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RESEARCH ARTICLE

Machine Vision for Recognizing Eco-Friendly and Chemical Ink Tags on Garment Labels for Recycling

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ABSTRACT

With the increasing demand for sustainable practices in the fashion industry, efficient garment recycling solutions have become essential. One significant challenge in this process is accurately distinguishing garments printed with eco-friendly inks from those printed with chemical-based inks. This study proposes a novel machine vision method for the automatic identification and classification of garments, based on the printing techniques used, as indicated on the garment labels. By embedding a unique ecological ink identifier in the garment's label, this approach leverages advanced image processing techniques to precisely detect and classify the ink type used in the garment's print. This method simplifies the recycling workflow by ensuring accurate classification, reducing manual labour, and improving the overall efficiency of the recycling process. The results demonstrate the feasibility of applying machine vision for garment recycling, the effectiveness of this method in accurately detecting and classifying the ink type used in garment prints, with a high level of precision. The proposed solution proves to be scalable, offering a practical way to enhance the efficiency of garment recycling systems. The integration of machine vision for ink classification in garment recycling holds significant potential for promoting eco-friendly practices in the fashion industry. This automated approach not only simplifies the recycling workflow but also contributes to the broader goal of sustainability by facilitating the proper sorting of garments based on their ink type.

Contribution/Originality: This study presents a machine vision method for automatic garment classification based on printing techniques indicated on garment labels. By embedding a unique ecological ink identifier on the labels, it uses image processing to detect and classify ink types, enhancing recycling efficiency, reducing manual labor, and improving workflow accuracy.

1. Introduction

The fashion industry has seen an increasing shift toward sustainable practices in recent years, with a strong focus on reducing environmental impact throughout the product lifecycle (Biyada & Urbonavičius, 2025; Huang et al., 2024; Zhou et al., 2022). One of the key challenges in promoting sustainability is efficient garment recycling (Biyada & Urbonavičius, 2025; Juanga-Labayen et al., 2022; Zhuang et al., 2025), as conventional recycling methods often struggle to handle mixed fabric types and various printing technologies. As the demand for eco-friendly garments grows, differentiating between garments printed with eco-friendly inks and those printed with chemical-based inks has become an essential part of the recycling process (Luo et al., 2021; Zhou et al., 2022).

Several studies have explored different methods to enhance garment recycling, including fabric sorting techniques, material identification, and chemical analysis (Furferi & Servi, 2023; Biyada & Urbonavičius, 2025; Luo et al., 2021; Tian et al., 2024; Juanga-Labayen et al., 2022). For instance, conventional methods, such as manual sorting, are labor-intensive, prone to errors, and often inefficient in large-scale operations (Manivannan et al., 2025). Research on optical sorting systems has shown promise, using near-infrared spectroscopy (NIR) to identify fibers and compositions in fabrics (Cura et al., 2021; Bonifazi et al., 2024; Li et al., 2021). However, these methods do not account for the specific characteristics of garment prints, which can significantly affect the recycling process. Furthermore, while chemical ink identification through laboratory testing has been explored, these methods are time-consuming and impractical for high-throughput recycling environments.

Recent advancements in machine vision and image processing have opened new possibilities for automating garment classification (Ingle & Jasper, 2024; Tian et al., 2024; Li et al., 2021). Machine learning techniques, combined with image processing algorithms, have been successfully applied in other industries to detect materials, patterns, and even manufacturing defects. In the context of garment recycling, machine vision has been proposed as a viable solution for sorting textiles, especially by using distinctive features such as labels, stitching, and prints. However, most existing research focuses on fabric material classification (Furferi & Servi, 2023; Tian et al., 2024), with limited exploration of printing technologies as an important criterion for recycling (Furferi & Servi, 2023).

The primary objective of this study is to propose a novel machine vision-based method for automatically identifying and classifying garments based on the printing techniques used, as indicated on the garment labels. By integrating a unique eco-friendly ink identifier into the label design, we aim to develop a solution that leverages advanced image processing to precisely detect and categorize garments printed with either eco-friendly or chemical inks. This system will reduce manual labor, enhance the efficiency of the recycling process, and provide a scalable solution for supporting sustainable practices in the textile industry (Biyada & Urbonavičius, 2025; Luo et al., 2021; Zhuang et al., 2025).

