

A Real-Time Augmented Reality System for Apparel Visualization

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ABSTRACT This paper presents a real-time augmented reality (AR) system for trying on outfits virtually to visualize apparel on the human body. An Augmented Reality-based visualization system is developed that can display chosen clothing styles and designs on a human body while in front of a camera. The objectives are to gather the requirements of the AR visualization system, design the system based on the requirements obtained, and implement, test and evaluate the performance of the system. Operational, non-functional and hardware requirements of the system were elicited via an extensive literature review. The AR system's architecture was outlined and designed using UML tools like flowchart, use-case and activity diagrams. The apparel visualization system implementation leverages computer vision techniques, real-time image processing and augmented reality visualization. Python 3, Mediapipe v0.8.6.2, OpenCV and Visual Studio Code were utilized in the development of the system. The system was evaluated via beta testing using a survey method with a sample size of twenty-one (21), and a questionnaire tool. The evaluation was based on performance metrics including user experience, responsiveness, accuracy and usability, realism and performance in different lighting conditions. 66.7% had a "good" user experience, 86.7% of the respondents indicated that the system responded adequately, and 76.2% of users responded that the garments aligned correctly with points on their bodies. An average success rate of 48.42% and 8.9 FPS was recorded in bright lighting conditions while a 40.23% success rate and 8.23 FPS when it was darker.

KEYWORDS Augmented Reality, Fashion, Computer-Vision, Real-Time Systems, Apparel Visualization.

I. INTRODUCTION

The advent of Augmented Reality (AR) technology has ushered in a transformative era across numerous sectors, including education, healthcare, entertainment, and notably, fashion and retail [1]. Augmented Reality (AR) is an innovative technological tool used to enhance real-world environments with additional virtual information [2, 3, 4]. The ability of augmented reality (AR) to superimpose digital information into the real world using smartphones, tablets, or specialist AR glasses offers a captivating and dynamic user experience that goes beyond conventional digital interactions [5, 6]. AR technology is revolutionizing the way people shop for clothes and accessories by allowing them to see how they look in real time. This technology bridges the gap between physical stores and internet shopping by letting users view items on themselves or in their surroundings [7, 8, 9]. Throughout history, the fashion industry has consistently been at the forefront of embracing cutting-edge technologies to improve the whole shopping experience for consumers [10]. Since its inception, the online retail industry has consistently adapted to fulfil the evolving demands and desires of consumers, including virtual

and augmented reality technologies along the way [11]. The AR into apparel visualization is specifically designed to tackle persistent obstacles in online buying, such as the inability to physically try on garments or precisely assess the fit and appearance of a garment [12].

The purpose of incorporating AR technology in the fashion and retail business goes beyond simply offering a unique shopping experience. It involves enhancing customer happiness by providing more precise fitting and style suggestions, decreasing the number of returns by presenting a more accurate portrayal of products, and finally, boosting sales by involving customers in an interactive and personalized shopping experience [13]. Moreover, AR systems for apparel visualization combine technology and creativity, utilizing cutting-edge computer vision, graphics rendering, and user interface design to develop realistic and scalable solutions that meet the evolving requirements of retailers and consumers [14].

Ongoing improvements in Information Technology (IT) have allowed for substantial changes in daily activities as a result of digital technology innovations. The fashion world is

not exempted from these innovations, as indicated by the application of 3D (three-dimensional) systems, together with virtual and augmented reality techniques in creating consumer-focused experiences [15]. The creation of virtual clothing simulation applications, which has been crucial to the IT-based digitalization of the fashion industry, has sparked ongoing technical advancements for systems that can virtually convert 2D design work to 3D design work [16].

AR has been increasingly used in fashion to allow customers to engage with virtual items in ways that grab their attention, and boost their ability to visualize objects and, presumably, their subsequent perception of the brand. AR has been integrated into fashion apps, online stores, and in-store displays, allowing customers to preview outfits, try on makeup, and see how accessories would look on them. AR technology is also used for virtual fashion shows and product presentations, providing a more interactive and engaging experience for viewers [17]. Studies have shown that the use of AR in fashion can improve customer engagement, increase product views and purchase intent, and provide valuable data for fashion brands to understand their customer's preferences and make informed decisions [18]. When fashion consumers are led to have exciting buying experiences, there is an increase in their purchase intentions leading to an improvement in market power [19].

