DEFECT DETECTION IN GARMENT INDUSTRY 5.0: DIGITAL HUMAN MODELLING APPROACH

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Abstract: *Garment manufacturing has embraced the integration of digital human modelling (DHM) within the context of Industry 5.0 (I5.0), where human-machine collaboration (HMC) is at the forefront of technological advancements. This chapter explores the synergy between DHM and defect detection such as stitching errors, pattern inaccuracies, fabric flaws, and alignment issues, in the context of Garment Industry 5.0. The combination of DHM and defect detection in Industry 5.0 facilitates real-time quality control, as well as improved accuracy and efficiency in garment production. This chapter discusses the opportunities and challenges associated with defect detection for DHM in the context of I5.0, with the collaboration between human expertise and artificial intelligence (AI) systems. The adoption of DHM and defect detection in I5.0 fosters a collaborative environment where humans and machines work together to enhance quality control processes, optimize production workflows, and ensure garments meet or exceed customer expectations.*

Key words: *Defect detection, DHM, Garment Industry 5.0, HMC, AI.*

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1. Introduction

Artificial intelligence (AI) is a powerful tool for detecting and analyzing garment defects at different stages of production and quality control in the context of Industry 5.0 (I5.0). AI can be employed to automate the inspection process, accurately identify defects, and analyze their characteristics. This technology enhances efficiency, reduces human error, and improves overall quality in the garment industry (Elemmi et al., 2022). In the context of garment production and quality control in I5.0, AI can be applied in the following ways:

AI, specifically deep learning techniques like CNNs, enhances visual inspection in the garment industry. Trained on labelled image datasets, AI models accurately recognize and classify defects such as stitching errors, fabric flaws, color inconsistencies, and misalignment. This improves quality control processes and overall product quality.

AI-powered systems enhance garment quality control by automating garment scanning and defect identification. This improves efficiency, reduces human error, and maintains consistent quality standards. Integrated cameras or scanning devices capture garment images, which are analyzed in real-time by AI algorithms for immediate feedback and corrective actions.

Defect classification plays a vital role in the garment industry, and AI technology offers the capability to learn and accurately categorize defects based on factors such as severity, type, and location. By training AI models on an extensive dataset of defect samples, the system can effectively identify and classify defects with precision. This classification process enables manufacturers to prioritize quality issues, allocate appropriate resources, and take necessary actions to rectify or prevent them. The accurate identification and categorization of defects provided by AI systems assist in optimizing quality control procedures and enhancing the overall quality management process in garment manufacturing.

Pattern recognition is a valuable application of AI in the garment industry, as it enables the analysis of garment patterns to identify anomalies or deviations from the intended design (Hann and Thomas, 2010). AI algorithms can compare these patterns against reference models or a comprehensive database, facilitating the detection of inconsistencies such as erroneous logo placement, inaccurate sizing, or deviations from the expected design specifications. This capability empowers manufacturers to proactively flag and address design-related issues, ensuring adherence to design standards and enhancing the overall quality control process in garment production.

Predictive analytics, facilitated by AI models, offer significant value in the garment industry by leveraging historical defect data to forecast and mitigate future defects. Through the analysis of patterns and correlations in defect occurrences, manufacturers can identify potential problem areas and implement proactive measures to address them effectively. The utilization of predictive analytics enables optimization of production processes, enhancement of material selection practices, and reduction of defects throughout garment manufacturing. By leveraging AI-driven predictive analytics, manufacturers can improve operational efficiency, enhance product quality, and minimize the occurrence of defects, thereby contributing to the overall success and competitiveness of their manufacturing processes.

Real-time feedback plays a crucial role in the garment industry, allowing for prompt detection and correction of defects. AI systems provide this immediate feedback to production line operators or quality control personnel. By enabling quick identification of defects, the likelihood of their propagation along the production line is reduced. As a result, real-time feedback contributes to higher overall quality and efficiency in the garment manufacturing process (Sjödin et al., 2021).

Data analysis and insights play a crucial role in the garment industry when utilizing AI technology (Tekic and Füller, 2023). AI has the capability to process large volumes of defect data, enabling the identification of trends and valuable insights. By analyzing this data, manufacturers can identify recurring defects, understand underlying causes, and make informed decisions to improve processes, maintenance, training, and supplier selection. This data-driven approach enhances manufacturing operations, reduces defects, and improves product quality.