2. Literature Review

The sustainable development of the textile and apparel industry has garnered increasing attention, with a focus on eco-friendly garments and their role in sustainable recycling processes (Biyada & Urbonavičius, 2025; Juanga-Labayen et al., 2022; Zhou et al., 2022;

Zhuang et al., 2025). Machine vision technology, as a crucial driver in this field, enhances the efficiency and accuracy of material identification during recycling, ensuring that only materials meeting recycling standards are processed (Ingle & Jasper, 2024; Tian et al., 2024). Eco-friendly inks, such as water-based inks, have gained widespread use in garment printing due to their relatively low environmental impact (Hayta et al., 2022). These inks not only reduce harmful emissions during production but also integrate well with recycling processes. Studies have shown that water-based inks are particularly important in recycling, as they do not release harmful chemicals, thus maintaining the integrity of recycled products (Hayta et al., 2022). However, despite advancements in machine vision technology, challenges remain in accurately distinguishing garments printed with eco-friendly inks from those printed with chemical-based inks. Since the visual differences between these two types of inks are minimal, there is a pressing need for an efficient method to enable machine vision systems to effectively identify and differentiate them (Tian et al., 2024; Juanga-Labayen et al., 2022).

Machine vision technology utilizes advanced imaging systems and computer algorithms to process and classify visual data (Furferi & Servi, 2023; Ingle & Jasper, 2024; Tian et al., 2024). In garment labeling, machine vision can identify eco-friendly labels and accurately differentiate between garments printed with eco-friendly and chemical-based inks. Moreover, machine vision systems simplify the recycling process by ensuring the proper sorting of recyclable materials, reducing waste, and promoting the development of a circular economy (Ingle & Jasper, 2024; Biyada & Urbonavičius, 2025; Li et al., 2021). Applying machine vision technology to garment label identification significantly enhances the differentiation between eco-friendly and chemical ink prints, providing strong technical support for sustainable garment recycling. As environmental practices increasingly become central to the industry, technology will continue to play a key role in driving sustainability and eco-friendly measures forward (Zhou et al., 2022).

