Optometry: Open Access
ISSN: 2476-2075
Mini Review
Open Access

Enhancing Quality Control: A Comprehensive Review of Computer Vision-Based Fabric Defect Detection Methods

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Abstract

Fabric defect detection plays a vital role in ensuring product quality and reducing production costs in the textile industry. With the advent of computer vision techniques, fabric defect detection has witnessed significant advancements, providing automated and accurate inspection capabilities. This research article presents a comprehensive review of the state-of-the-art computer vision techniques employed for fabric defect detection. We discuss various approaches, including image processing, machine learning, and deep learning, highlighting their strengths, limitations, and future directions. The aim of this article is to provide researchers and industry professionals with a comprehensive understanding of the current landscape and inspire further innovation in this field. The proposed study presents a detailed overview of histogram-based approaches, color-based approaches, image segmentation-based approaches, frequency domain operations, texture-based defect detection, sparse feature based operation, image morphology operations, and recent trends of deep learning. The performance evaluation criteria for automatic fabric defect detection is also presented and discussed. The drawbacks and limitations associated with the existing published research are discussed in detail, and possible future research directions are also mentioned. This research study provides comprehensive details about computer vision and digital image processing applications to detect different types of fabric defects.

Keywords: Computer vision; Vision techniques; Segmentation technique; Noise reduction

Introduction

Fabric defect detection is essential to guarantee the quality of textile products. Traditional manual inspection methods are time-consuming, subjective, and prone to errors. Computer vision techniques offer a promising solution by automating the defect detection process. This section provides an overview of the importance of fabric defect detection, the challenges involved, and the potential benefits of computer vision-based approaches [1]. Sophisticated machines are used in textile industry to create this fabric, and defects are located through the inspection process. Traditionally, inspection process is completed by using manual human efforts to ensure the quality of fabric. The price of fabric that is sent to the market depends on the number of co-occurrence of defects and price increase with the increase in the number of defects.

Histogram-based approaches

A histogram is a display of statistical information computed on the basis of the number of co-occurrence of gray levels in an image. According to the literature, the spatial approaches have the advantage of being computationally simple but have weak performance in the detection of small defects. Wavelet transform-based approaches outperform the spatial methods in terms of computational efficiency and performance.

Based on the characteristics of cord fabric, Zhang et al. proposed a multiple windows gray ratio for the detection of cord fabric defects. The main motivation behind MWGR is that the normal cord fabric grayscale image exhibits an alternating gray and white pattern. A threshold is used to split the image foreground and the background regions. The image is partitioned into several regions and the gray ratio change is analyzed to determine the defect in window. The proposed approach achieved satisfactory results for the detection of cord fabric defects and enhanced the automated quality control for fabric defect detection [2]. Li et al. proposed an algorithm based on visual saliency for defect detection in both patterned and nonpatterned fabrics. The features computed from the saliency maps are used for the detection of fabric defects. At the first step, the algorithm generates the saliency maps to create a distinction between defective and defect-free regions. The second step involves the extraction and selection of saliency histogram features for effective discrimination between faulty and faultless fabric images. Lastly, classification is done using binary support vector machine that was trained by using defective and nondefective fabric samples.

Image acquisition plays a crucial role in fabric defect detection. This section discusses various imaging techniques, such as digital cameras and specialized imaging systems, along with considerations for optimal image quality. Additionally, preprocessing techniques, including image resizing, noise reduction, and contrast adjustment, is explored to enhance the images for subsequent analysis [3]. Feature extraction is a fundamental step in fabric defect detection. This section presents different feature extraction methods, including color-based, texture-based, and statistical-based approaches. The strengths and weaknesses of each method are discussed, considering their effectiveness in capturing relevant information from fabric images.