Body tracking in AR refers to the process of using sensors or cameras to capture and interpret movements and gestures of a user's body to activate AR experiences. These sensors may be placed on the user's body, or in the surrounding environment.

Different approaches to body tracking in AR, include marker-based tracking, markerless tracking, and skeleton-based tracking. Marker-based tracking involves placing markers or fiducial markers on the user's body, which are then tracked by cameras or sensors in the environment. Markerless tracking uses computer vision algorithms to track and analyze the user's silhouette, body shape, movements and other visual cues without the need for markers or fiducials. In skeleton-based tracking, a digital skeletal model of the user's body is created based on the positions of key joints and bones. The skeletal model is then used to track the user's movements to drive AR experiences such as virtual try-ons that allow users to see how a garment would look and feel.

AR applications for fashion apparel usually require the user to have accurate knowledge about their body measurements and may sometimes take some time to give results. This study thereby presents a real-time implementation that works even when users do not have accurate up-to-date statistics of their body measurements. It accurately detects the user in front of the mounted camera, allows them to select their desired clothing style from the available options, and displays their selected style and textile on their bodies, using AR.

The study aims to create a real-time AR system that can show selected apparel patterns and styles on a human body. The specific goals include: collecting the criteria for the AR visualization system, designing it based on those requirements, and testing and assessing its performance. The system allows users to see the different fashion styles on their bodies in real time, enabling them to make faster fashion decisions.

II. RELATED WORKS

The integration of VR and mobile eye-tracking technologies for shopper research was studied in [20]. The advantages of this combination over traditional methods were discussed, offering enhanced control and realism in experimental settings. The

authors reviewed various eye-tracking technologies and highlighted the unique opportunities presented by VR for studying shopper behavior, particularly with augmented reality for shopper assistance. The paper emphasizes the potential for more controlled and realistic research environments that closely mimic real-world shopping experiences.

The effectiveness of AR in e-commerce was investigated in [21] through two main studies focusing on sunglasses and watches. The first study compared AR with traditional web-based product presentations, finding AR to be more engaging and effective in enhancing novelty, immersion, enjoyment, and usefulness, leading to more positive attitudes towards products and higher purchase intentions. The second study examined the influence of AR and web-based presentations on consumer evaluations, highlighting the roles of interactivity and vividness. It also includes sentiment analysis and text analytics of participants' opinions on AR, revealing mixed feelings about the technology's newness and usability issues.

For bodies with unusual traits, a 3D virtual try-on system was proposed in [22]. In this study, a try-on system only for trousers for various kinds of asymmetrically shaped female bodies was developed. The subject of the study had unusually shaped lower limbs and pelvis which made it difficult for industrially produced waist-supporting clothing (skirts, trousers) to fit the subject's body well. The Made to Measure (MTM) component of the GEMINI CAD system was used to create the reference patterns.

The authors of [23] created a virtual try-on system (PATRON). When the garment's tag is scanned with a mobile device, a 3D representation of the wearer wearing the garment is displayed on the clothing tag using augmented reality. By rotating the camera around the tag or the tag itself, a user may examine the model from any angle. This system uses a 3D scanner, 3DBuilder and Kinect. Fiducial marker detection, feature detection, and edge detection were used to carry out tracking. The try-on system was created to prioritize and protect users' privacy.

[24] presented a Computer-Aided Design system (CAD) with the ability to move, rotate, fix, and drag clothing patterns to appropriate points on 3D representations of the human body. This physical-based modelling of garment designs stretches and flexes as a result of changes in the contour of the body surface. To achieve the final garment that can be viewed on a 3D model, the system was emulated in a virtual sewing process that required the movement of fabric garment patterns. This system majorly pertains to pattern-based garment design.

[25] provided a Matlab and augmented reality (AR) solution for the identification of people based on the image background and image light fluctuations. The initial step of background separation involved developing a morphological structuring element and using it to apply a Laplacian filter. An edge detection technique was then used to identify the human's edges in the captured images. The structure of the human anatomy served as a foundation for feature point extraction. The inaccuracies were corrected by superimposing the image of the person with the twisted garment.

