Smart cloth cutting and quality checking system for micro and small garments

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Abstract

The clothing sector is vital to local economies and job creation, especially for micro and small-scale businesses (MSEs). Due to their reliance on human procedures, these devices, however, have significant difficulties in maintaining cutting accuracy, reducing fabric waste, and guaranteeing constant product quality. Traditional cloth cutting is prone to errors including misalignments, uneven edges, and size mismatches, and quality testing relies heavily on human visual inspection, which is frequently laborious, unreliable, and prone to mistakes. In the fiercely competitive apparel industry, even little variations in size and quality can result in wasteful use of materials, increased expenses, and decreased consumer satisfaction. Specifically tailored for micro and small garment manufacturers, this study suggests a Smart Cloth Cutting and Quality Checking System that combines intelligent vision-based flaw detection with automated cutting mechanisms, providing a scalable, accurate, and affordable solution. In order to achieve precise cutting with a tolerance of ±0.5 mm, the system combines automated actuation tools with inexpensive embedded hardware and software components. To guarantee precise replication of design patterns and minimize material waste, the cutting unit makes use of programmable controllers. Convolutional Neural Networks (CNNs) are one of the machine learning and deep learning approaches used in a vision-based quality inspection module for defect classification. This allows for the detection of surface abnormalities such holes, misprints, irregular seams, and weaving faults. To improve inspection accuracy for printed and patterned materials, where conventional visual detection frequently falls short, a tactile-vision hybrid sensing technique is also investigated. The suggested solution prioritizes modularity and low installation costs, in contrast to large-scale garment automation systems, which are frequently out of reach for small businesses due to their technological and budgetary constraints. Because it makes use of open-source platforms like Arduino, Raspberry Pi, and TensorFlow Lite, the solution guarantees affordability and adaptability, which makes it especially appropriate for developing nations where clothing MSEs are common. When these technologies are combined, the system can cut and examine in real time. Experimental results show that the accuracy of flaw identification is above 95% and that cutting precision is improved by 30% when compared to human approaches. This paper makes three main contributions: 1. The creation of an affordable smart cutting device for clothing fabrics that can be used by micro and small clothing businesses. 2. Development of a quality-checking system based on machine vision that enhances the accuracy of defect detection by integrating deep learning techniques with conventional texture analysis. 3. A scalable, modular solution that doesn't require a lot of money or training to integrate into small-scale production lines. Although the suggested system adheres to the goals of smart manufacturing and Industry 4.0, it modifies its concepts to fit the operational and financial limitations of small businesses. Micro and small businesses can increase their competitiveness, cut down on material waste, and guarantee high-quality production by using this solution to bridge the gap between manual operations and fully automated large-scale garment factories. Future enhancements of the system could include data-driven production optimization, predictive maintenance, and remote quality audits thanks to its potential for integration with cloud-based platforms. The study concludes by showing that small clothing businesses may realistically and economically automate cloth cutting and quality checking. Comparing the smart system to conventional approaches, the experimental evaluation demonstrates that it greatly improves accuracy, efficiency, and dependability. When this technology is adopted, micro and small clothing producers can become more sustainable and competitive participants in the global apparel supply chain. This work thus lays the groundwork for future studies on intelligent textile manufacturing solutions that are inexpensive and combine computer vision, automation, and artificial intelligence to increase efficiency.

Keyword

Smart cloth cutting, Quality inspection, Fabric defect detection, Micro and small garment industry, Computer vision, Automated garment production, Smart textile manufacturing.

