Real-Time Fabric Intelligence: A Modern Fusion of Machine Learning and lot in Woven Textile Analysis

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Abstract

Fabric, a versatile material composed of interwoven fibers, serves diverse purposes spanning from clothing and furnishings to industrial applications. It exists in both natural forms like cotton and wool, and synthetic forms such as polyester and nylon, each impacting characteristics like texture, breathability, and strength. Fabric structure refers to the construction of textiles, particularly evident in woven fabrics where yarns interlace perpendicular to each other, forming geometric patterns like plain, herringbone, and diamond. The textile industry continuously innovates fabric production techniques, including automated processes and software-driven quality control. This paper explores the development of a novel software system for automatic fabric structure detection, leveraging advanced algorithms to analyze images and categorize fabric patterns. This innovation holds promise for streamlining quality control and aiding design processes in industries like textiles and fashion. The research demonstrates the efficacy and accuracy of the software, marking a significant advancement in automated fabric analysis. Furthermore, it highlights the potential applications in textile manufacturing and quality assurance, contributing to improved efficiency and laying the groundwork for enhanced quality control processes. Ultimately, this paper aims to innovate fabric formula detection, empowering industries and consumers, fostering efficiency, and advancing knowledge in the field.

Keywords
Fabric structure detection, Computer vision in textiles, Automated fabric analysis, Machine learning, Product design

1 Introduction

Fabric analysis and design detection have long been integral processes within the textile and fashion sectors, shaping the quality, aesthetics, and functionality of textile products. However, traditional methods often suffer from inefficiencies, subjectivity, and susceptibility to errors in quality control. In response to these challenges, we present a pioneering solution poised to revolutionize fabric analysis and design – Real-Time Fabric Intelligence.

Our envisioned product represents a groundbreaking integration of cutting-edge technologies, notably harnessing the power of computer vision, machine learning, and Internet of Things (IoT) innovations. At its core, our solution is designed to automate and optimize the intricate processes involved in fabric analysis, offering a transformative shift towards efficiency, precision, and enhanced quality control. Central to our approach is the utilization of advanced image processing algorithms, empowered by state-of-the-art convolutional neural networks (CNNs) and high-resolution imaging techniques. By leveraging these technologies, our system enables real-time, automated analysis of fabric patterns, textures, and designs with unparalleled accuracy. This not only expedites the inspection process but also significantly reduces the margin for error, ensuring meticulous quality control standards are met consistently. Moreover, our solution extends beyond mere analysis, encompassing a spectrum of functionalities aimed at driving innovation and value across the textile industry. Through the integration of big data analytics, we empower fabric designers with actionable insights derived from comprehensive datasets, facilitating informed decision-making and enabling the creation of tailored fabrics aligned with market preferences and trends. Furthermore, we pioneer the incorporation of augmented reality (AR) applications, offering consumers immersive virtual fabric try-ons to enhance their shopping experiences and facilitate confident purchasing decisions. Additionally, by seamlessly integrating electronics and sensors into textiles, our solution catalyzes the emergence of smart fabrics capable of adapting and responding to environmental stimuli or user preferences, thereby opening avenues for novel applications in wearable technology and beyond.

Beyond its technological prowess, our product is underpinned by a commitment to sustainability and efficiency. Through the utilization of virtual prototyping tools, we streamline the design process, minimizing waste and providing stakeholders with realistic previews of fabric appearance before initiating production cycles. Real-Time Fabric Intelligence signifies a paradigm shift in fabric analysis and design, heralding a new era of innovation, customization, and efficiency within the textile industry. As technological progress continues to redefine industry standards, our solution stands poised to address the evolving needs and challenges of a dynamic marketplace, unlocking new possibilities and driving sustained growth and competitiveness across the textile and fashion sectors.