The implementation of AI for garment defect detection and analysis in the context of I5.0 requires a combination of computer vision techniques, machine learning algorithms, and access to high-quality labelled datasets. Continuous training and refinement of AI models are essential in the garment industry for accurate and reliable defect identification. By regularly updating these models, organizations can enhance their quality control processes, reduce errors, and optimize production efficiency (Hristova, 2019). This commitment to ongoing improvement allows for better defect recognition and improves product quality and customer satisfaction. Table 1 presents the stages of production and quality control for AI-based garment defect detection.

Stage of Production	**Quality Control Process**	**AI-Based Garment Defect Detection**
Fabric Inspection	Automated fabric scanning and defect detection using AI algorithms	Identifying fabric flaws, misprints, or irregularities
Cutting and Sewing	Visual inspection of stitched garments by AI systems	Detecting stitching errors, misalignment, or uneven seams
Finishing and Trimming	AI-powered visual analysis of finished garments	Identifying defects in buttons, zippers, hems, or trimmings
Printing and Embellishments	AI-driven image analysis for printed or embellished garments	Detecting print defects, color inconsistencies, or misplaced embellishments
Final Inspection	AI-based comprehensive assessment of completed garments	Identifying overall quality issues, sizing discrepancies, or aesthetic flaws
Packaging and Shipping	AI-assisted scanning of packaged garments	Ensuring the absence of defects before shipping

Tab. 1. Quality Control Stages for AI-based Garment Defect Detection.

The adoption of digital human modelling (DHM) and defect detection in I5.0 fosters a collaborative environment where humans and machines work together to enhance quality control processes, optimize production workflows, and ensure garments meet or exceed customer expectations. As Industry 5.0 continues to shape the future of garment manufacturing, defect detection in DHM holds significant potential to revolutionize quality control practices and advance the overall productivity and sustainability of the industry.

This chapter presents a comprehensive exploration of defect detection in Garment Industry 5.0 using DHM approach. The concept of defect detection in the context of I5.0 is introduced, followed by the presentation of a potential artificial algorithm for effective defect identification. The methodological section emphasizes the integration of anthropometric data in the clothing industry to address the need for improved fit and sizing. Essential anthropometric measures are discussed for technological design, focusing on standardizing population comparisons and creating databases through the utilization of body measurement systems within the framework of I5.0. Furthermore, the concept of virtual human models and their role in simulating realistic human representation in virtual environments is explored. In conclusion, this chapter provides a comprehensive discussion of the findings, encompassing managerial implications, research limitations, and future research directions, thereby shedding light on the crucial aspects of defect detection in Garment I5.0 and paving the way for further advancements in the field.

2. Defect Detection in Garment I5.0

Defect detection in Garment I5.0 involves harnessing advanced algorithms to achieve enhanced quality control. Defects in a product can be indicative of inadequate quality, although their presence may not always signify a deficiency in the overall product. Various fabric imperfections can have unique effects on the size and fit of garments. Uneven fabric shrinkage can lead to a decreased number of items or post-purchase shrinkage after laundering. Flaws in fabric or sewing processes can result in stretched or distorted fabric, while processing-related folds or creases can introduce irregularities. During production, imperfections may be either disregarded or addressed to minimize their impact on the final product (Gill, 2008).

When addressing defect detection algorithms in garment manufacturing, artificial algorithms play essential roles, making notable contributions (Jeyaraj et al., 2019). Convolutional Neural Networks (CNN) stand out as the predominant algorithm employed in garment defect detection. Renowned for their exceptional proficiency in analyzing visual data, such as images or videos, CNNs prove to be well-suited for detecting an array of garment defects, encompassing stitching errors, fabric flaws, color inconsistencies, and misalignments. The remarkable capacity of CNNs to acquire and extract intricate features from garment images has significantly contributed to their widespread popularity and success in the realm of garment defect detection. Despite being extensively utilized, it is worth noting that various other algorithms can also be effectively applied in this context for garment defect detection. Table 2 indicates the applications of artificial algorithms for defect detection in garment manufacturing.

Algorithm	Application
Convolutional Neural Networks (CNN)	Stitching errors, fabric flaws, color inconsistencies, misalignments
Recurrent Convolutional Neural Networks (RCNN)	Stitching errors, fabric flaws, color inconsistencies, misalignments
Support Vector Machines (SVM)	Classification of various garment defects based on labeled data
Random Forest (RF)	Handling large and complex defect datasets, accurate defect classification
Deep Belief Networks (DBN)	Complex pattern and feature extraction from garment images
Genetic Algorithms (GA)	Parameter optimization for defect detection algorithms
Recurrent Neural Networks (RNN)	Analysis of sequential defect data, capturing temporal dependencies
Gaussian Mixture Models (GMM)	Clustering and classification of defects, distinguishing from normal patterns
K-Nearest Neighbors (KNN)	Similar defect identification and grouping

Tab. 2. AI Algorithms for Garment Defect Detection.