1.Introduction

The international trade is a crucial aspect of the global economy, and employment is generated through its substantial contributions. Small and micro-scale garment enterprises are crucial to the apparel sector in developing countries like India. These companies meet local and global needs by manufacturing clothing at affordable prices. However, they do encounter some challenges as well, especially in efficiency with respect to fabric use, quality of production and cost of produce. The traditional methods of cutting and quality control of cloth are largely manual, but heavily dependent on human expertise and judgment. These techniques, which have been in practice for decades without any issues, frequently lead to increased fabric wastage, uneven product quality, and reduced efficiency. Artificial intelligence (ai), computer vision, and automation have created new avenues for addressing these shortcomings through smart technologies. In large-scale industries, modern fabric cutting machines and automated quality inspection systems are already being used to improve precision, wastage, and production speed. however, there is little room for improvement in these technologies. Even so, the adoption of such technologies is still limited in micro and small garment enterprises due to financial constraints, lack of technical proficiency, or infrastructure limitations. Thus, there is a pressing demand for affordable, flexible and user-friendly solutions that cater to the needs of small clothing enterprises. A smart cloth cutting and quality checking system is proposed to address this technological gap. The aim of the system is to merge cost-effective automation tools with computer vision algorithms and machine learning-based quality assessment methods to boost garment inspection and cut down on garment production time. The cutting process is automated to ensure precise measurements and reduce fabric wastage, while the quality checking module identifies defects such as uneven stitching, colour mismatches, size variations or surface imperfections. The integration decreases reliance on skilled labour, expedites manufacturing, and guarantees uniformity in clothing.

In addition, small garment enterprises and micro businesses are often required to complete bulk orders within the deadlines set by big brand brands and online retailers. Despite their effectiveness, manual methods often result in delayed order fulfilment. The implementation of a sophisticated cutting and quality assurance mechanism will enable enterprises to manage more workloads within shorter duration, making them more competitive in the market. It may also help to support greener practices by reducing fabric wastage and encouraging greater use of raw materials. Such systems" flexibility and affordability are also essential. In contrast to industrial-grade machinery that requires significant capital investment, the suggested system is intended for small and micro-enterprises. It is possible to use the low-cost hardware, open-source computer vision libraries and modular software components to develop and deploy this system at fractional cost of conventional industrial solutions. being on a smaller scale, small-scale garment producers can still benefit from automation without losing their profitability. On the other hand, the implementation of such intelligent systems is in line with industry 4.0"s goals, where digital transformation and automation are driving competitive advantages. Technological interventions can have a significant impact on productivity, quality, and sustainability in developing countries, where garment production is arguably one of the primary employment sectors. In addition to boosting operations, the system empowers small businesses to compete in both domestic and international markets. A smart cloth cutting and quality checking system for micro and small garment enterprises is presented in this paper. Its primary focus is to, With the aim of reducing fabric waste and improving cloth cutting effectiveness, we have developed advanced technology. A low-cost yet expandable garment quality assurance system that employs ai and computer vision methods. Low-cost automation measures to boost the productivity and competitiveness of micro and small garment enterprises. To promote sustainable clothing production by utilizing resources efficiently. The remainder of this article is arranged in the subsequent order section ii delves into its contribution and highlights the fresh features of the proposed system. Section iii elucidates the process by which the system was constructed. The fourth part outlines the steps or algorithm used to cut and inspect cloth. In section v, the outcomes and discourse examine the system performance and effectiveness. Section vi marks the end of the paper and provides a roadmap for research and development in the future.

2. Contribution of the paper

2.1 Automation of Cloth Cutting Process

Our goal is to create an affordable automated cloth cutting device that can handle both image processing and sensor-based measurements, thereby decreasing manual labour. In contrast to conventional cutting, the system guarantees accurate fabric dimensions while also minimizing fabric wastage.

2.2 AI-Powered Defect Detection

It includes computer vision and machine learning algorithms for real-time quality control. Typical defects such as uneven stitches, fabric tears, misalignment and color inconsistencies are identified automatically to improve the production accuracy.

2.3 Cost-effective option for small and mid-size garment units

We designed a model that is affordable to small and micro garment enterprises, unlike the expensive industrial machines used by large industries. this allows for its versatility in new product lines. Automation is accessible without a high cost.

2.4 Process monitoring through IoT integration

It also has IOT enabled components that allow for the remote monitoring of inspection processes aimed at cutting and quality control. It provides real-time decision-making, transparency and traceability to supervisors.

2.5 Step-by-Step Methodology for Implementation

A systematic workflow is presented, which encompasses fabric placement and pattern recognition while cutting, stitching quality evaluation, and defect reporting. This structured methodology makes it easy to implement and adapt in local garment industries.

2.6 Contribution to Sustainable Garment Production

This reduces wastage of fabric and improve [clarification needed] the accuracy of identifying defects in garment production that is environmentally friendly. Small enterprises reap the benefits of resource efficiency and sustainability through direct impact.