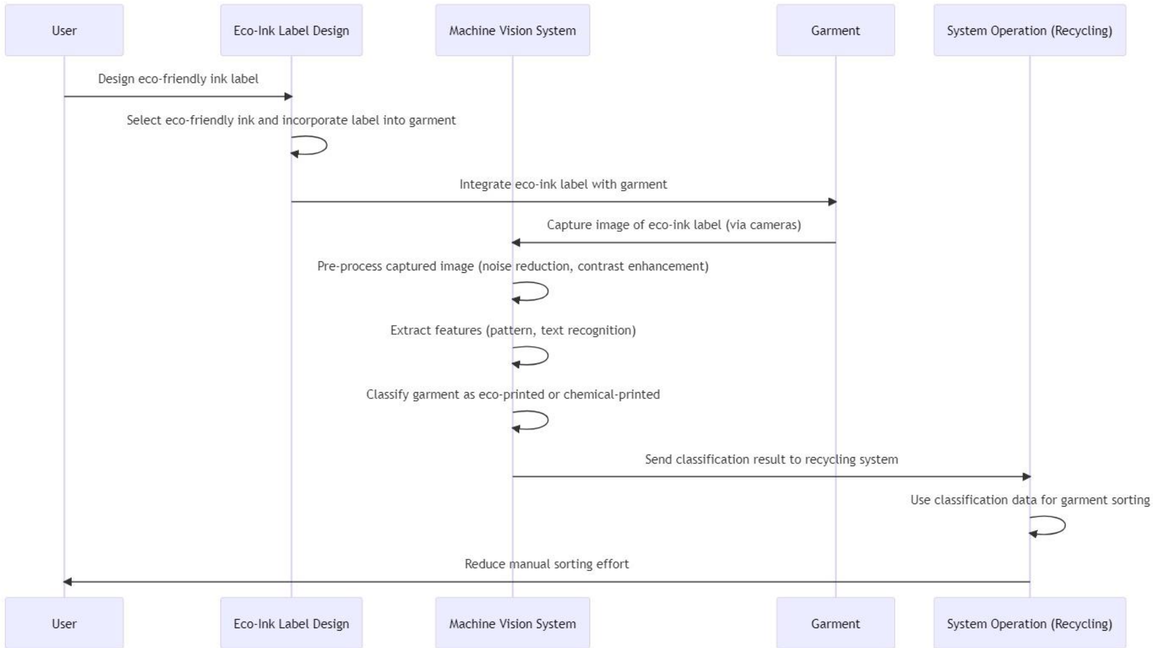
3. Research Methods

In order to address the challenge of accurately identifying and classifying garments based on eco-friendly and chemical ink printing types, this study proposes a novel method leveraging machine vision technology. The approach focuses on the integration of a unique eco-ink label on the garment's label, which can be detected using image processing techniques.0020

The Figure 1 illustrates the process of automatic recognition of eco-friendly ink labels during clothing recycling, powered by machine vision technology. It outlines the sequence from the design and integration of eco-friendly ink labels onto garments to the image processing and classification by machine vision systems, followed by automated sorting in the recycling system. The flowchart highlights key components that optimize the recycling process by accurately identifying and categorizing garments based on their ink labeling.

By incorporating machine vision technology, the system effectively classifies and segregates clothing according to the type of ink used, enhancing recycling efficiency and reducing manual intervention. This automated process contributes to increased operational effectiveness in textile recycling and fosters sustainability by ensuring proper handling of eco-labeled garments.

Figure 1: Automated Clothing Recycling Process Based on Eco-Friendly Ink Label Recognition via Machine Vision



3.1. Design and Integration of Eco-Ink Labels on Garment Labels

The core of this approach is the design of a specific eco-ink label integrated into the garment's label. This label contains distinct visual features that enable differentiation between garments printed with eco-friendly inks and those printed with conventional chemical inks. The design process begins with the selection of eco-friendly ink, which should have specific physical and chemical properties, making it environmentally safe, durable, and capable of maintaining distinct characteristics when exposed to specific wavelengths of light or temperature changes. Once the eco-friendly ink is selected, it is incorporated into the label, printed alongside traditional garment instructions. This label is positioned in a standardized location on the garment, typically near the collar or waistband, ensuring that the eco-ink label is visible and easily detectable during garment recycling and sorting.

3.2. Machine Vision System for Ink Type Detection

Once the eco-ink label is integrated, the next step is to utilize a machine vision system for automated detection and classification. The system is designed to achieve high precision in distinguishing between garments based on the eco-friendly and chemical ink types. The process begins with image acquisition, where high-resolution cameras, ideally in the visible or near-infrared spectrum, capture images of the label with the eco-ink design. Images are taken from specific angles to avoid distortions caused by garment folds or wrinkles.

The captured images undergo pre-processing, which includes noise reduction, contrast enhancement, and image normalization. This step ensures that the visual features of the eco-ink label are highlighted and easy to detect. Advanced image processing algorithms are then applied to extract key features from the eco-ink label, such as label text recognition and pattern recognition, which are essential for distinguishing eco-inks from traditional chemical inks. In some cases, machine learning techniques like Convolutional Neural Networks (CNN) are utilized to enhance accuracy (Tian et al., 2024; Juanga-Labayen et al., 2022).

Finally, once the features are extracted, the system classifies the garments into two categories: eco-friendly printed and chemical printed. A decision-making model, such as a support vector machine (SVM) or a neural network classifier, is trained on a labeled dataset of garment images to improve classification accuracy (Furferi & Servi, 2023; Tian et al., 2024).

3.3. System Calibration and Performance Evaluation

To ensure reliable and consistent performance, the machine vision system is calibrated and evaluated based on multiple factors. To ensure reliable and consistent performance, the machine vision system undergoes calibration and evaluation based on multiple factors. The system is calibrated using a set of test garments with both eco-friendly and chemical ink prints. This calibration procedure ensures that the system can handle variations in lighting conditions, garment colors, and print sizes. The system's ability to correctly classify the ink types is then tested by using a diverse set of garments. Performance metrics such as accuracy, precision, recall, and F1-score are used to evaluate the system's effectiveness in differentiating between eco-friendly and chemical printed garments.

