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Exploring the effectiveness of an augmented reality dressing room

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Abstract In this paper, we describe our experience with the design of an augmented reality dressing room in which 3D models of a dress are overlaid with a color image from a camera to provide the function of a sort of virtual mirror. In such a way, the customer can move around to understand if a dress suits and fits them well. The project is implemented in Unity 4 Pro in combination with the Microsoft Kinect 2 for the tracking process. Design issues and technical implementation as well as the prospects for further development of the techniques are discussed. To assess the validity of our proposal, we have conducted a user study using 47 participants with different levels of experience with video games and devices used to play them. The empirical method used is qualitative. To this end, we used questionnaire-based surveys. The obtained results suggest that our solution represents a viable means to simulate dressing rooms, and participants in the study found the interaction with our 3D models to be natural for understanding if a dress suits and fits them well. Overall, the participants found our application very useful from a practical point of view.

Keywords Augmented reality · Human body tracking · Dressing room

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1 Introduction

In the modern era, shopping has become a highly popular and time-consuming activity. In particular, for some people, clothes shopping is a leisure activity, whereas, for others, it is stressful and tedious because of the amount of guesswork involved in determining if clothing suits and fits the individual well. A virtual dressing room enables shoppers to try on virtual clothes to check one or more sizes, fits or styles rather than physically doing so, allowing shoppers to make their purchases quickly and easily. Experiments on virtual dressing room technology have been conducted for many years. In particular, fit technologies started to be widely reported in 2010 [5]. Initially, this approach was based on the creation of a mechanical model of a torso based on a shopper's measurements. Using this model, customers are able to try on shirts in various sizes so that they can choose the best fit in a particular style. Other fit technologies are now available from an increasing variety of providers and are in use by a growing number of prominent retailers. These fit technologies are based on different approaches, including size recommendation services [31], body scanners [19], 3D customer models [25], photo-accurate virtual fitting rooms [22], and, recently, augmented reality [14]. In a dressing room based on augmented reality using a webcam, the shoppers try virtual clothing on themselves, thus enabling them to check the fit or the style virtually rather than physically. In addition, such a kind of software also uses a motion capture system that allows users to use hand motions to browse the clothing catalog and determining if a set of clothes suits them while standing in front of a vertical display. This approach is the most promising because it is closer to a real shopping experience but also allows shoppers to make purchases quickly and easily. However, little research has been conducted on the design and development of a virtual dressing room in terms of usability (ease of use and learnability) [13]. This is an important aspect because if virtual dressing rooms are undeniable opportunities for retailers, they must also be so for the shoppers. By providing shoppers with a more personalized experience, as illustrated in a 2015 report by Walker Sands, 35% of customers would shop online more often if they were able to try items on virtually rather than simply view images of the items [26]. In other terms, preliminary studies suggest the intention of users in adopting this new technology but empirical evaluations that aim to predict the factors that influence the success of this technology are required.

The visual tracking of human body motions is an interesting field with a wide range of applications, from motion capture for the movie and gaming industry to surveillance to human-computer interaction. In each of these areas, there is a need to track how a human body moves. Recent developments in sensor technologies allow for accurate and robust human body tracking, thereby enabling a set of new possibilities. In particular, entertainment technologies, such as the Microsoft Kinect [7] and other related devices, have lowered the barrier to entry to these possibilities in terms of both cost and developmental complexity. However, the technology behind Kinect has been used in many contexts (not only in gaming) ranging from advanced user interfaces to high-quality 3D scans [3].

In this paper, we propose an augmented virtual dressing room application based on the visual tracking of human body motions (also simply a tool or 3D application herein). It is designed to be computationally efficient and to be used with inexpensive hardware. In fact, it can be run on a common desktop PC equipped with an off-the-shelf Microsoft Kinect 2 device. The way in which this application has been developed can enhance the way customers shop and help them choose the correct type of clothing. The major benefits of such an application can be summarized as follows: *(i)* improved ability to make the correct purchase, reducing the time required; *(ii)* many more opportunities for fashion designers to conduct creative experiments; and *(iii)* usefulness for other goods such as jewelry, glasses, handbags, and shoes. We also present and discuss here the technical solutions chosen for the implementation of our approach in a sample dressing room application. This sample application has a user interface that allows the user to choose clothing by making a hand movement toward it.