Visual inspection is essential for quality control in the textile industry. Automated product inspection using pattern recognition or defect detection software is becoming more prevalent. Early identification and correction of fabric defects are crucial to minimize costs. Manual quality assessment is time-consuming, and there is a need for faster and more accurate defect detection to keep up with production speed (Anagnostopoulos et al., 2001).

Design feature points play a significant role in cutting planes and virtual assembly applications, while body measurement enables the creation of virtual clothing shapes based on the symbolic structure of the human body. Nevertheless, 3D feature extraction, which encompasses feature recognition, remains a challenging aspect in geometric modeling and computer graphics (Donmezer, 2023).

3. Integrating Anthropometric Data in the Clothing Industry: A Necessity for Improved Fit and Sizing

The incorporation of anthropometric measurements for textiles into international standards is highly beneficial. Various instruments can be employed to record these measurements, including the relatively new application of 3D scanners in anthropometry. 3D scanners generate a 3D point cloud representing the human body, which finds application in multiple domains such as technological design processes, apparel and car design, reverse engineering, and medical applications. Recently, digital human models have been developed using 3D point cloud data, referred to as digital humans. Anthropometric data extracted from scans holds significant importance for quality control purposes and the diverse requirements of apparel applications. In several systems, anthropometry involves determining landmarks and placing marker stickers, with the scanner system then calculating the positions of these marker stickers (ISO 20685-2). This ISO 20685-2 standard provides guidelines and evaluation protocols for assessing the surface shape and repeatability of relative landmark positions when using 3D scanning methodologies for the creation of anthropometric databases. It aims to ensure the accuracy and reliability of 3D scanning techniques used in ergonomics and anthropometry research. The standard focuses on evaluating the quality and consistency of scanned data to support the development of internationally compatible anthropometric databases for various applications. Flowchart illustrates the needs of the clothing industry in relation to anthropometric data (Figure 1).

Fig. 1. Meeting the Clothing Industry's Needs: The Role of Anthropometric Data (Donmezer, 2023).

4. Essential Anthropometric Measures for Technological Design: Standardizing Population Comparisons and Database Creation

ISO 15535 provides essential anthropometric measures for comparing population groups and establishing anthropometric databases. These measures are valuable for ergonomists in defining population groups and using geometric data for designing work and living environments. The list also serves as a basis for extracting one- and two-dimensional measurements from three-dimensional recordings. It serves as a comprehensive guide for recording anthropometric dimensions, conveying foundational anatomical and anthropometric knowledge to ergonomists and designers (ISO 15535). Additionally, the standard clarifies measurement principles for developing design solutions (ISO 7250-1). With the aim of standardization and facilitating data comparison, ISO 15535 aligns with national or international agreements or regulations. It encourages the description of population groups and facilitates the comparison of anthropometric data among member organizations. Further specific measurements may supplement the anthropometric dimensions outlined in this International Standard, considering diverse application requirements (ISO 7250-1).

5. The Body Measurement System

The framework for 3D surface scanning in human body measurement addresses 3D surface scanning in human body measurement, while allowing for extension to include head, hand, and foot scanners. By promoting compatibility and interoperability, this framework enhances the effectiveness of human body measurement practices. The body measurement system incorporates a standing or sitting person, employing the X, Y, and Z axes to define directions. The X axis represents the direction from back to front (sagittal axis), the Y axis represents the direction from side to side (transverse axis), and the Z axis represents the lower direction to the side (longitudinal axis) (Figure 2). This system allows for precise and comprehensive body measurements in various orientations and positions.