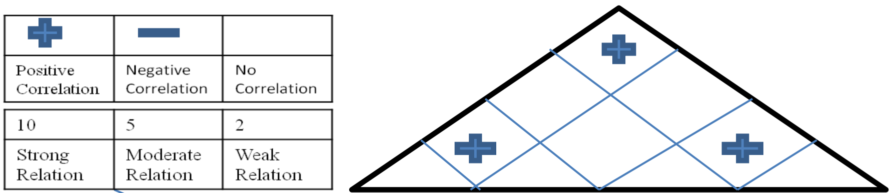
2 Literature Review

Fabric quality control in the textile industry is paramount for ensuring product integrity and customer satisfaction. Stojanovic et al. (2001) introduce an automatic vision-based system designed for quality control of web textile fabrics. Their proposed algorithm integrates binary, textural, and neural network algorithms, resulting in high detection rates with good localization accuracy under real industrial conditions. This system offers compatibility with standard inspection tools, low false alarm rates, and cost-effectiveness, making it a promising solution for fabric defect detection and quality control. Malaca et al. (2019) delve into real-time classification of fabric textures for the automotive industry, addressing challenges posed by uncontrolled lighting conditions. Their research explores pre-processing techniques and feature selection methods to enhance classification accuracy. By comparing artificial neural networks (ANN) and support vector machines (SVM), the study demonstrates the effectiveness of SVM in achieving robust classification results. Their proposed approach, incorporating histogram equalization, Laws filter, Sobel filter, and multi-scale analysis, offers improved efficiency and production gains for industrial applications. Automatic detection of fabric defects using machine vision is crucial for quality control in cotton textile factories. W. Wei et al. (2021) explore the application of deep learning image processing techniques, particularly convolutional neural networks (CNNs), for defect classification. Their study compares unsupervised learning algorithms, such as autoencoders (AE) and variational autoencoders (VAE), and introduces mean structural similarity (MSSIM) as a training loss function to enhance performance. Their optimized algorithm achieves real-time fabric defect detection, showcasing the potential of deep learning in industrial applications. Huart and Postaire (1994) present an automated system for fabric quality control, integrating a linear vision machine onto weavers. Their system utilizes a multi sensor device and local detection operators to identify flaws in real-time. By extrapolating fabric images and employing morphological filtering and syntactic classification, the system effectively discriminates and identifies fabric flaws, offering a comprehensive solution for on-line diagnosis and quality assurance in fabric manufacturing. Wen and Wong (2018) provide insights into the current landscape of computer vision applications in the textile industry, highlighting areas for further exploration and development. Tong (2017) focuses on developing effective computer vision-based defect detection models for different fabric types, addressing the diverse needs of textile manufacturers. Tan et al. (2021) present a novel illuminating textile with touch-less number gesture recognition capabilities, offering enhanced interactivity and value for users. B. Wei et al. (2021) identify research trends and potential future directions for leveraging computer vision in textile quality control. Abouelela et al. (2005) propose an automated visual inspection system for textiles, offering a practical solution for automated textile inspection. Shang et al. (2023) provide a comprehensive overview of existing defect detection techniques, offering insights into the current landscape of fabric defect detection and predictions for future development trends in the field.

3 Methodology

3.1 Quality Function Deployment(QFD)

Figure 1 illustrates our Quality Function Deployment (QFD) analysis for Real-Time Fabric Intelligence. The analysis identified four key functional requirements essential for meeting customer demands: measurement precision, seamless sample size handling, real-time monitoring, and advanced image processing algorithms. Among these, advanced image processing algorithms emerged as the most crucial, highlighting the pivotal role of technological innovation in our product's success. The significance placed on high-resolution sensors underscores our commitment to delivering exceptional quality and performance.