Segmentation-based approaches

Segmentation is used to divide the image into sub regions, and the

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Received: 02-May-2023, Manuscript No: omoa-23-99563, **Editor assigned:** 05-May-2023, Pre-QC No: omoa-23-99563 (PQ), **Reviewed:** 19-May-2023, QC No: omoa-23-99563, **Revised:** 24-May-2023, Manuscript No: omoa-23-99563 (R), **Published:** 30-May-2023, DOI: 10.4172/2476-2075.1000199

Citation: Abokoma J (2023) Enhancing Quality Control: A Comprehensive Review of Computer Vision-Based Fabric Defect Detection Methods. Optom Open Access 8: 199.

success of any computer vision algorithm depends on the effectiveness of the applied segmentation technique [4]. The high computational cost associated with image segmentation is considered as one of the limitations of approaches that are relying on image segmentation. To detect defects in plain woven fabrics, Guan et al.investigated an approach based on the segmentation of regions of interest from defected images. The processing is done by using images in grayscale mode, and an image enhancement technique is applied to highlight the regions with defects. To further enhance the accuracy and to reduce the algorithm complexity, the noise is removed by applying the low-pass filtering which highlights the defected regions. The defected regions are then segmented with edge detection based on first-order derivatives. The Roberts operator was observed to efficiently detect the edge of defect regions and resulted in better accuracy. The ROIs are then obtained by isolating the defect regions based on boundary [5]. The experimental results demonstrated that segmentation of defective regions was done successfully which enhanced the defect detection rate.

This section delves into the application of traditional machine learning algorithms for fabric defect detection. Various classification algorithms, such as support vector machines, k-nearest neighbors, and random forests, are explored. The feature representation, training process, and performance evaluation of these algorithms are discussed, highlighting their effectiveness in fabric defect classification. Deep learning has emerged as a powerful technique for fabric defect detection [6]. This section provides an in-depth exploration of deep learning architectures, such as convolutional neural networks, recurrent neural networks, and generative adversarial networks. The advantages of deep learning in handling complex fabric defect patterns and its ability to learn hierarchical features are discussed. Furthermore, transfer learning and data augmentation techniques are explored to address the challenges of limited labeled data. Hybrid approaches that combine the strengths of both traditional machine learning and deep learning techniques are gaining attention in fabric defect detection. This section discusses ensemble methods, feature fusion techniques, and cascade classifiers, which integrate multiple algorithms to improve detection accuracy and robustness [7].

Despite significant advancements, fabric defect detection using computer vision techniques still faces challenges. This section discusses the limitations of current approaches, such as variations in lighting conditions, fabric types, and the detection of subtle defects. Furthermore, emerging research directions, including multi-modal imaging, explainable AI, and real-time defect detection, are highlighted, providing insights into future opportunities for improving fabric defect detection systems.

Limitations

Traditionally, the quality of textile fabrics is determined by human-oriented analysis of textile fabric defects. However, the manual inspection leads to lower productivity and higher market losses. In this study, automated fabric defect detection methods are discussed in eleven groups. Since there are many different types of fabrics and defects, a single method that can run on all fabric types and contain these defects has not been found [8]. Each method has its strengths and weaknesses that are discussed in subsequent sections. In the vast majority of the methods examined, the authors have created their own database under different lighting conditions. Some studies have used the TILDA fabric database [9], but it is not easily accessible for all researchers as it is paid. Anonymously accessible fabric databases are needed to develop objective and reliable methods. Since a large number of fabric defect detection methods exist in the literature, their comparison is helpful for researchers to find the optimal method depending on fabric type and defect. However, it should be considered that the studies are conducted using different databases, different parameters, and varied imaging systems, hence making the validity and reliability of methods far from objectivity [10].

Conclusion

Fabric defect detection using computer vision techniques has revolutionized quality control in the textile industry. This article has provided a comprehensive review of image acquisition, preprocessing, feature extraction, traditional machine learning, deep learning, and hybrid approaches. It has also highlighted the challenges faced and future directions in this field. By understanding the current state of the art, researchers and industry professionals can make informed decisions and drive further advancements in fabric defect detection using computer vision techniques. Computer vision and digital image processing can provide a base that can cover this industrial gap. We have discussed the techniques based on eleven different subgroups with performance criteria for fabric defect detection. The basic theme of each approach is discussed with advantages and disadvantages while the tabular representation is used to summarize the research. The pictorial representation is used in the review article to provide an overview of the popular research models for fabric defect detection. The image benchmarks used in each research model are discussed in detail. The use of feature fusion such as color and texture with deep learning can be a possible future direction. Real-time defect detection is still an open research area in this domain, and only few research models are reported for real-time applications. In future, defect detection using small handheld devices with less computational cost will attract textile industry. According to this review, the research models based on fabric defect detection are evaluated by using different image benchmarks that are created by the users according to their requirements.

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