Grenze International Journal of Engineering and Technology, June Issue

CoutureX Enchant: AI-Driven Smart Fashion Personalization

Darshana Kiruthika K V[1], Abina Sri K[2] and J. Sathiamoorthy[3]
[1-3]Dept. of Artificial Intelligence and Data Science, St. Joseph's Institute of Technology, Chennai, India
Email: d.kiruthika.kv@gmail.com

***Abstract*— Fashion in the contemporary world has an enormous impact on the cultural norms and even individuality. Nonetheless, the conventional fashion retail business is not able to fulfil the rising needs of customers in terms of personalization, precise fit and instant design. This paper introduces CoutureX Enchant, a smart retailing system based on artificial intelligence, which changes the way of purchasing clothes by means of robotic manufacturing of clothes and interactive smart mirrors. Due to the embedded robots, real-time image processing, and standard machine learning algorithms, the customers can have access to, edit, and print apparel on order. Robotic arms can cut, sew, fold and pack and Smart mirrors can create virtual try-ons using 3D modelling. The key benefits of this combined solution are that it would reduce labor expenses, enhance customer experience, and update the store experience by providing scalable and sustainable automation.**

***Index Terms*— Smart Mirror, Fashion Technology, AI in Retail, Robotic Automation, Personalized Clothing, Virtual Try-On, Machine Learning, Embedded Systems.**

I. Introduction

Consumers are increasingly demanding the aspects of uniqueness, self-expression and having a sense of control over what they wear, thus the fashion business is rapidly changing. Rather than accepting mass-produced, standard-size clothes that often do not fit them very well, the customers of the modern world are willing to have their clothing, not only to represent their unique style, but also their body type, comfort specifications, and even their mood or their event. Nevertheless, to fulfill this requirement of real-time personalization and customization is still a challenge to the conventional physical and mortar retailing companies. Lots of companies cannot offer a proper size variety and design alternatives on a shelf as well as standardized size charts can seldom reflect the actual variety of a body shape and proportions observed between customers, and trying on new designs may be de-motivating, awkward, or even unpleasant to the customer. These differences in the accuracy of fit and visual interaction are normally manifested in high rates of returns, wasted time, and an increase in the scale of unsold or excess inventory; these issues ultimately strain the profit margins and sustainability goals of both brands and retailers. Another trend that emerged over the past few years is the recent increase in the demand of consumers to have smarter, more flexible technologies that would enable them to preview how a piece of clothing would look and feel prior to purchase. The tools that have been created as a response to this necessity include online virtual test rooms and AI-based sizing advice, but these elements are largely limited to e-commerce and do not match the speed and accuracy of the same aspect in the brick-and-mortar shops.

Grenze ID: 01.GIJET.12.2.10_22

Also unmentioned is the issue of how clothing is made and shipped to the correct size and fashion to every client in time and at a reasonable and competitive price. Retailers and manufacturers are also being pressured to lower waste and labor costs and at the same time keep-up with the fast-changing fashions. One of the hardest designs to adapt is custom and unique designs which means that the company production line is largely dependent on manual processes such as cutting and stitching patterns hence the reasons behind the company suffering with low inventories and environmental impacts.

To overcome these issues, this paper proposes the case of CoutureX Enchant, a high-tech, AI-enhanced retail vision that implements mass customisation in real time into the building. It is a blend of a smart interactive mirror, robotic clothes manufacturing, and body measurement and images algorithms under a single roof. The Smart Mirror is the primary interface of the user that uses the depth cameras and position determination to get the accurate body measurements. The consumer can see what other patterns, colors and fits would look like even though they would not even have to put them on by developing a realistic 3D image of them.

After the client has determined the last design decisions, they are left to the backend modules in the system. A cutting and marking machine robot is a machine that is used in the processing of the chosen cloth used with the specifications of the customer in mind. The components are then processed by the robotic arms which sew and assemble the garment to the pattern of choice.

Lastly, the completed clothing is automatically folded and packed in a way that allows the customer to retrieve the same on the same day. The idea demonstrates the difference that robotics and smart mirrors can make.

II. Literature Review

Because of the ongoing issues, related to unsatisfied consumers, ill-fitting, and excessive stock, the fashion industry has been consistent in its digital transformation within the last 20 years. Virtual fitting and body measurement technologies have been significantly impacted upon by the current research and commercial solutions, attempting to fill the gap in between online shopping and in-store shopping experiences.