In addition, we present the results of an empirical study used to preliminarily assess the validity of our augmented virtual dressing room application. The empirical method is qualitative since we used questionnaire-based surveys. We administered these surveys to 47 participants. This study is preliminary in the sense that it does not focus on the major benefits delineated before. To study all these benefits a long-term investigation (taking place over the years) is needed. On this matter, different kinds of investigations (e.g., survey and controlled experiments) with different kinds of participants and in different contexts need to be conducted.

Summarizing, we investigate in our empirical study the following primary research question:

> *To what extent does an augmenting reality technology for a virtual dressing room application impact the way customers shop?*

The work presented in this paper is based on the work presented in [9], where we preliminarily proposed our approach and its supporting software tool. The current paper extends the previous paper as follows:

1. An improved and extended description of the approach and tool used to enable the augmented virtual dressing;
2. A qualitative empirical assessment is conducted with users;
3. The results of this empirical assessment are discussed together with their possible practical implications.

Structure The paper is organized as follows. In Section 2, we present a summary of the fundamentals of the technologies adopted to develop our application, while research related to our work is highlighted in Section 3. In Section 4, we present the design of this application, and the design of our empirical investigation is shown in Section 5. The experimental results are illustrated and discussed in Section 6. In this section, we also highlight possible threats that could affect the validity of the obtained results and delineate some possible practical implications related to the use of our application. Final remarks and future work conclude the paper.

2 Background

The following section will provide a basic outline of the fundamentals, particularly those of the two technologies used by our approach: Microsoft Kinect 2 (a.k.a. Kinect One) and Unity 3D.

The Microsoft Kinect 2 [6] is a device for the Xbox One gaming console that allows users to control and interact with games through a natural user interface using gestures and spoken commands. Kinect 2 has a cone-shaped tracking area of 70°. A user comes into full view of the Kinect 2 camera at approximately 1.4 m. At distances closer to the camera, only partial skeletal tracking is possible. The maximum Kinect 2 tracking range is 4.2 m from the camera. At its closest full-body tracking range, the user can move up to 1 m to each side of the camera. At its maximum range, the user can move up to 2.9 m from each side of the camera. This results in a total tracking range of slightly over 10^2 [12]. The tracking process of the Microsoft Kinect 2 is based on the retrieval of particular body joint positions [28]. This algorithm allows one to detect and track the user's skeleton in real time in a stable and efficient manner. Moreover, the algorithm allows for a full rotation of the body and a robust distinction between the left and right side of a user's body.

Unity 3D [30] is a feature-rich, fully integrated development engine that provides out-of-the-box functionality for the creation of interactive 3D content. Using Unity, it is possible to publish on multiple platforms, such as PC, Web, iOS, Android and Xbox, which also enables the augmented reality dressing room in combination with the Kinect to be executed on several operating systems. The complete toolset, intuitive workspace and on-the-fly play testing and editing feature of Unity saves developers time and effort. Unity enables developers to extend its functionality using platform-specific native code libraries called native plugins. Developers can access features, such as OS calls and third-party code libraries, that would otherwise not be available to Unity. Through this feature, the Microsoft Kinect API set is available in Unity Pro (the commercial full version), giving developers full access to the Kinect core functionality. In particular, these plugins enable vision detection and tracking functionality within Unity and allows developers to easily create augmenting applications and games [7].

3 Related work

In the past, several approaches that reflected the current state of the art in human body tracking technologies have been implemented for augmented reality dressing rooms. However, the large majority of previous works were essential based on real-time 2D image/video techniques, where the consumer was able to superimpose the clothes on their real-time video images to visualize themselves wearing the clothes [13]. Briefly, three lines of research in this area are image processing, fiducial markers, and hardware-based tracking.

Martin and Oruklu [21] presented an image processing design flow for visualizing an augmented dressing room designed to be compatible with a common webcam. The software is implemented by a three-stage algorithm: detection and sizing of the user body, detection of reference points based on face detection and augmented reality markers, and superimposition of the clothing over the user image. The limitation of the tracking only allows one to superimpose clothes as 2D images. A similar approach is described by Shaikh et al. [27].