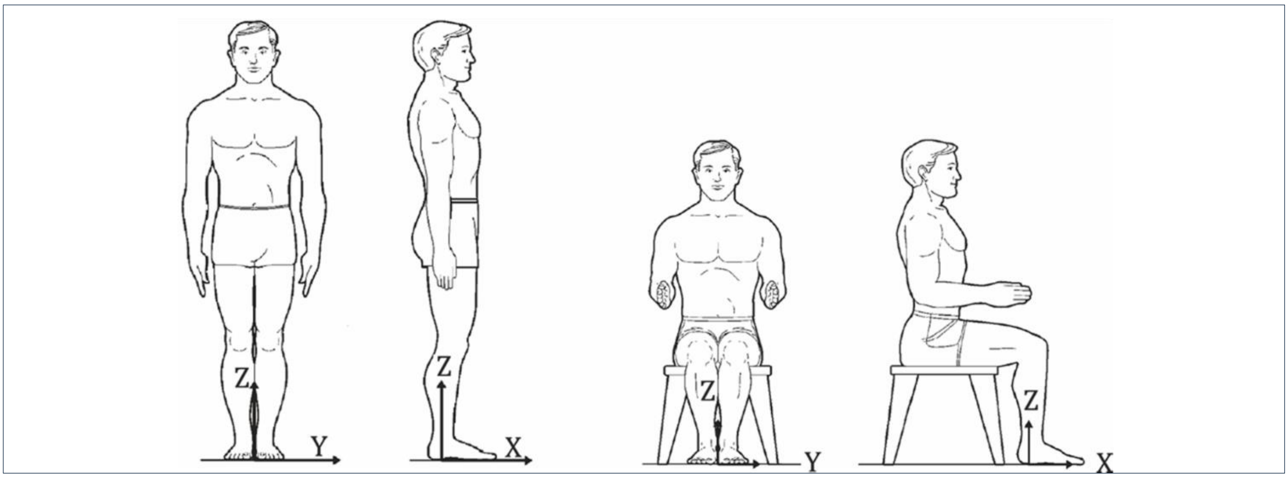

Fig. 2. Body Measurement System with X, Y, and Z Axes: Enhancing Precision in Standing and Sitting Positions.

6. Virtual Human Model: Simulating Realistic Human Representation in Virtual Environments

The virtual human model is created through 3D scanning of the real body and its conversion into digital formats. It finds applications in the apparel industry and various industrial uses. The model is based on the physical dimensions and shape characteristics of the human body. It is particularly relevant in the online fashion market, where virtual applications and digital technologies are used for sales and customization. However, the lack of international standards for the sizing system in textile production remains a challenge. Online sales aim to enhance communication and reliability of fashion products through visual confirmation (ISO 18825-1).

ISO 18825-2 is a standard that specifies the requirements for creating a virtual human body. The virtual human body includes a virtual skeleton that enables the body to express realistic motions and poses. This standard is aimed at users of virtual clothing systems, and its developed reliability can assist designers and manufacturers in the garment industry to create and test their clothing designs on a digital body before producing the actual garments. By doing so, designers and manufacturers can ensure that the final product meets a certain level of quality and is fit for its intended purpose.

ISO 18825-2 (Figure 3) provides standards for creating a reliable virtual human body, including a virtual skeleton that enables realistic motions and poses, which is essential in creating a robust digital human model for the garment industry.

The use of virtual joints in digital human modeling can improve the accuracy of garment defect detection in the garment industry, according to ISO 18825. While this standard is not directly intended for users of virtual human bodies by selling online, it can assist in improving the reliability of virtual human bodies for users of virtual clothing systems.