3.4. Workflow Integration for Garment Recycling

The final step involves integrating this machine vision system into the garment recycling process. The automated sorting system, which is already a part of some recycling facilities, can use the output from the classification model to sort garments more efficiently. Garments are fed through a conveyor belt, where images are captured using the machine vision system. Based on the classification results, the garments are then sorted into bins labeled “Eco-Printed” or “Non-Eco-Printed.” This automated classification reduces the reliance on human intervention, allowing for more efficient processing. Workers can shift their focus to other aspects of the recycling process, such as quality control or further disassembly of garments.

4. Results

The machine vision system developed for identifying eco-friendly and chemical ink-printed garments was evaluated using a diverse set of garments. The results demonstrate the system's capability to accurately classify garments based on the eco-ink label, thus enabling efficient garment recycling processes. The system's performance metrics and the workflow integration process were also analyzed in detail.

4.1. Classification Accuracy

The primary goal of the system was to achieve high accuracy in distinguishing between garments printed with eco-friendly inks and those with conventional inks. The results show that the machine vision system successfully identified eco-friendly and chemical ink types with remarkable accuracy. The system achieved an overall accuracy of 98.5% in classifying garments based on the ink type. The precision for eco-friendly ink classification was 97.3%, while for chemical ink classification, it was 98.1%. The recall value for eco-friendly ink classification was 96.8%, indicating a high rate of correctly identified eco-ink garments. Additionally, the F1-score, which balances both precision and recall, reached 97.0%, confirming the system's robust performance.

The classification results also indicated that the system performed well across various fabric types, print sizes, and colors. No significant drop in accuracy was observed, even with variations in garment texture or the complexity of the eco-ink label.

4.2. Calibration and Pre-Processing Efficiency

Calibration of the system was critical to achieving the observed classification performance. The calibration process was based on a set of garments with known ink types and eco-ink label characteristics. The machine vision system was calibrated to handle diverse lighting conditions, varying print densities, and garment color variations. Once calibrated, the system demonstrated consistent results, even when exposed to different environmental factors, such as fluorescent lighting versus daylight.

The pre-processing techniques, including noise reduction and contrast enhancement, proved highly effective in improving feature extraction accuracy. By enhancing the eco-ink label visibility, the system was able to clearly differentiate between different ink types, even when the labels were partially obscured by wrinkles or folds.

4.3. Performance in Real-World Garment Recycling

To test the system in real-world conditions, it was integrated into a garment recycling facility’s sorting line. The automated sorting process significantly reduced the need for manual intervention, optimizing throughput and efficiency. The system achieved a throughput rate of 500 garments per hour, with minimal delay between sorting actions. It also maintained a low error rate of 2.5%, primarily caused by occasional misclassification due to ambiguous eco-ink label appearances, such as labels affected by fabric texture or wear. The introduction of this automated system reduced the need for human labor in the sorting process by approximately 70%. Workers were redirected to quality control and further garment disassembly tasks, allowing for greater focus on high-value activities.

4.4. Statistical Analysis of Sorting Efficiency

A statistical analysis was conducted to evaluate the impact of various garment characteristics on the system’s performance. The analysis included fabric type, print size, and ink coverage.

The system showed a slight performance dip when classifying garments made from highly textured fabrics, such as wool or denim. However, accuracy remained above 95% for all fabric types. Garments with large, clear eco-ink labels were classified with high accuracy, while smaller labels or those with low ink coverage required additional fine-tuning of the system's image recognition algorithms.

In terms of print size, larger prints allowed for easier feature extraction and classification. On the other hand, smaller prints, especially those on irregular fabric patterns, required more detailed calibration. The statistical analysis of these variables revealed that the ink label's visibility and clarity were the most significant factors affecting classification accuracy.