Fiducial-marker-based tracking is based on the automatic detection of patterns in digital images taken from a camera. Kjærside et al. [18] proposed a tag-based approach that requires manual labeling of body parts with one or more markers. The video frames received from the camera are analyzed in real time using image processing techniques to determine the 3D position and orientation of the markers and then to create an augmented reality of the customer wearing clothing. Another similar approach was presented by [2]. The capturing of a person is accomplished using small colored markers on the user. The markers are positioned on specific joints. Moreover, the markers have different colors according to the actual placement on the body. A disadvantage of this approach is that a user cannot be captured from the side. More generally, a disadvantage of this marker-based tracking is that the printed marker pattern has to be placed on the user's body, which may be time consuming and cumbersome to use from a consumer's point of view. In addition, the manual labeling of body parts with tags may also give way to a source of error.

Tracking hardware has provided a more accurate and robust solution enabling one to investigate various augmented reality dressing approaches. The solution by [15] is based on a 2D model that is scaled based on the distance between the user and the Kinect sensor and then overlaid with the video image. The technique is designed for t-shirts, and the paper does not depict the treatment for other clothes. Another similar approach based on depth data provided by the Kinect is presented by [25]. In addition, our work attempts to exploit the body tracking technologies based on the Microsoft Kinect. A key difference with respect to the previous solutions is the use of 3D clothing with skeleton animations. These requirements allow complete room freedom and adds movement flexibility by utilizing smooth continuous tracking.

Recently, several commercial applications based on the Kinect have appeared. Such virtual fitting rooms are available from FaceCake [10] and Fitnect [11], for example. However, these solutions do not address research-related questions on usability and user experience. Two papers presented an evaluation of a usability and user experience test of a virtual dressing room. In [14], a virtual dressing room solution is based on an avatar solution. Using a front-end module, an avatar is chosen as a close representation of the person's size and shape, and a back-end module involving the 3D scanning of clothing is used to produce digital clothing for the virtual dressing room. A total of 75 people participated in the experiment. In particular, teenagers and young adults found the virtual dressing room to be of high interest and presented signs of excitement. In [13], the author presented a usability and user experience study based on a webcam-based system named LazyLazy [33]. In this system, the camera tracks the position, and the 2D image of a piece of clothes is applied to a real-time image of the customer. In this experiment, 30 subjects within the age range of 13 - 47 tested the virtual dressing room. The overall impression was fairly good. The system was fun, interesting and, for most, fairly easy to use (Fig. 1).

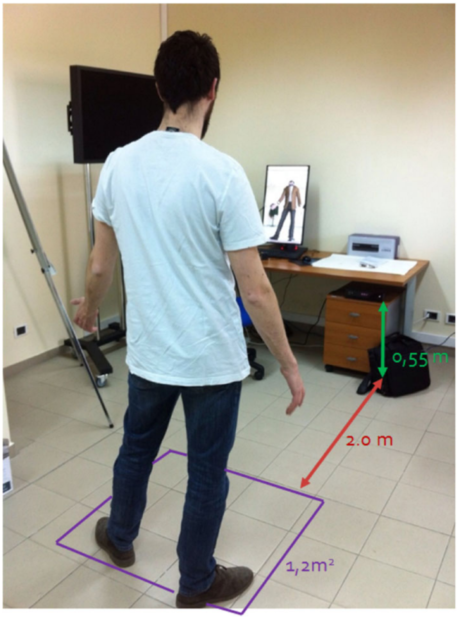


Fig. 1 An intended basic setup of the dressing room. The setup consists of the Kinect 2 device, a vertical display, and a computer. The person in front of the Kinect is interacting at a certain distance and inside a limited area. The green dimension line indicates the placement of the Kinect

4 Design of the augmented reality dressing room

The objective of our augmented reality dressing room is to allow users to try on clothing virtually in front of a large vertical screen to quickly see how a piece of clothing fits physically and aesthetically. In this way, the customers can try on many more articles of clothing in less time. The feeling after virtually wearing an item should help to affect the decision to buy it or physically try the item on.

Most approaches based on body tracking map a 2D texture as a cloth on the user's body [29]. Hence, when the user moves around, the clothing does not accurately capture the user's position and movement, causing several unaesthetic effects. To achieve a more realistic simulation of the process of dressing, we based our approach on the adoption of a 3D model of the clothing. This approach has several advantages. First, it does not make any assumption on the user's dimensions (e.g., body shape, height, width, length of limbs) from the data captured by the Kinect and thus does not require a previous 3D scanning. Secondly, the whole 3D model of the clothing will always follow the motion of the user captured by the Kinect. As the user moves around, the Kinect will capture skeletal tracking information that will be mapped onto the 3D model of the clothing. In such a way, the clothing will perform the same movements as the user. Hence, a realistic simulation of fitting is achieved through the interaction between the skeleton of the user and the skeleton of the 3D model of the clothing.