Customer Importance Rating	Functional Requirements / Customer requirements	Advance Image Processing Algorithm	High Resolution Sensors	Secure Remote Access Platform	Compatibility with industry standard units	Weighted Factor
6	Measurement Precision	10	10		2	132
5	Sample Size Handling	5	10		5	100
4	Real time Monitoring	10		10	10	120
3	Low cost	10	10	2	2	72
2	Durability	10	5	2	2	38
1	Reliability	10	10	10	10	40
	Total importance score	185	160	60	97	
	Importance%	37%	31%	12%	20%	
	Priorities Rank	1	2	4	3	

Figure 1: House of Quality

3.2 Functional Decomposition

Figure 2 illustrates the functional decomposition of our Real-Time Fabric Intelligence system. It delineates the intricate orchestration of hardware, software, and lightbox realms, each playing a pivotal role in unraveling the hidden intricacies of fabric structure. The Microlens component brings clarity to microscopic details, while the Database and Algorithm Layers process and analyze data, transforming it into actionable insights. The Lightbox realm, represented by the Junction Box and Optical Strip, choreographs an elegant dance of light and structure, powered by the Electric Power System. Together, these components synergize to form our Fabric Structure Detector, blending technology and artistry in a collaborative pursuit.

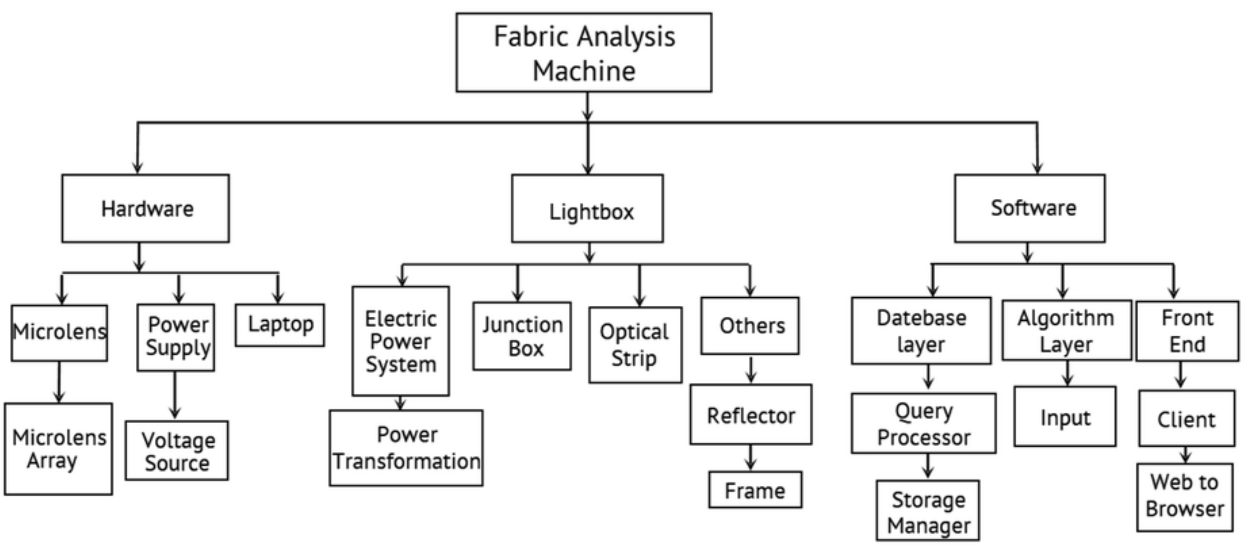


Figure 2: Functional Decomposition

3.3 Black Box

Figure 3 provides a visual depiction of the black box within our Real-Time Fabric Intelligence system. It illustrates the nuanced interplay of inputs orchestrating a sophisticated progression. Energy infusion initiates a transformative journey through fabric exploration, with material serving as the central focal point and information guiding with precision. Optical reactivity, catalyzed by internal energy dynamics, unveils the fabric's intricate essence. This intricate process unfolds within the black box, where energy, material, and information converge to reveal a captivating fabric identity.

