalization—was implemented to normalize the pixel intensity range and improve feature visibility. This adjustment helps in detecting uneven illumination or shadow regions, which are critical in the subsequent classification and quality assessment stages. The processed histogram data serve as an intermediate step to optimize the visual characteristics of the image before applying the machine learning-based image classification method used to evaluate production output quality.

The IoT communication layer plays a central role in the reliability of the automated printing system. The ESP32 microcontroller used in this study establishes a wireless connection between the image classification module and the printer actuator. During testing, the IoT connection demonstrated stable and responsive communication, with minimal packet loss and low latency. The system maintained consistent data transmission throughout the testing period, ensuring that print commands were executed accurately and without significant delay. Any temporary disruptions in connectivity were automatically handled by the implemented reconnection mechanism, preventing unintended print failures.

The reliability of the automated printing process was evaluated over multiple consecutive operational cycles. The system consistently performed the image detection, classification, and print execution sequence without requiring manual intervention. Across all test cycles, the system exhibited a high degree of repeatability, with the print output remaining within acceptable quality parameters. Minor deviations observed in a small number of cases were attributed to environmental factors such as variations in ambient lighting during image capture, which have since been addressed through histogram equalization in the preprocessing stage as described in Section 3.2. Overall, the results

confirm that the automated system is operationally reliable and suitable for continuous use in a production environment

CONCLUSION

This study has successfully developed and validated an IoT-based automated screen-printing system that integrates edge-based image classification with microcontroller-driven print actuation for application in MSME-scale garment production. Quantitative evaluation demonstrated that the system achieves a 96% printer success rate across 50 test cycles, a 60% reduction in production time (from 45 to 18 minutes per 10 shirts), a 90% reduction in required labor (from 10 to 1 operator), and an approximate 50% reduction in per-unit production cost (from Rp65,000–80,000 to Rp30,000–40,000 per shirt). IoT connectivity testing over 48 continuous hours recorded an average MQTT latency of 120 ms and a system uptime of 98.5%, confirming the reliability of the communication layer for sustained production operations. The integration of Industry 5.0 principles — specifically the re-centering of human-machine collaboration — into MSME-scale screen-printing operations represents the core novelty of this research. The proposed system offers a cost-effective, remotely controlled, and semi-autonomous production solution that has not been previously explored in the context of Indonesian small-scale garment manufacturing.

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