To use this approach, we require an off-line step before the interaction phase that consists of the skeleton animation editing in the 3D model of the dress. Skeleton animation is a well-know technique used in computer animation in which a character is represented by two parts: a surface representation called the mesh used to render the character and a hierarchical set of interconnected bones called the skeleton. Each bone in the skeleton is associated with some portion of the mesh's visual representation. In such a way, the movement of a portion of the skin is influenced by one or more associated bones [24]. Rigging is the process of constructing the series of bones used to animate the mesh. In such a way, it is possible to animate humans and more general it can be used to control the deformation of any object, e.g. a door, a spoon, a building, or a cloth, because it serves to make the creation of the animation more intuitive. In the process of the rigging, each bone has a three-dimensional transformation (position, scale and orientation), and a parent bone. The bones, therefore, form a hierarchy. The full transform of a child node is the product of its parent transform and its own transform. So moving a thigh-bone will move the lower leg too. As the bones change their transformation over time the skeleton of the character is animated and accordingly the associated 3D model [20].

Usually, a 3D computer graphics program, for instance, 3D Studio Max, which is the program we used for our implementation, provides a default skeleton to animate humans. A modeler must only place joints exactly where they would be in a real-world skeleton and associate the bones with the mesh (Fig. 2). In our case, the rigging is very easy because we can use the default skeleton provided for a human character; however, it is only necessary to associate the bones bound to the mesh of the 3D model of the clothing (left and right foot bones are never used). For instance, in the case of a long skirt, we require only the spine base and the right and left knees.

The Microsoft Kinect SDK 2.0 provides information about the location of users standing in front of the Kinect sensor array, including detailed position and orientation information. Those data are provided to the application code as a set of 20 points (Fig. 3), namely the skeleton position. This skeleton represents a user's current position and pose.

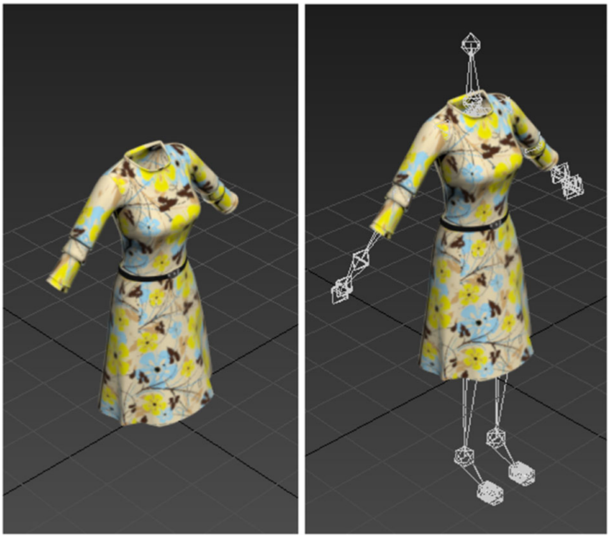


Fig. 2 A 3D dress without and with the skeleton. Before adding a biped skeleton, we need to prepare a 3D dress into which to place the skeleton. The biped skeleton is a well-know two-legged figure created as a linked hierarchy and designed for animation. The biped skeleton has special properties that make it instantly ready to animate

Body joints are used to locate the parts of the 3D model of the clothing and hence represent a user's current position and pose. In addition, the applications can, therefore, utilize the skeleton data for measurements of different dimensions of users' parts and control. In particular, we use the Euclidean distance from the head to one of the ankles to estimate the user's height and the distance between the left and right shoulder to estimate the user's width. Skeleton data are retrieved using the following image retrieval method: calling a frame retrieval method and passing a buffer. Our application can then use an event model by hooking an event to an event handler to capture the frame when a new frame of skeleton data is ready.

Our approach can be summarized as follows: 1) Extraction of the user tracking information from the video stream and depth information, 2) Positioning of the 3D model of the clothing using the skeletal tracker of the Kinect SDK, 3) Scaling of the model using the Euclidean distance between the body joints and the distance from the user to the sensor, and 4) Superimposition of the 3D model of the dress on the user.