[26] proposed a virtual try-on system that converts the output to 2D garment images with the user's measurements for manufacturers. This approach implements the use of a cloned 3D body displayed on a web interface. The user can set the clone's measurements manually according to their body measurements. The garments are then fitted to their personally

sized clone, and corresponding 2D patterns that were generated were sent to the manufacturers.

Previous studies explored various aspects of fashion apparel try-on applications which involve the use of 3D body models and various try-on technologies. This study attempts to add a feature of real-time garment overlay visualization while employing techniques that ensure more accuracy and improved user experience.

III. METHODOLOGY

A. SYSTEM DESIGN AND IMPLEMENTATION

System requirements were compiled via an extensive literature review. These include operational, non-functional and hardware requirements.

The design of the architecture includes a flowchart, use-case and activity diagrams. The flowchart in Figure 1 specifies the beginning and end of the processes involved as well as the flow of stages in between. It depicts what causes a particular event in the system and shows the subsequent steps. The use case diagram in Figure 2 indicates the key actors and players in the system as well as their roles. The activity diagram shown in Figure 3 describes the activities performed by the computer, the user, and the system as the relationship between the activities.

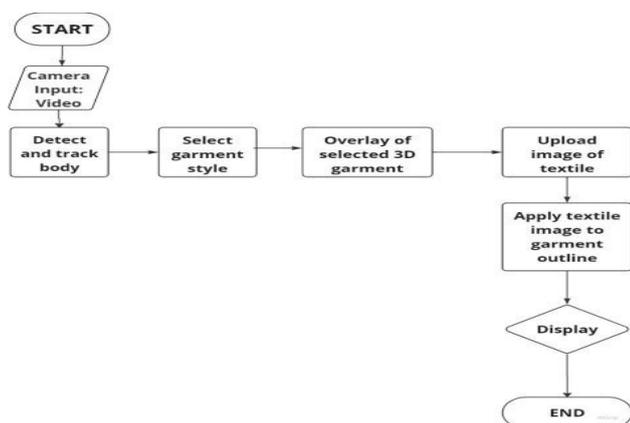


Figure 1. Flowchart of the real-time AR system for apparel

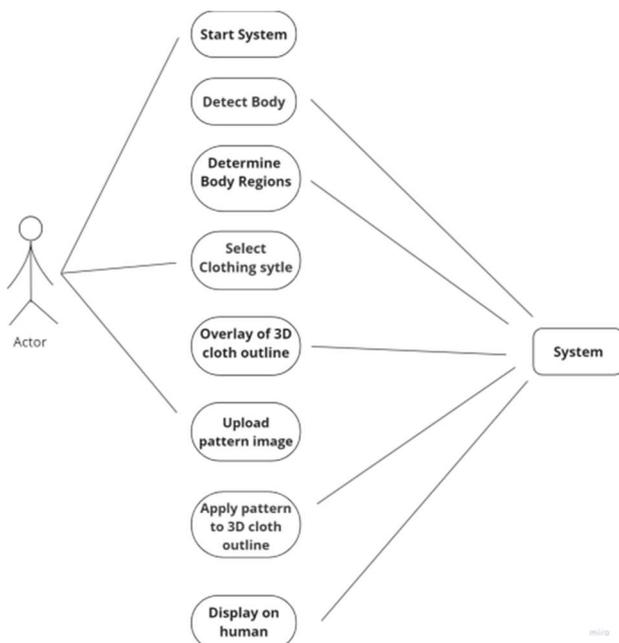


Figure 2. Use case diagram of the real-time AR system for apparel visualization

The real-time AR system for apparel visualization was implemented using tools including Python 3, Mediapipe v0.8.6.2, OpenCV and Visual Studio Code. Python is used to create AR experiences for web browsers using technologies such as WebXR and more. Its interactive interpreter allows for rapid prototyping and experimentation. MediaPipe is an open-source, cross-platform framework for building multi-modal machine learning pipelines. Its pose estimation module is known to provide an accurate estimate of the position and orientation of a human body in 3D space.