This production of augmented reality (AR) and virtual try-on tools was one of the first significant projects to defeat the issue of size unpredictability and style visualization to the consumer. Indicatively, Zeekit created an augmented reality (AR)-enabled fitting room, which superimposes user-created images with 2D ones of garments to provide a crude evaluation of fit and appearance [1]. Similarly, TrueFit can cut down on the size choices that are most likely to fit a client by referring to the huge pool of brand-based sizing information and past client purchases [2]. Even though these technologies have demonstrated potential in decreasing returns on online retailers they are generally not associated with real-time production systems of clothing or in-store customizing production processes. Meanwhile, scholarly studies have examined increasingly more complex techniques of accurately determining body shapes. The concept of hierarchical object recognition system that was proposed by Stiefelhagen and Al-Halah [3] was used to establish a foundation of utilizing semantic features in estimating a human pose. To generate valid 3D avatars with virtual try-on, pose estimation algorithms, which detect important body landmarks, are highly trained upon using datasets like COCO [5] and the CMU PIE database [4]. Nevertheless, they are frequently restricted to e-commerce applications or research laboratories and have not been actively implemented along with the production facilities of real clothes. Another similar field that is becoming more widely used is Robotic automation that is primarily applied to large textile factories, which is where it is suggested that a hierarchical architecture of recognition at zero shots could be implemented, which would be prior to the actual execution of semantic features in human posing recognition. To generate valid 3D avatars with virtual try-on, pose estimation algorithms, which detect important body landmarks, are highly trained upon using datasets like COCO [5] and the CMU PIE database [4]. Nevertheless, they are frequently restricted to e-commerce applications or research laboratories and have not been actively implemented along with the production facilities of real clothes. Another of these that seems to be increasingly common is robo automation, largely deployed in large textile factories [6]. There are some commercial efforts to bridge the front-end customisation tools and the back-end manufacturing. As an illustration, several of the most popular flagship stores now offer custom embroideries or small-scale printing of T-shirts and denim products, yet even such services still fundamentally depend on manual operations, such as stitching or hand-cutting of materials operated by an operator. Moreover, the time demanded to effect such changes may take a few hours or even days, which do not comply with the requirements of the modern consumer of the same-visit or quick purchase [7]. Smart mirrors and interactive store interfaces are also being researched new. Some of the large retailers such as Nike and H&M have set up a few rudimentary smart mirrors that enable clients to order alternative fittings at the fitting rooms or receive individualized suggestions [8]. These types of mirrors are not connected with body measurements or the garment-making process; even though they are found to be more practical, these types of mirrors are circulated mostly in marketing or inventory. Considering all the above, one can easily conclude that a solution is sought that will facilitate the incorporation of the the advantages of the currently available robotic automation, posture estimation, and virtual try-on systems into a single cohesive, practical system of real-time, in-store customising of clothing. The developments of CoutureX Enchant include the implementation of a digital pattern generating module, semi-automated robotic cutting and sewing, and an interactive smart mirror with 3D rendering, location recognition, and a depth sensing feature. In contrast to the majority of the other former methods, this method has enabled the use of end-to-end mass customization allowing customers to design, foresaw, and pick their own-dress clothes in a single shopping trip. According to the literature, integrating these elements into a smooth working process may close a wide existing gap in the current retail process and open the way to the more interactive and sustainable shopping experience.

III. PROPOSED METHODOLOGY

To address the limitation of conventional technological approaches to selling and tailor clothing, the CoutureX Enchant system recommends an intelligence-based retail platform that would eliminate the weaknesses of the previous systems. The system supports sustainability, efficiency in operations, and customisation by incorporating the computer vision approach to body measurements, digital pattern making, automated cutting, and semi-automated sewing support.

The given methodology is focused on on-demand clothes production under the influence of real-time measurements procurement and workflow unification both on digital and physical media as opposed to the models in retail that employ bulk stocks and existing sizes schemes as shown in Fig. 1.