Because the clothing is in 3D, the application allows the turning around of the user. Thus, the users can perform a full rotation in front of the monitor to see their front and back side. To perform this action, we experimentally found that the body joints are adequately detected within the distance range of approximately [2m…3.2m] (see Fig. 1). A drawback of this approach is that the 3D model is superimposed onto the top layer, and the user always stays behind the model. This causes some inevitable artifacts, for some types of clothing, when the user performs certain actions such as folding their arms.

The user interface elements in our application are depicted in Fig. 4 with some examples of clothing. The button on the upper right side allows us to force the application to re-acquire the user's dimensions. The buttons on the right and left central sides are functions for the selection of the previous and next set of clothes. A hand position indicator shows the

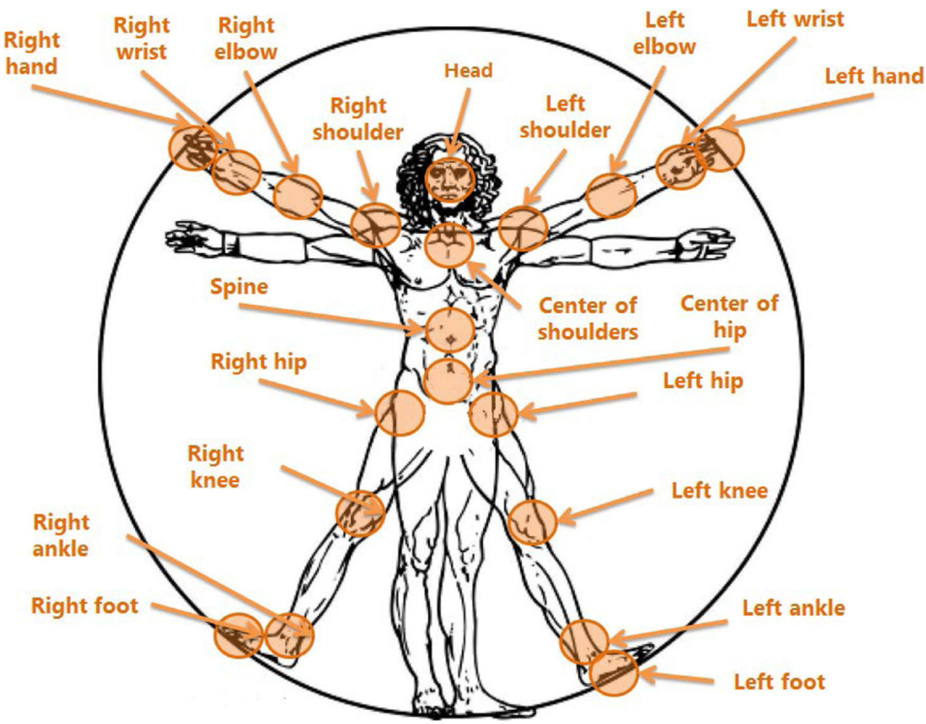


Fig. 3 The 20 joints that constitute a Kinect skeleton are detected and tracked by the Natural User Interfaces provided with the SDK [8]

current coordinates of the hand on the screen, similar to a mouse. This provides a simple means of interaction by just holding the hand above the elements and waiting two seconds to switch from one set of clothes to another.

5 Empirical assessment

In this section, we present the planning and design of our user study. The study was conducted by following the recommendations provided by [16, 17], and [32].

5.1 Goal

In this study, we have defined and investigated the following research questions (RQs):

RQ1: Do shop customers find straightforward the interaction with the augmented reality dressing room when browsing the clothing catalog and suitable the wearing of a clothing from that catalog?
RQ2: Do shop customers find the augmented reality dressing room to be useful?
RQ3: Do shop customers find the augmented reality dressing room to be easy to use?
RQ4: Do shop customers find the augmented reality dressing room to be playful?

Fig. 4 The user interface of the application and some examples of clothing. The green arrow icons on the left and on the right are used to browse the clothing. A click is simulated by closing the hand over these icons. A restart icon is located on the top. This icon is used when a new user enters the dressing room

RQ1 has been defined to study specific aspects (i.e., browsing the clothing catalog and the wearing of a clothing) related to the developed augmented reality dressing room. We defined the remaining RQs to study what the potential shop customers perceived (as a whole) about: usefulness, easiness, and playfulness of that dressing room, respectively.