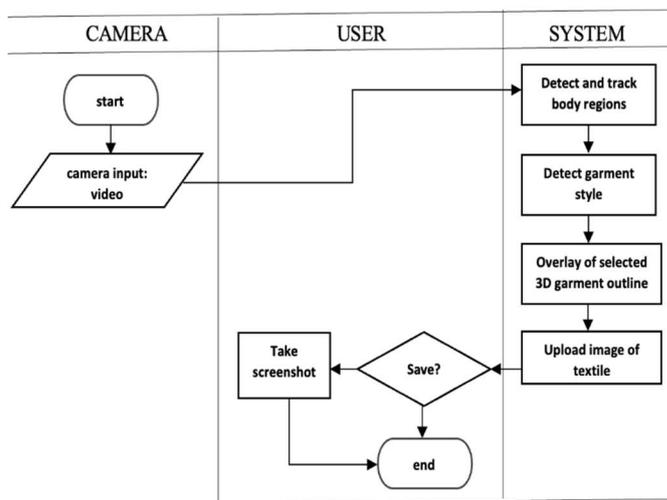


Figure 3: Activity Diagram of real-time AR system for apparel visualization

OpenCV (Open Source Computer Vision) on the other hand, is a versatile library for image and video processing, with features like platform support, machine learning capabilities, and object detection and recognition features that make it a great fit for computer vision projects.

Visual Studio Code (also known as VS Code) is a free and open-source code editor with flexibility, speed, and extensive customization options. Using these tools, the user of the AR system is then able to interact with the web interface of the apparel visualization system that enables them to start the system, select their desired style, upload a textile, and view the overlay of the style on their person.

The system was evaluated using a beta testing approach where the beta version of the real-time AR system for apparel visualization was engaged in a survey. The AR system was distributed to a sample size of twenty-one (21) end-users to test the rate and provide feedback on system quality.

The survey was implemented using a questionnaire tool that featured questions about the system in such areas as user experience, ease of use, the usefulness of the AR system in making fashion choices, how realistic and accurate the clothes looked on the body, and recommended future improvements. Performance criteria employed include user experience, responsiveness, accuracy, usability and realism. The testing of the AR system also focused on measuring the performance of its body-tracking features under different light settings using tracking percentage and frames per second (FPS).

IV. IMPLEMENTATION AND RESULTS

A. SYSTEM REQUIREMENTS

Operational Requirements: From the review of the literature and related works done, operational requirements were elicited for the real-time augmented reality system for apparel visualization. The system should be able to:

- detect a human body standing in front of the sensor in real-time;
- identify particular points on the human body;
- apply an overlay of the selected apparel on the human body;
- transfer the image of the textile uploaded to the overlay of the apparel;
- capture or save the image of the final look.

Non-Functional Requirements: Efficiency, usability requirements and performance were identified as the non-functional requirements of the real-time AR system for apparel visualization. The system is expected to:

- perform as optimal as possible in terms of memory, speed, and use of resources;
- be easily understood by its end users and they should be able to operate the system with ease;
- accommodate the specified input accurately and should be reliable.

Hardware Requirements: A laptop with a minimum of 8GB RAM with a high-resolution camera having good low-light performance was used as the camera input. The high-resolution camera provided a clear and immersive AR experience that enhanced the apparel visualization quality of the AR system. It had a memory that handled the real-time image data as a video livestream.

B. SYSTEM IMPLEMENTATION SETUP

The real-time augmented reality system for apparel visualization includes five modules: Video Livestream Capture; Body Detection and Tracking; 3D Overlay of Garment Style; and Apparel visualization: combined overlay of garment style and textile material.

- **Video Livestream Capture:** Enabling access to the laptop’s video camera to capture live stream input of the human body, is the initial stage of implementation of the system. OpenCV’s ‘cv2.VideoCapture’ function and the MediaPipe library were used to activate the camera and enable the module to receive live video streams for image processing operations. The real-time video stream of the users’ bodies is then sent to the next module for image processing activities involving tracking of various points of the human body.
- **Body Detection and Tracking:** The second phase of the development process involves the activation of body detection and tracking in the system. MediaPipe’s body detection module enables the system to accurately detect a user’s body within the captured video stream. Using MediaPipe, OpenCV, and Python programming language, specific coordinate points on the human body are isolated and used to determine the regions in which the tracking coordinates are placed. These body tracking coordinates each have designated labels, as shown in Figure 4. These body coordinates are then used to display the outline of the body within the video livestream. This module is also able to track the user’s body even as it moves and changes positions. Figure 5 depicts the body tracking coordinates on

the human subject obtained from the video live feed of the camera.