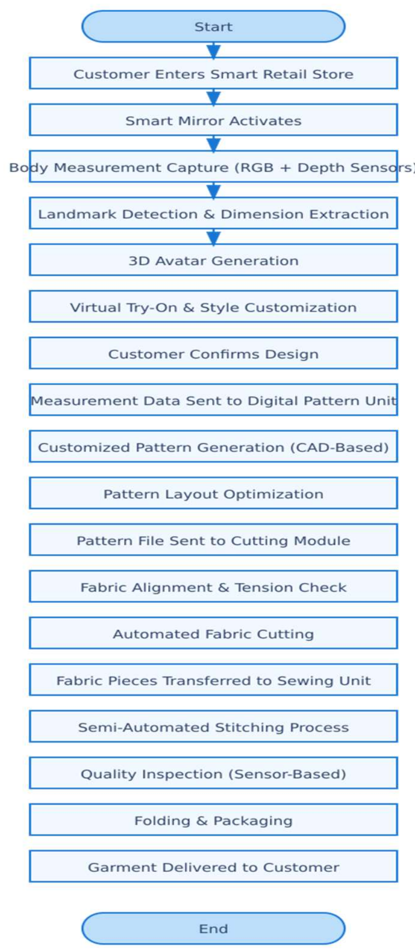

Figure 1 depicts the overall operating workflow

A. System Architecture

An Architecture of a System

To discuss the system architecture, it has four functional layers:

- Interaction Layer: This interface logs the body measurements and customization of the customer through Smart Mirror Interface.
  Processing Layer: This layer converts the measuring data to digital clothing patterns through CAD-based methods, which are optimized.
- Fabrication Layer: Automatic cutting, fabric marking and semi-automatic stitching.
  Control and Data Layer- The control and data layer contains a centralized local server to make module-to-module interactions, and to store encrypted customer profiles.
  This stratified design makes this system flexible to scale, maintainable and there is also smooth progression between the digitalized customization and the actual production.

To discuss the system architecture, it has four functional layers:

- Interaction Layer: This interface logs the body measurements and customization of the customer through Smart Mirror Interface. Processing Layer: This layer converts the measuring data to digital clothing patterns through CAD-based methods, which are optimized. • Fabrication Layer: Automatic cutting, fabric marking and semi-automatic stitching. Control and Data Layer- The control and data layer contains a centralized local server to make module-to-module interactions, and to store encrypted customer profiles.

B. Intelligent Body Measurement Acquisition

The initial stage of the process is automatic body measurement extraction on the basis of colour RGB cameras and depth-sensing cameras, installed into the Smart Mirror.

The techniques of computer vision and posture estimation can reveal the essential body features which include shoulder breadth, waist circumference, hips position, length of sleeve and distance of inseam. The received spatial coordinates are made to process to be given precise dimensional parameters without the need to have human tape measuring.

The technology then creates a 3D avatar which is similar to the body of the customer in terms of measurements. Customers will be able to test on the various styles and designs virtually, adjust the design elements and review the fit of the avatar in real-time before manufacturing has been approved.

This process has lesser transporting of room fitting, and the sizing problems that are characterized with the normal retail clothes disappear.

C. Automated Fabric Processing

After the client has approved the design, the measurement data is passed through the Digital Pattern Generation Unit.

This module design is done using computer-aided design (CAD) tools whereby the designs of the personalized clothing designs are made based on the body measurements of a particular person. The design includes structural margins, factors of fabric elasticity, seam allowances etc. automatically.

Pattern layout optimization algorithms reduce the amount of waste produced during the cutting of fabric. Standardized digital formats which are compatible with automated cutting equipment are used in producing the final pattern files.

This level serves as the virtual integration between computer-generated personalization and real production.

D. Data Management and Workflow Coordination

The processing layer provides perfect pattern information to the Fabric Marking and Cutting Module.

The roll fabrics are firmly placed on cutting bed with tension and alignment sensors. These are some types of sensors that identify any folds, distortions or uneven surfaces before a cut starts.

Laser or blade-based cutting methods faithfully follow the computer-generated digital path. Machine vision monitoring: This provides dimensional consistency as well as quality inspection during the cutting. Fabric components are all branded to ensure that they are tracked accurately at the later stages.

This automation is advantageous in the efficacy of the material utilization, preventing human error, and enhancing repeatability.

E. Sustainability-Oriented Design Approach

The main characteristic of the CoutureX Enchant architecture is scalability and flexibility to different retail scenarios. Based on operational requirements, stores may implement any given modules or the whole system.

The strategy completely reduces fabric wastage and non-selling inventory cause by producing clothes on order rather than holding large quantities. This policy is aligned to the environmentally sound retailing patterns and green production methods.
A novel model of smart fashion retail is the hybrid of digital design, data of intelligence gauging as well as semi-automated production.