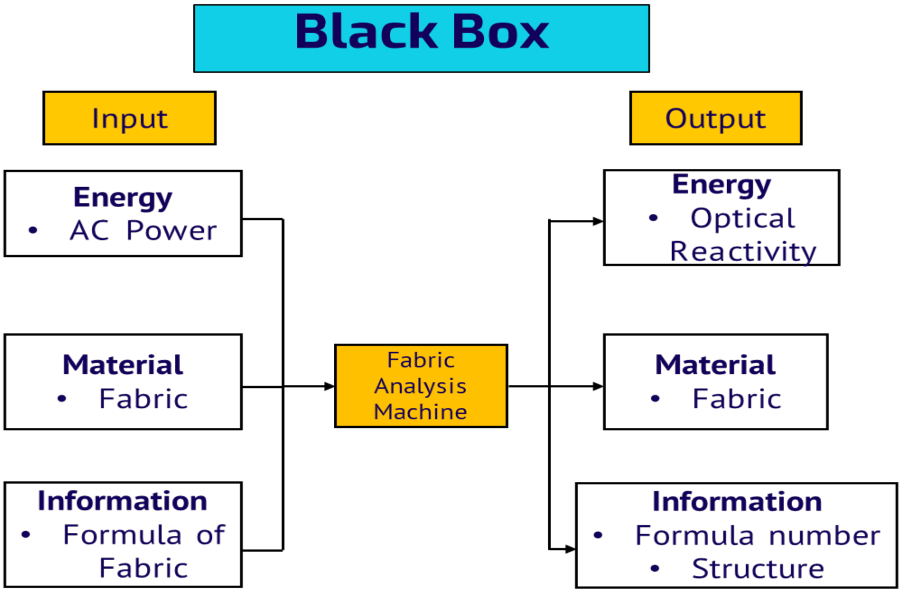


Figure 3: Schematic representation of the black box

3.4 Detailed Design

The process of product design emerges as a pivotal stage in the creation of any product, where even a single error can potentially compromise the product's effectiveness. Thus, meticulous care is deemed essential throughout the design process. Typically, design activities are facilitated through the utilization of specialized software such as SolidWorks, AutoCAD, CATIA, and similar platforms. In the context of our convertible step chair project, the design phase extensively relied on SolidWorks 2023 for its advanced design capabilities. The design documentation encompasses three primary types of drawings, namely Part Drawings, Assembly Drawings, and Final Drawings. Each drawing type plays a distinct role in delineating various aspects of the design, facilitating comprehensive understanding and execution of the project.g