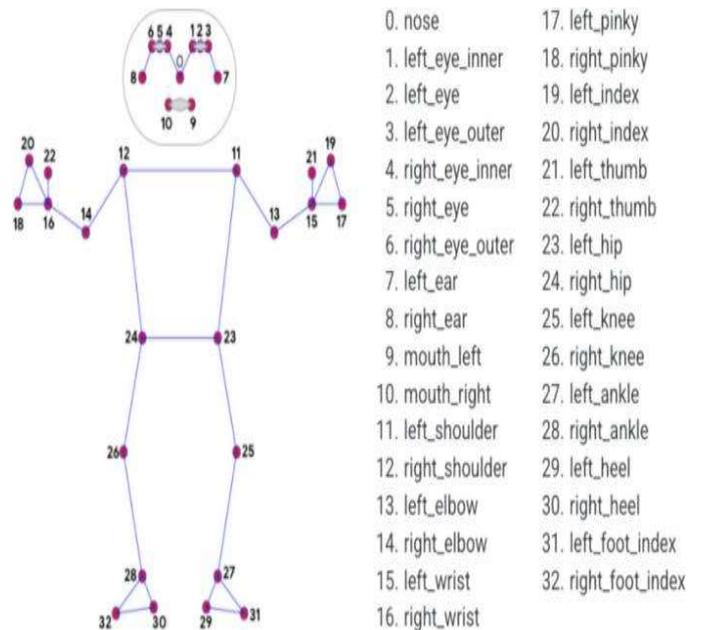


Figure 4. The body tracking coordinates with their designated labels

Once the body outline is mapped out from the video Livestream, the next phase of development is to enable the user to select their preferred garment style in a 3-dimensional (3D) format. Using Augmented Reality and image processing techniques in Python and OpenCV, the overlay of the 3D garment style is displayed over the corresponding body tracking coordinates in the video livestream.

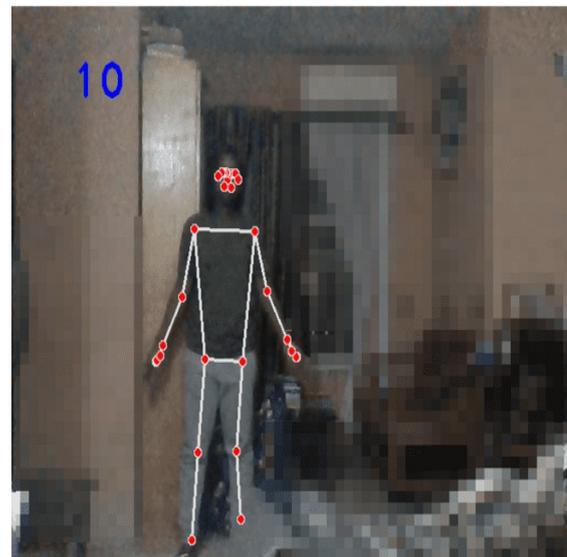


Figure 5. The body tracking coordinates on the human subject 3D Overlay of Garment Style

In Figure 6, the user of the AR system selected the “T-shirt” as the garment style. For this choice, the upper *body tracking coordinates* are ‘11’ and ‘12’, which represent the ‘right shoulder’ and ‘left shoulder’, respectively.

A scaling factor is used in this module to prevent the garment style from moving out of focus when the user is at various distances from the camera. This also helps to achieve

accurate body tracking coordinates with users of diverse body sizes.