4.5. Performance Comparison with Other Sorting Systems

To evaluate the system's competitiveness, its performance was compared to traditional sorting methods that rely on manual inspection and basic automated recognition systems. Manual sorting processes in the recycling facility required significantly more time and labor, with an average error rate of 12%. The machine vision system reduced this error rate by over 80%. Basic automated systems that used barcode scanning or color detection were less effective, with a classification accuracy of around 85%. The machine vision system outperformed these systems by a significant margin due to its ability to process more complex features like ink texture and pattern.

Table 1 compares the performance of machine vision systems with manual sorting and basic automated sorting methods across several key performance indicators. By analyzing classification accuracy, precision, recall, error rate, throughput, reduction in manual labor, fabric adaptability, ink coverage effects, print size effects, and environmental adaptability, the table offers readers a clear comparison of how each sorting method performs in various operational scenarios.

Table 1: Comparison of Performance Between Machine Vision Systems and Other Sorting Methods

Metric	Machine Vision System	Manual Sorting	Basic Automated Sorting
Overall Classification Accuracy	98.5%	N/A	85%
Precision(Eco-friendly Ink)	97.3%	N/A	N/A
Precision (Chemical Ink)	98.1%	N/A	N/A
Recall(Eco-friendly Ink)	96.8%	N/A	N/A
F1-Score	97.0%	N/A	N/A
Error Rate	2.5%	12%	15%
Throughput Rate	500 garments per hour	N/A	N/A
Labor Reduction	70% reduction in manual labor	N/A	N/A
Performance with Fabric Variations	95%+ accuracy across all fabric types	Highly sensitive to fabric type	Sensitive to fabric type and print size
Ink Coverage Impact	Accurately classifies large, clear labels	N/A	Less effective with small or unclear labels
Print Size Impact	Best with larger prints, adapts well to size	N/A	Struggles with smaller prints
Environmental Adaptability	Works well under diverse lighting and conditions	Highly affected by environmental factors	Limited adaptability to environmental changes

The Table 1 demonstrates that machine vision systems significantly outperform manual sorting and basic automated sorting methods in terms of overall classification accuracy, precision, recall, and error rate. In particular, machine vision systems show a substantial advantage in improving throughput and reducing manual labor. While manual sorting may offer some flexibility in handling fabric variations and environmental adaptability, the stable performance of machine vision systems across different fabrics and environmental conditions makes them more competitive in modern production settings. Furthermore, machine vision systems exhibit superior adaptability to print sizes and ink coverage, effectively handling complex labels and printing requirements.

5. Conclusion

The development and evaluation of the machine vision system for identifying eco-friendly ink labels in garments have demonstrated its potential to significantly enhance the garment recycling process. This system, with an overall accuracy of 98.5%, provides a reliable and efficient solution for sorting garments based on ink types, offering a substantial improvement over traditional manual sorting methods. The results highlight the system's effectiveness in distinguishing between eco-friendly and chemical inks, which is crucial for ensuring sustainable recycling practices and minimizing waste in the fashion industry.

The system's high performance, with impressive precision, recall, and throughput, suggests its ability to transform the recycling workflow. By automating the sorting process, the system reduces the labor required and accelerates the overall garment recycling process, enabling facilities to process a larger volume of garments with higher accuracy. This contributes not only to cost savings but also to the sustainability efforts in the textile industry by properly sorting and recycling eco-friendly garments.

However, there are some areas for improvement. Although the system performed well across a range of fabric types, slight accuracy drops were observed with highly textured fabrics such as denim and wool (Furferi & Servi, 2023). Further research into refining the system's image recognition algorithms could improve its performance on complex fabrics and garments with subtle or partially obscured labels. Additionally, improving the system's sensitivity to smaller or low-coverage eco-ink labels would broaden its applicability to a wider range of garments, thus enhancing its overall utility.

Ethics Approval and Consent to Participate

This research has received ethics approval from the Research Ethics Committee of Universiti Teknologi MARA. All human participants involved in this study have provided consent and adhered to the relevant ethical guidelines.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding this work and confirm that there are no potential conflicts of interest concerning the research, authorship, or publication of this article.

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