IV. EXPERIMENTAL SETUP AND IMPLEMENTATION

A. Hardware Components

The target CoutureX Enchant system will be developed using commercially available hardware components to make it viable in the market. The prototype system is built upon sensing, visualization and semi-automated fabrication core within a smart retail area. The Smart Mirror is a Smart Mirror module that gathers body positions and space readings and has a RGB high-resolution camera and depth-sensing camera (Intel RealSense or similar device). The virtual try-on interface and 3D avatar is rendered on an integrated large LED display panel. The processing and control tasks are performed in a high-performance computing unit (a workstation with the ability to handle a virtual scene with graphicard or an embedded edge computer device). It guarantees real time fluid visualization.
The Digital Pattern Generation Unit can generate clothing templates in the form of DXF or as an encrypted algorithm in less than the time consumed by a CAD-capable system to generate them.<|human|>The Digital Pattern Generation Unit can also generate clothing templates using a CAD-capable system and be it in the form of DXF or an encrypted algorithm.
SVG formats. A CNC blade cutter can take in files of a vector input format, for automated cutting with a laser or an automated blade cutter. Table I presents the key hardware components and their corresponding specifications used in the prototype architecture.

TABLE I: LISTS THE KEY HARDWARE COMPONENTS AND THEIR REQUIREMENTS WITHIN THE PROTOTYPE ARCHITECTURE

Component	Model / Type	Function	Purpose
RGB Camera	HD Camera	Visual Capture	Body posture detection
Depth Sensor	Depth Camera	Spatial Mapping	3D measurement extraction
Smart Display	LED Panel	Visualization	Virtual try-on interface
Processing Unit	GPU Workstation / Edge AI Device	AI Computation	Pose estimation & rendering
CAD System	Pattern Design Software	Pattern Creation	Customized garment template
CNC Cutter	Blade/Laser Cutter	Fabric Cutting	Precision pattern cutting
Sewing Machine	Semi-Automated Unit	Stitching	Garment assembly
Robotic Arm	Servo-Based Arm	Fabric Handling	Alignment & positioning
Local Server	Embedded Controller	Coordination	Data management

B. Software Components

The three software architecture layers include the control, processing and interface layers.

Layer of Interaction
The Smart Mirror interface is created with a graphical user interface framework and with the assistance of the computer vision libraries. Landmarks on the body are located and readings obtained via open-source computer programs such as OpenCV and pose estimation algorithms.
The 3D avatars and simulation of clothing are created by the use of rendering engines that are able to overlay the cloth texture on the body polygons.

Layer of Processing
The processing layer takes the following:
Algorithms Body landmark detection algorithms.
Measured quantities are calibrated by logic.

- Reconstructing 3D avatars
- Digital pattern generation algorithms
- Pattern layout optimization.

Pattern files are created in standardized formats compatible with cnc cutting equipment. To save client profiles, the encryption of data is used.

C. Experimental Setup

The prototype was experimented in a controlled in-door setting which represented the design of a smart retail outlet. The Smart Mirror device was placed in the center of people who were mingling. The RGB and depth cameras were integrated to the right so as to capture the full body. The captured body data were locally processed to generate lighting conditions that helped in enhancing the accuracy of the landmark detection. Measurement parameters and a corresponding 3D avatar was generated. Virtual clothing was developed to recreate try-on experiences. To test the logic of customization, sample measurement data were manipulated to test the Digital Pattern Generation module. Findings of the pattern files generated were tested on layout optimization and structural precision.

D. Implementation Workflow

Workflow for Implementation
The operational workflow has seven key steps:
data gathering regarding body measurements by depth sensing and RGB.
Landmark detection pose estimation and processing.
drawing up 3D avatars and imitating virtual test-ons.
verification upon the design of the customer.
Planning of space and designing of digital patterns.
To ensure that the process of the transfer of the virtual customizing to the real cloth production follows a smooth process, every single process is linked through the centralized logic of control.

V. RESULT AND DISCUSSION

A. Experimental Results

The CoutureX Enchant system prototype framework was tested in an intelligent retail simulated setting produced within a controlled indoor setting. The overall objectives of the evaluation included constancy of measurement extractions, virtual try-on displaying achievement, digital pattern and electronic workflow effectiveness.
Three scenarios of body positions were studied:

- Installing a neutral position.

A little movement of the arms

- Side view rotation

It was revealed that the RGB and depth-based body measurement module were reliable in the detection of landmarks when the luminance remains constant. When body movements were high to the extent that the measurements were out of consistency, the 3D avatar rendering technology enabled the precise matching of overlapping virtual garments to the body landmarks. Other areas of style adaptation which were not overtly distorted included the alteration of color, and change in sleeve length and the change in neckline.