Figure 6. The 3D Overlay of a 'T-shirt' garment style

- Apparel Visualization: Combined Overlay of Garment Style and Textile Material:** After the user has selected the preferred garment style, the preferred textile material is also selected. Python and OpenCV were also employed in the combination of the image of the textile material and the initial garment style selected. Using the 'cv2.addWeighted' function, the images of these two items were combined into one image that was used for the final overlay. The images are to be resized to avoid errors. Due to the outlook of the combined image, Gaussian filtering was used to adjust the image and blur out the unnecessary details. Subsequently, the image generated from the combination of garment style and textile material was displayed to the user, serving as the final output and apparel visualization of the AR system. The user is allowed to upload a picture of the preferred textile material or pattern. The textile material uploaded to combine with the 3D garment style displays the final output and apparel visualization of the AR system as depicted in Figure 7, where an image of a 'purple textile material is combined with the 't-shirt' garment style to create a purple t-shirt apparel look which is then overlaid on the user's body in real-time within the video live stream.

C. CODE SNIPPETS

The real-time AR system for apparel visualization was developed using tools including Python 3, Mediapipe v0.8.6.2, OpenCV and Visual Studio Code. Figure 8 shows a snippet of the code implementation using the AR tools.



Figure 7: Final output and apparel visualization of a purple t-shirt apparel look

```

import cv2
import mediapipe as mp
import time
import math

class poseDetector():
    def __init__(self, mode=False, smooth=True, detectionCon=0.5, trackCon=0.5):
        self.mode = mode
        self.smooth = smooth
        self.detectionCon = detectionCon
        self.trackCon = trackCon
        self.pTime = 0
        self.mpDraw = mp.solutions.drawing_utils
        self.mpPose = mp.solutions.pose
        self.pose = self.mpPose.Pose(static_image_mode=self.mode, smooth_landmarks=self.smooth, min_detection_confidence=self.detectionCon, min_tracking_confidence=self.trackCon)
    def findPose(self, img, draw=True):
        imgRGB = cv2.cvtColor(img, cv2.COLOR_BGR2RGB)
        self.results = self.pose.process(imgRGB)
        if self.results.pose_landmarks:
            if draw:
                self.mpDraw.draw_landmarks(img, self.results.pose_landmarks, self.mpPose.POSE_CONNECTIONS)
        return img
    def getPosition(self, img):
        self.lmList = []
        if self.results.pose_landmarks:
            for id, lm in enumerate(self.results.pose_landmarks.landmark):
                h, w, c = img.shape
                cx, cy = int(lm.x * w), int(lm.y * h)
                self.lmList.append([id, cx, cy])
        return self.lmList
    def showFps(self, img):
        cTime = time.time()
        print(cTime, self.pTime)
        fbs = 1 / (cTime - self.pTime)
        self.pTime = cTime
        cv2.putText(img, str(int(fbs)), (70, 80), cv2.FONT_HERSHEY_PLAIN, 3, (255, 0, 0), 3)
    def findAngle(self, img, p1, p2, p3, draw=True):

```

Figure 8. Code snippets for the system implementation

V. EVALUATION

After the system was implemented, the stakeholders involved in the project (end-users) evaluated the system to verify that it met both the functional and non-functional requirements that were set during the initial phase. Functional and performance

tests were also initiated to ensure that the system is bug-free and works optimally.

Beta Testing was carried out using a survey method involving twenty-one (21) male and female end users having various body types. They provided feedback via a questionnaire tool and the feedback received was used to make final refinements and enhancements to the AR system before its full release. The questions revolve around the major performance criteria identified for the real-time AR system for apparel visualization. These criteria include user experience, responsiveness, accuracy usability and realism. The body tracking features of the AR system were also evaluated based on its performance in different lighting conditions.

A. USER EXPERIENCE

The “user experience” metric analyzed the general experience the user had while interacting with the system. Figure 9 indicates the user's rating of their overall experience using the system with “1” being ‘Very bad experience’ and “5” being

‘Very good experience’. From the responses, 66.7% and 28.6% indicated that they had “good” and “very good” experiences respectively, while 4.8% of the respondents indicated that they had a “neutral” experience while interacting with the system.