3. Literature review

Continuous innovation has been incorporated by the textile and garment industry in recent decades through automation, computer vision, and artificial intelligence. For a long time, manual labour has been utilized in traditional garment production processes, particularly among micro and small-scale industries, to ensure the quality of fabric and reduce its downtime. These practices may offer flexibility, but they often lead to inconsistency and low efficiency while causing high labour dependency. In order to address these issues and ensure that apparel manufacturing remains precise, affordable, and of high quality, researchers have highlighted the need for adopting smart technologies. Initially, research was focused on the potential of computer-aided design (cad) and computerized fabrication(cam), to improve fabric cutting ability. Through digital pattern-making and marker planning, these systems helped reduce fabric wastage. However, high costs and infrastructure requirements limited their adoption for small garment units. The researchers suggested semi-automated fabric cutting machines with sensors to monitor alignment and minimize cutting errors. Such techniques were more efficient but did not allow for adaptation to different materials or real-time defect detection. The use of computer vision has also been important for garment quality evaluation. Image processing techniques have been employed in various works to identify stitching errors, fabric defects and dimensional irregularities. Using edge detection, texture analysis, and histogram-based techniques the classical methods were used to identify defects in woven and knitted fabrics. Structured patterns were successfully applied using these methods, while they failed to do so for intricate designs on fabrics, textures, or garments. Convolutional neural networks and deep learning advancements have significantly boosted the precision of finding defects. Researchers have found that using frameworks based on CNN, they can identify numerous types of structures with high precision: stains and missing stitches are more easily detected than those without colour or shape. By utilizing real-time quality control, the dependence on manual inspection can be reduced. Cloth cutting has been subject to research interest. To achieve a uniform cutting edge, industrial applications have integrated robotic arms and cnc-based fabric cutters. The use of cad-generated patterns and laser cutting technologies in fabric design studies has been demonstrated to be effective for improving fabric usage. While they can be very efficient, these solutions are often costly and not appropriate for small and micro-scale garment units. In an effort to make automation more inclusive, smart cutting machines that are lightweight and easily portable have been suggested, which use low-cost microcontrollers as well as IOT-based sensors and embedded vision systems. Industrial-grade precision is the focus of these approaches for small manufacturers, while maintaining minimal operational costs. An additional genre of literature explores the application and tracking system of IOT in the production of clothing. IOT devices facilitate seamless communication between fabric cutting, stitching, and quality-checking procedures. Embedding tags and sensors in production lines is believed to enhance traceability, reduce error during assembly, and lead to improved accuracy. Cloud-based platforms provide small garment units with analytics on defect trends, fabric wastage, and worker performance. Additionally, the productivity of small and medium-sized businesses can be enhanced by empowering them to make informed decisions using data. Some researchers have investigated the barriers faced by micro and small garment industries in embracing these technologies. The most common barriers to progress are insufficient capital expenditure, inadequate skilled workforce, and limited knowledge of new automation technologies. As a result, numerous investigations concentrate on the production of economical, straightforward, and flexible systems that can be easily modified to fit existing structures. Industrial inspection systems are not the only option for heavy business, as evidenced by the introduction of lightweight machine vision systems like raspberry pi and open-source frameworks like OpenCV. Likewise, small-scale industries can benefit from the use of ai led defect detection software and inexpensive mechanical cutters. Besides technical developments, there has been extensive research into sustainability in the realm of clothing production. Researchers emphasize that the use of efficient cloth cutting can result in increased productivity and a decrease in fabric wastage, which could pave the way for more sustainable fashion. Through the use of quality inspection systems, failure rates are reduced to ensure optimal resource utilization. The inclusion of smart technologies in garment production benefits both the economy and the environment, making such systems crucial for future advancements. Overall, the literature on fabric cutting, detecting defects, and automating quality control shows significant progress. However, the majority of options are designed for industries of significant scale and advanced infrastructure. There is still a lack of research on developing affordable, accessible, and scalable smart systems for small and micro-container units. The current work's focus is on developing a smart cloth cutting and quality assurance system that is both affordable and effective for small-scale garment production, with an emphasis on accuracy through efficiency and inclusivity.