3.4.1 Main Parts

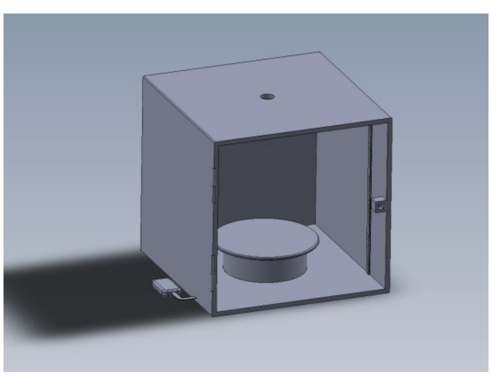


Figure 4: Box

Figure 5: Microscope

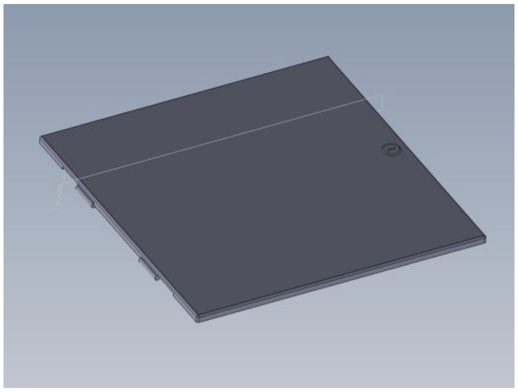


Figure 6: Door

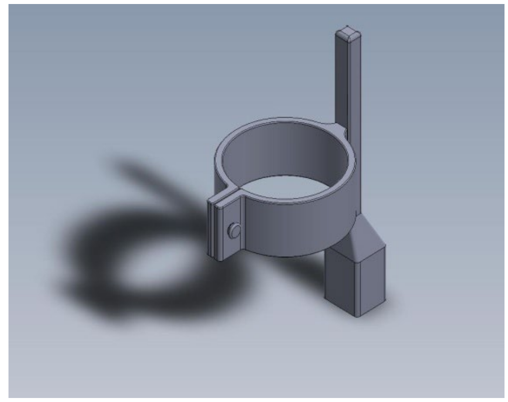


Figure 7: Holder

3.4.2 Final Assembly

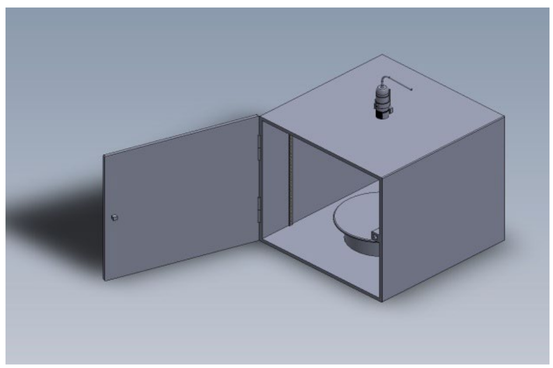


Figure 8: Fabric Analysis Machine

3.4.3 Orthographic Views

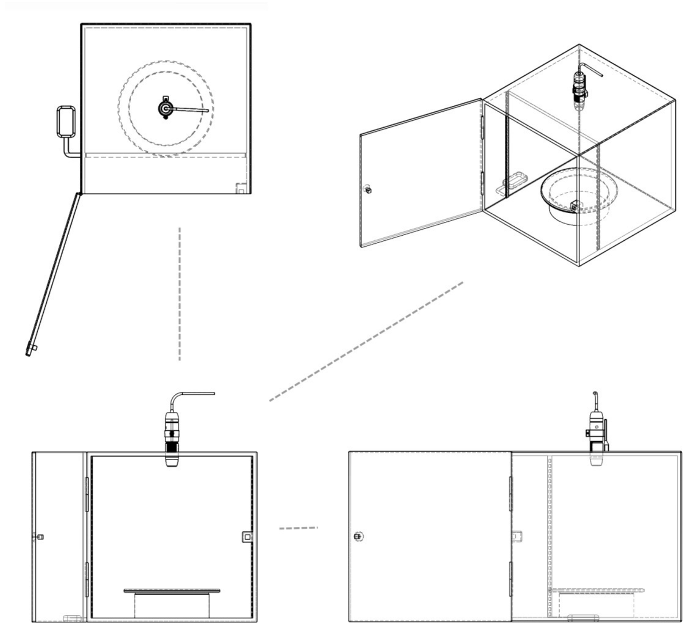


Figure 9: Orthographic views with Isometric view

The design phase plays a pivotal role in elucidating the functionality and aesthetics of the product. As emphasized previously, errors at this stage can lead to significant complications, underscoring the necessity for meticulousness. Thus, it is imperative to exercise caution and employ appropriate design software such as SolidWorks, AutoCAD, or CATIA to generate detailed drawings encompassing parts, assemblies, and the final product. This meticulous approach is instrumental in safeguarding the quality and intended functionality of the product.

4 Material Selection

The weighted average method was utilized for the comparison of several material choices in the Real-Time Fabric Intelligence project. Through a thorough examination of all criteria and essential features, a clear understanding was gained, facilitating the selection between alternatives. The weighted average method proved reliable, successful, and relatively simple to employ in our situation.

4.1 Alternative Material Selection with Weighted Average Method

Table 1 presents an assessment of the relative significance of different characteristics through comparison. The findings highlight the Color Rendering Index (CRI) and Lifespan (hours) as paramount, underscoring their crucial role in maintaining consistent illumination, which aligns with the primary objective of the light source. Additionally, the table evaluates several other critical criteria, contributing to the determination of a relative importance coefficient.