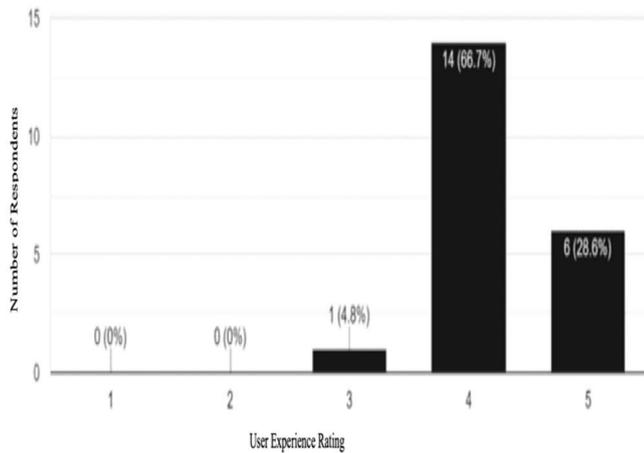


Figure 9. Rating of overall user experience

B.. RESPONSIVENESS

This criterion defines the performance of all the aspects of the AR system when the users interact with it. The responsiveness ratings of ‘Yes’, ‘No’ and ‘Maybe’ were based on whether or not the system responded to actions and interactions. As depicted in Figure 10, 86.7% of the respondents indicated that the system responded quickly to various actions like moving around, moving closer or farther away from the camera and so on. All respondents (100%) also indicated that they were able to navigate the system easily.

C. ACCURACY

The accuracy metric was based on body tracking accuracy. The ratings of ‘Yes’, ‘No’ and ‘Maybe’ were employed to check whether or not the virtual garment aligned satisfactorily with users’ bodies. Figure 11 shows that 76.2% of users responded that the garments aligned correctly with points on their bodies.

D. USABILITY

This parameter described the ‘ease of use’ and the user's understanding of the AR system. Users rated their agreement on a scale of 1 to 5, with ‘1’ being ‘Strongly Agree’ that the application was understood and easy to use, and ‘5’ being ‘Strongly Disagree’. Figure 12 shows the highest vote to be “Agree” by 47.6% of the respondents.

E. REALISM

This metric measured the level of realism of the apparel visualization based on *the overlay of the garment on the user's body* in the AR system. A rating scale of 1 to 5 was established, with ‘1’ being ‘Very unrealistic’ and ‘5’ being ‘Very realistic’. The highest ratings were ‘2’ and ‘3’ as depicted in Figure 13, where 33.3% of the users found the overlay to be ‘Very unrealistic’ while 38.1% of users were ‘neutral’. This indicated that further improvement of the system was necessary in terms of realism.