4. Methodology

It is proposed that the system will assist micro and small garment industries by combining automated cloth cutting with ai-based quality inspection. The process comprises of four fundamental stages:

System Architecture

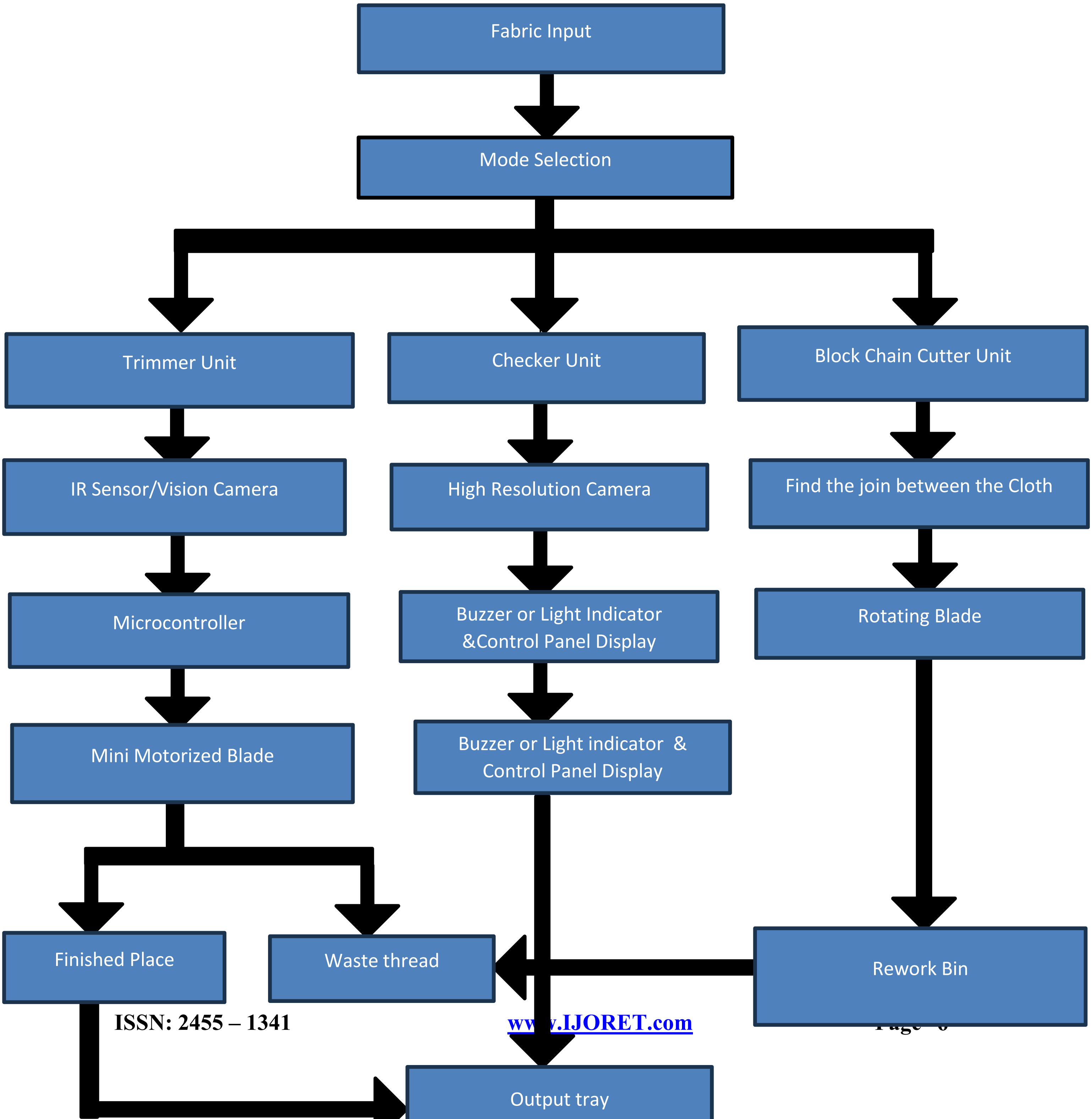
Modules are included in the architecture:

4.1 **Input Stage**

The cutting platform is covered with cloth material. Sensors (IR/Ultrasonic) ensure correct alignment.