Table 1: Relative importance of goals of light source

Selection Citeria	1	2	3	4	5	6	Positive Decisions	Relative Emphasis Co-efficient
Luminous Efficacy (lumens/watt)	0	0	1				1	0.1
Color Rendering Index (CRI)	1			1	0		2	0.2
Color Temperature (Kelvin)		1		0		0	1	0.1
Lifespan (hours)			0		1	1	2	0.2

	Total number of positive decisions	6	0.6

Table 02 presents the properties of potential materials for the light source, with four candidate sources selected for evaluation.

Table 02: Properties of candidate materials of light source

Materials	Luminous Efficacy	Color Rendering Index	Color Temperature	Lifespan
LED (Light-Emitting Diode)	200	70	3000	25000
Fluorescent Lamp (CFL - Compact Fluorescent Lamp)	50	80	2800	8000
Incandescent Bulb	10	95	2700	1000
Halogen Lamp	18	95	3000	2000

The scaled values of properties and performance indices for the light source are presented in Table 03. It is observed that among the four candidate materials, the performance index of LED (Light-Emitting Diode) exceeds that of the other light sources. Consequently, it can be inferred that LED emerges as a suitable choice for the light source.

Table 03: Scaled values of properties and performance index for light source

Materials	Luminous Efficacy	Color Rendering Index	Color Temperature	Lifespan (hours)	Performance Index
LED (Light-Emitting Diode)	100	73	100	100	54.6
Fluorescent Lamp (CFL - Compact Fluorescent Lamp)	25	85	93.33	32	32
Incandescent Bulb	5	100	90	4	30.3
Halogen Lamp	9	100	100	8	32

The relative importance of goals regarding light box materials is depicted in Table 04. Transparency (%) is identified as the most influential factor, given the primary objective of the light box to furnish a structured environment conducive to uniform lighting for fabric imaging under the microscope. Additionally, the table compares several other significant criteria, culminating in the determination of a relative importance coefficient.

Table 04: Relative importance of goals of light box materials

Selection Citeria	1	2	3	4	5	6	Positive Decisions	Relative Emphasis Co-efficient
Transparency (%)	1	1	1				3	0.3
Impact Strength (J/m)	0			1	0		1	0.1

Density (g/cm³)		0		0		1	1	0.1
Cost (per square meter)			0		1	0	1	0.1
	Total number of positive decisions						6	0.6

In Table 05, the properties of candidate materials for the light box are presented. Three materials have been selected as candidates for the light box.

Table 05: Properties of candidate materials of light box material

Materials	Transparency (%)	Impact Strength (J/m)	Density (g/cm³)	Cost (per square meter)
Acrylic	92	60	1.2	$40
ABS Plastic (for Entry-Level Enclosures)	60	70	1.05	$8
Polycarbonate	88	70	1.19	$60

In Table 06, scaled values of properties and performance indices for light box materials are presented. Among the three candidate materials, ABS Plastic is observed to exhibit a higher performance index. Consequently, it can be inferred that ABS Plastic is considered a preferable choice for the light box material in comparison to the other two candidates.

Table 06: Scaled values of properties and performance index for light box material

Materials	Transparency (%)	Impact Strength (J/m)	Density (g/cm³)	Cost (per square meter)	Performance Index
Acrylic	100	70	60	20	45
ABS Plastic (for Entry-Level Enclosures)	65	81	75	100	45.1
Polycarbonate	95	81	60	13	43.9

5 Conclusion

The development of Real-Time Fabric Intelligence represents a pivotal advancement in fabric analysis and design within the textile industry. Through the integration of cutting-edge technologies including computer vision, machine learning, and IoT innovations, our system offers a revolutionary approach to quality control and structural analysis. The incorporation of advanced image processing algorithms, augmented reality applications, and smart fabric capabilities not only enhances the efficiency of fabric analysis processes but also ensures unmatched precision and accuracy. Moreover, our steadfast commitment to sustainability and efficiency underscores our dedication to addressing the evolving demands of the industry. Real-Time Fabric Intelligence signifies a transformative shift, ushering in a new era of innovation, customization, and operational excellence in fabric analysis and design.

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