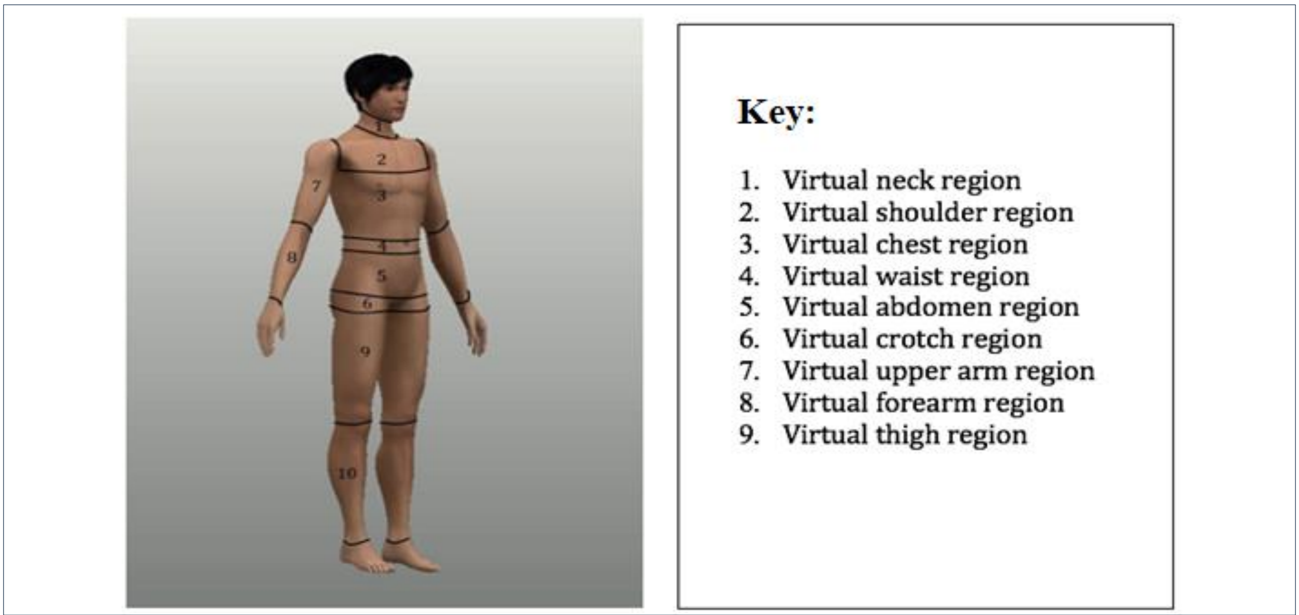

Fig. 3. The key point of a body (ISO 18825-2).

7. Conclusion

Basic human body measurements are crucial in technological design, especially in the garment industry. These measurements serve as a guide for designers and manufacturers in creating clothes that fit well and are comfortable to wear. The measurements can vary depending on factors such as age, gender, and ethnicity. In Garment Industry 5.0, the use of digital human modeling allows for a more accurate representation of these measurements and can help designers create clothes that fit a wider range of body types. This approach can lead to increased customer satisfaction and fewer returns due to ill-fitting clothing.

There is a lack of standardized sizing in women's and men's clothing globally, which contributes to inconsistent size charts across brands. This inconsistency creates confusion for customers when shopping online. Customers often experience disappointment with dress deliveries, leading to a decline in online clothing purchases. The increase in returns and decrease in customer loyalty can negatively impact profit margins.

In the garment industry, digital human modeling is becoming increasingly important with the advent of Garment I5.0. By creating a digital body, designers and manufacturers can simulate various body types and clothing designs, test for defects, and visualize the final product before it is produced. This approach can help reduce costs, speed up the production process, and improve the overall quality of the finished product. Furthermore, digital human modelling can detect defects in the early stages of the production process, which can minimize the need for costly rework and improve overall efficiency. As I5.0 continues to evolve, it is likely that digital human modelling will become even more widely adopted and will play an increasingly important role in the garment industry. Defect detection is an essential aspect of the garment industry, especially with the emergence of Garment I5.0. With the help of digital human modeling, defects can be detected and corrected before the garment is even produced. This approach not only saves time and money but also ensures that the final product meets an acceptable level of quality.

In conclusion, the utilization of digital human modeling in defect detection represents a significant advancement in ensuring garment quality and enhancing production efficiency. Digital human modeling presents a promising solution for defect detection in the garment industry. Through the creation of virtual human models, designers can effectively identify defects in garment design or construction that might otherwise go unnoticed during the traditional production process. This integration of advanced technology offers the potential to revolutionize the industry's quality control practices and contribute to the overall optimization and sustainability of garment manufacturing. By utilizing digital human modeling, designers can optimize the design and fit of garments, addressing potential issues that may not be apparent through physical inspection alone.

In the future, the research plan encompasses three key components. First, the evaluation of the AI-based defect detection system will be conducted in real-world settings. This evaluation will utilize comprehensive performance metrics to assess the system's accuracy and efficiency in detecting various types of defects. By validating the practical applicability and effectiveness of the defect detection solution, its ability to enhance product quality and optimize garment manufacturing processes will be ensured. Next, the research plan places a strong emphasis on establishing collaborative partnerships with garment manufacturers and industry experts. In proactively reaching out to potential partners, clear and precise communication of the research objectives will be essential.

Deploying AI-based defect detection systems in real-world production environments might encounter technical integration complexities. Factors such as existing infrastructure, compatibility with manufacturing processes, and cost implications need to be carefully considered and addressed during implementation. Convincing garment manufacturers to adopt and implement the proposed defect detection system requires overcoming potential resistance to change and demonstrating tangible benefits.

By thoughtfully considering and addressing these limitations, the research can develop practical and robust defect detection solutions that positively impact garment manufacturing processes and contribute to the industry's quality and efficiency. In this digital age, the comprehensive approach in this chapter seeks to improve garment product quality, minimize defects, and enhance manufacturing efficiency. This is achieved through validating and optimizing defect detection systems and fostering collaborative partnerships.

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