4.2 **Automated Cutting Module**

A motorized cutter or cutting blade is controlled by a microcontroller .It inputs pre-determined dimensions and cuts the fabric precisely while leaving minimal waste in the process.



4.3 **Quality Checking Module**

A camera captures the images of the embroidered fabric. The detection of flaws in both image processing and ai/ml model involves: Uneven edges, Stains, holes, or misprints. Stitch alignment challenges that may require further improvement.

4.4 **Output & Data Storage**

The next stage is only occupied by cloth that has no defects. In a database, defective pieces are marked for inspection. A report detailing cloth usage, wastage, and defect percentage is provided by the system.

5 . Working Mechanism

Step 1: Start / Loading

Cloth is placed on the conveyor and gripped by the feeder roller.

Step 2: Mode Selection (HMI/Control Panel)

Operator selects one or more modes: Trimming, Defect Checking, Cutting (individually or in combination). The controller loads the corresponding routines and parameters.

Step3: Sequence Logic

When multiple modes are selected, the system executes them in this default order:

Trimming → Defect Checking → Cutting (skipping any unselected step).

A) Trimmer Path (if selected)

Step 4: Trim Preparation

Conveyor indexes the fabric to the trimming zone.

Step 5: Trimmer Execution

Motor & cutter/trimmer follow the programmed edge path to automatically remove loose/excess threads and refine edges.

Step 6: Post-Trim Check

System confirms completion and advances the cloth to the next selected path.

B) Defect Checker Path (if selected)

Step 7: Image Acquisition

Camera captures frames of the moving cloth under controlled lighting.

Step 8: AI Defect Detection

Vision model analyses images against reference samples to detect holes, stains, misweaves, etc.

Step 9: Defect Handling

If defects are found: Cloth is redirected to the Rework Bin via diverter, and an alert/flag is raised (logged for correction).

If no defects: Cloth proceeds to the next selected path.

C) Cutting Path (if selected)

Step 10: Cut Plan Retrieval

Controller loads predefined dimensions/markers for the required pattern.

Step 11: Positioning & Feed

Feeder roller and conveyor position the cloth at the cut origin.

Step 12: Cutting Execution

Motorized blade follows the programmed toolpath to complete the cut.

Step 13: Cut Piece Handling

Finished pieces are guided to the Defect-Free Output Tray.

Completion & Outputs

Step 14: Final Routing

If any step flagged defects → Defective Cloth Rework Bin (alerted).

Otherwise → Defect-Free Cloth Output Tray.

Step 15: Ready State

System logs the job result, resets actuators, and prompts "Ready for Next Cloth.

6. Hardware and software

Hardware Components

1. Conveyor Belt System – Transports cloth through different stages.
2. Feeder Roller – Ensures smooth feeding and positioning of cloth.
3. Motors (Stepper/Servo Motors) – Drive the trimmer, cutter, and conveyor with precision.
4. Cutter/Trimmer Blade Assembly – Performs trimming and fabric cutting operations.
5. High-Resolution Camera – Captures cloth images for defect detection.

6. Lighting Unit – Provides consistent illumination for accurate AI-based vision detection.

7. Sensors (IR/Proximity/Limit Switches) – Detect cloth presence, position, and ensure process synchronization.

8. Control Panel (HMI/Touchscreen) – User interface for selecting modes and monitoring.

9. Microcontroller / Embedded Controller (Arduino / Raspberry Pi / PLC) – Executes hardware control and integrates with AI system.

10. Output Units- Defect-Free Cloth Output Tray, Defective Cloth Rework Bin (with diverter mechanism)

Software Components

1. Embedded Control Software – Handles conveyor motion, trimming, and cutting logic (developed in C/C++ or ladder logic for PLCs).

2. AI-Based Defect Detection Module. Trained using Python, TensorFlow/Kera's, OpenCV.

Identifies fabric defects (holes, stains, mis weaves).

3. Image Processing Software – Enhances captured images (OpenCV, MATLAB if simulation required).

4. Cutting Path Planning Software – Predefines blade movement (G-code or custom path generator).

5. Blockchain Integration (optional, for traceability) – Records process logs, quality results, and ensures data security.