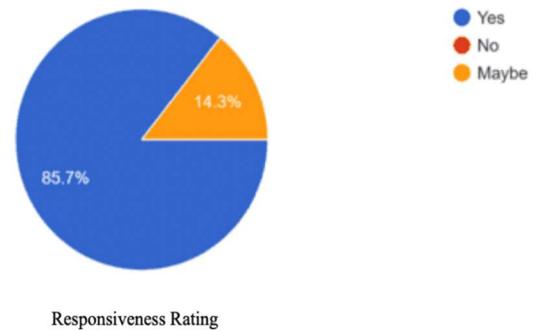


Figure 10. Rating on the system’s responsiveness

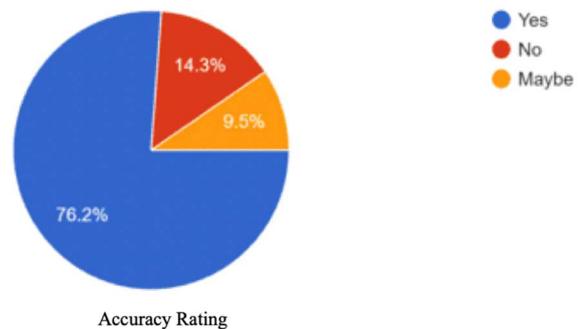


Figure 11. Rating on the system’s accuracy

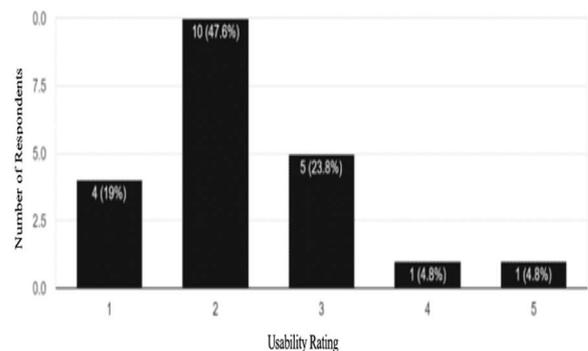


Figure 12. Rating on the system’s usability

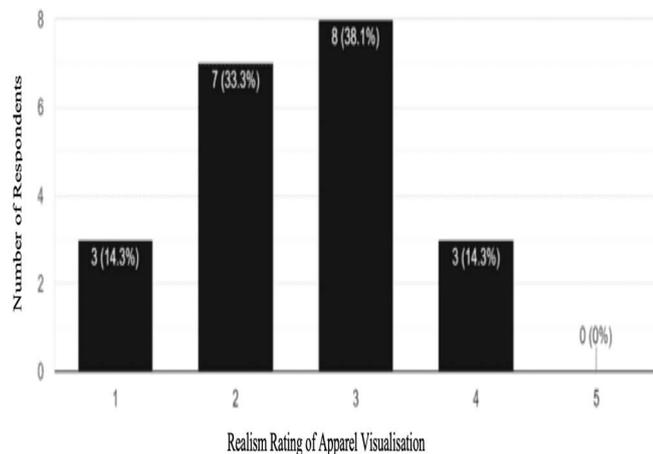


Figure 13. Rating on the system’s usability

F. PERFORMANCE IN LIGHTING CONDITION

The AR system was evaluated based on the performance of its body tracking features in different lighting conditions using tracking percentage and frames per second (FPS). Under brighter lighting conditions, the system yielded an average success rate of 48.42% and 8.9 FPS, peaking at 66% and 153 frames in 30 seconds. While under low lighting conditions, the system produced diminished results with a 40.23% success rate and 8.23 FPS, reaching a peak of 54.7% and 144 frames. This indicates that the performance of the accuracy of the system is higher with brighter lighting conditions.

Feedback from the testing and evaluation detailed generally positive feedback on the system’s usability, preference for physical clothing try-on experiences, accuracy of the apparel visualization, experience navigating the system, and general satisfaction. The system's navigation, usability, reactivity, and precision of the fashion clothing alignment received positive feedback. From the evaluation done, it was discovered that with users with larger body sizes, the overlay was displayed less realistically than for users with smaller body sizes. The system was also found to be dependent on a well-lit environment to ensure precise tracking of body landmarks for accurate overlay positioning. Recommendations received also included the inclusion of a larger range of fashion styles and improvements for the realism of the displayed apparel.

VI. CONCLUSION

The AR system receives the video stream from the camera and proceeds to implement body tracking of various points of the human body. An overlay of the 3D garment type selected is displayed on the image of the human body captured via the video stream. The preferred textile material is then uploaded to the 3D garment overlay giving an apparel visualization of the selected fashion style. This apparel visualization simulation can support total fashion coordination for outfits based on the user’s choice and does not require computer or fashion expertise. It can also be widely used to support a customized method of cloth shopping.

The AR system for apparel visualization used basic garment styles as a case study where only the front part of the garment is visible. Future iterations of the system would include covering the back of the garment as well as enhancing system accuracy across environments with different lighting conditions. Improved Graphical User Interface (GUI) that

fosters user interaction should be included for better user experience. The final apparel visualization output could be more refined and realistic, with a more extensive clothing style catalogue and database.

The paper’s innovation lies in its contributions to the field of apparel visualization using augmented reality and computer vision techniques via the integration of several technologies, technical robustness of the methodologies, and user feedback and consumer behavior. The integration of technologies including computer vision techniques, real-time image processing, and augmented reality visualization aids in addressing challenges such as accurate garment alignment on the human body in real-time. The paper also introduces the technical robustness of the methodologies involved which creates a framework for future research and industry applications. The user feedback and consumer behavior reported in this paper also underscores the practical relevance of the research. Such insights serve to guide future refinements in system design and implementation to better meet user expectations and industry standards. The AR system for apparel visualization also holds the possibility to influence how consumers shop for clothing online or in-store, potentially reducing item return rates due to better visualization accuracy. This is projected to enhance the overall customer satisfaction in the industry.

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