B. Virtual Try-On Analysis Performance.

The virtual try-on module was demonstrated to be very useful in the visualization of garments in real-time. Part of the implementation of pose estimation and 3D avatar mapping enabled the customers to spin their avatar and preview garments at different angle orientations. Even though controlled store lighting ensured consistency in detection performance, lighting conditions did affect the accuracy of landmarks. In the case where the person stood at his or her natural position, the system worked at its optimum. Despite the fact that the analysis was done at a prototype level, the findings suggest high viability in retail implementation.

C. Workflow Analysis Efficiency.

The efficiency of the whole workflow, such as acquiring measurements to designing digital patterns, was measured. The wait time of the customer was low as the process of acquiring measurements and creating avatars requires only several seconds. Pattern creation and optimization were soon started as the concept was verified. Through a local server, there was constant and continuous data exchange between modules.
Semi-automation of a stitching system and fabric cutting simulations confirmed seamless integration of modules, thus confirming real-time clothing production in store is possible.

D. Comparison with Existing Works.

The majority of the existing LPG monitoring systems apply single sensors techniques like weight or ultrasonic measurements which can lead to a poor degree of accuracy. Also, a great number of prototypes only offer reactive notifications and do not have a predictive intelligence or supplier integration. Conversely, the proposed system will provide:

- Multi-sensors fusion to enhance accuracy.
- Anticipatory analytics of proactive planning.
- Suppliers Integration Automated refill.

VI. Discussions

There have been some drawbacks, even though there were potentially encouraging results in the prototype level. Stable posture and controlled light is required to provide valid measurements. The excessive body movements may lead to minor differences in landmark recognition. The existing system analysis was administered in a controlled setting and not in a busy retail scenario. The practice can cause additional uncertainty with real-life implementation. To simplify more complicated garment designs, though, human factors remain necessary, even with semi-automated stitching. All-around automation would need additional investment and more sophisticated textile robotics.

VII. Limitations

The results demonstrate a great level of integration capacity of the system and its architectural viability. The Smart Mirror can successfully bridge the gap between personalized measurements and online visualization. The modular design is used to ensure smooth transition of virtual customizing into the actual clothing manufacture through digital pattern generation, scalability, sustainability and maintainability. The CoutureX Enchant system is an innovative forward-thinking, smart retail, which entails semi-automation of production and AI-based customization; however, since the large-scale commercial implementation will require further confirmation and industrial trials.

VIII. Conclusion

Within a one store setting, this paper outlined a platform of AI-powered intelligent fashion customization involving intelligent body measurement, computer-aid pattern creation, electronic try-on devices, as well as semi-autonomous clothes printing. The suggested system integrates computer vision-based posture estimation, CAD-enabled customization and production modules with auto-generation modules to solve the major problems of conventional fashion shopping, such as reliant on inventory, size variation, and inefficiencies in each fitting process. The prototype level evaluation showed that the body landmark detection was robust under well-controlled conditions, 3D-avatars were rendered effectively and the workflow between the measurement acquisition and the pattern manufacturing were coordinated smoothly. The modular architecture will facilitate the easy flow of data between the interaction, processing and manufacturing levels facilitating production of custom-made apparel in a retail environment.

References

[1] Zeekit, “Virtual fitting room technology,” Proc. Intl. Conf. on Smart Retail Systems, pp. 123–129, 2019.

[2] TrueFit, “Data-driven size prediction and personalization,” Journal of Retail AI, vol. 12, no. 2, pp. 45–52, 2020.

[3] Z. Al-Halah and R. Stiefelhagen, “Zero-shot object recognition via hierarchical semantic attributes,” in Proc. IEEE Conf. on Computer Vision and Pattern Recognition, pp. 345–352, 2015.

[4] T. Sim, S. Baker, and M. Bsat, “The CMU pose, illumination, and expression database,” IEEE Trans. Pattern Anal. Mach. Intell., vol. 25, no. 12, pp. 1615–1618, 2003.

[5] COCO Dataset, “Common objects in context,” Vision Research Archive, vol. 14, pp. 201–209, 2017.

[6] SoftWear Automation, “Sewbot: Revolutionizing robotic garment manufacturing,” Intl. Journal of Robotics in Fashion, vol. 5, no. 3, pp. 101–108, 2021.

[7] M. Lee and D. Park, “Robotic automation in fabric alignment using machine vision,” Advanced Robotics, vol. 35, no. 4, pp. 221–233, 2022.

[8] R. Klein, “Smart mirrors and customer interaction in modern retail,” Intl. J. Retail Technol., vol. 9, no. 1, pp. 14–20, 2020.