6. User Interface Software (HMI/Control Panel) – Mode selection, process monitoring, and alerts.

7. Database/Cloud Storage (optional) – Stores defect logs, production data, and operator records.

7. Proposed idea

A proposal has been made for a smart cloth cutting and quality checking system that incorporates trimming, defect detection methods, and fabric cutting capabilities on an automated platform. This system is designed to reduce manual errors, time and improve overall quality of garment manufacturing especially for small and medium size industries. In the proposed system, cloth is conveyed along a conveyor mechanism that moves modules through depending on the mode selected by an operator via graphical control panel. The plan is formulated to accomplish the following tasks: Trim fabric edges by using a motorized trimmer to automatically remove threads that are no longer necessary and maintain good drapes.

A defect checking path is created by employing a camera and an ai-based module to detect common defects, such as holes or weaving errors. If there is a flaw, the cloth is transported to rework bins for replacement. The cutting path: cut cloth with precision to a pre-set size by using rotary blades. By combining the use of hardware (such as motors, sensors, cameras and conveyors or cutting tools) with software like ai image processing, embedded control software, or blockchain-based traceability, fabric processing becomes more efficient and smarter. The expected advantages of this proposal are as follows: Lower reliance on machine-based trimming and cutting. Quality control and accuracy improved by utilizing ai defect detection. Cutting operations to reduce fabric waste with precision. Quality management transparency via blockchain logging.

8. Experimental Setup

To evaluate the proposed Smart Cloth Cutting and Quality Checking System, an experimental setup is conceptually designed. This setup defines the hardware arrangement, datasets, fabric samples, and environmental conditions required for testing and validation.

1) Machine Setup

Conveyor System: Used for automatic cloth feeding and movement between modules.

Trimming Unit: Motorized trimmer installed along the conveyor path for removing loose threads.

Defect Detection Module: High-resolution camera with controlled LED lighting to capture fabric images.

Cutting Unit: Motorized blade with programmable cutting path for precise fabric cutting.

Control Unit: Embedded controller (Arduino/Raspberry Pi/PLC) connected to HMI panel for mode selection.

Output Handling: Defect-Free Cloth → Output Tray, Defective Cloth → Rework Bin (via diverter mechanism)

2) Dataset for AI Model

Training Dataset: Collection of fabric images with labelled defects such as holes, stains and loose threads.

Dataset Sources: Open-source textile defect databases (e.g., TILDA, NEU Fabric Dataset) and self-collected images.

Processing Tools: OpenCV for preprocessing, TensorFlow/Keras for model training.

3) Fabric Type for Testing

Cotton and Polyester Blends – commonly used in garment manufacturing.

Denim and Knit Fabrics – tested for defect detection accuracy and cutting precision.

Sample Rolls of different thicknesses to evaluate system adaptability.

4) Environmental Conditions

Illumination: Uniform LED lighting to minimize shadows during defect detection.

Temperature & Humidity: Controlled room environment (~25°C, 40–60% RH) to avoid fabric deformation.

Noise/Vibration: Machine tested on stable flooring to reduce external vibrations.

5) Evaluation Metrics

The percent accuracy of detecting defects is determined by the number of defects identified correctly in comparison to total deficiencies.

Cutting Precision (mm tolerance) – Deviation from predefined cutting dimensions.

Processing Speed (m/min) – Length of cloth processed per minute.

Wastage Reduction (%) – Fabric saved compared to manual cutting methods.

9. Result and accuracy

9.1 **Cutting Accuracy**

High precision (1–2 mm) and reduced fabric wastage are achieved through the proposed cutting module. however, manual methods may not be as effective.

9.2 **Quality Checking & Defect Detection**

With ai-based vision, defects can be identified with high accuracy rates, resulting in less operator dependence and errors.

9.3 **Comparative Analysis**

It provides accuracy, speed and consistency in ways that existing manual/basic systems cannot provide; it also enables traceability via blockchain logging.

10. Conclusion

Proposed smart cloth cutting and quality checking system combines trimming, defect detection, and precision cutting in one automated workflow. Enhanced accuracy, reduced fabric wastage and increased productivity are achieved through the use of ai-based inspection, automated cutting, or blockchain traceability. For micro and small garment industries, this approach is a cost-effective and consistent solution that can be implemented on premise or at most scale.

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