5.2 Study design

The participants were recruited through word of mouth advertising and student mailing lists. The participants booked the day and the time of their engagement using the online scheduling software Doodle. Their participation was voluntary and anonymous, and participants were not compensated for participating. They were informed that all the information they provided would remain confidential.

Our study was based on one-to-one (controlled) sessions between the observer and each participant. This choice has the advantage to have a high level of control, while students performed the assigned tasks. The use of one-to-one sessions is almost customary in qualitative studies because allow the observer to control and observe the execution of the study. Our study consisted of the following phases:

- *Fill in a pre-questionnaire.* We asked participants to fill in the questionnaire mentioned before the study occurred. The goal was to gather information on the experimental context, therein collecting demographic information (i.e., gender, age, and education level); ICT expertise, general attitudes toward video games, and general familiarity and experience with augmented reality. Participants were also asked to indicate whether they had poor eyesight and how they correct the possible problem. The pre-questionnaire is composed of the 14 statements. We reported the statements (they are not questions because they are not in interrogative form) of this questionnaire and their possible answers (a few of them based on a five points scale) in Appendix A.1. We used the Google form support to define this questionnaire and to administer it to the participants in the study.

- *Introducing the 3D supporting application.* We shortly introduced our 3D application to the participants. The observer was the same for each participant in the study, thus reproducing similar experimental conditions for each participant. In particular, the observer used a prearranged schema for each participant, namely a few sentences to describe how the application worked. The user interface was explained in terms of gestures to perform for interacting with the system: the hand is similar to a cursor, and double-clicking is performed by closing and opening the hand two times. The observer did not provide details on research topics of interest. At the end of this step, the participants could ask questions for clarification.
- *Freely use the application.* We first allowed the participants to freely use our 3D supporting application for no more than 5 minutes.
- *Browsing clothing catalog and dresses.* We asked participants to choose (and then dress in) one or more sets of clothes. Then, participants could move around with a clothing to check how it fit. We did not impose any time limitations. At the end of this phase, we asked participants to fill in a final questionnaire (or simply questionnaire, from here on). We report this questionnaire in Appendix A.2. This questionnaire includes statements to assess how participants perceived both the browsing of the content of the catalog and virtually trying on the clothes (suitability of a dress). The group of statements related to the task browsing the clothing catalog are labeled with T1, and those related to the clothing are labeled with T2. We used the answers to these statements to study research question RQ1. We also asked statements on the perceived usefulness of our application (PU), its ease of use (EOU), and its perceived playfulness (PP). Answers to statements related to PU were used to study research question RQ2, and those related to EOU were used to study RQ3. To study RQ4, we exploited the answers given to the statements concerning the PP. The total number of statements was 21 and admitted answers according to a 5 points scale (from very unlikely to very likely). Theses statements are inspired to the System Usability Scale for measuring the usability a wide variety of products and services, including hardware, software, mobile devices, websites and applications [4]. As for PP, we selected a subset of the statements proposed by Ahn et al. [1], who measured playfulness with respect to: concentration (time elapse, noise awareness, forget things), enjoyment (enjoyment, fun, happiness), curiosity (stimulus, exploration, imagination). Then, we opted for those statements aimed at investigating the concerns we believed more suitable for our developed solutions, namely time elapsed, noise, fun, and imagination.

  For example, we discarded those statements concerned with curiosity (e.g., stimulus and exploration) because we devised these statements not relevant for our study.

  Statements were administered to the participants in the Italian language to avoid the situation wherein those participants with a low familiarity with English would misunderstand questionnaires and then provide incorrect answers to their statements. This choice allowed use to reduce possible conclusion validity threats. It is also worth noting that we used Google Forms to define the questionnaire and to administer it to the participants.

5.3 Threats to validity

In this section, we discuss possible threats that could affect the validity of our results. Such a discussion allows us to better understand strengths and limitations of our empirical study. Although we attempted to mitigate and avoid threats to the validity to the greatest extend possible, some of these threats are unavoidable because they are related to the type of empirical investigation conducted [32].

5.3.1 Internal validity

A possible threat to internal validity is concerned with the interaction among participants for sharing information and perceptions of our 3D application. We attempted to address these concerns in several directions. Participants were asked to *(i)* return material once they concluded the study, *(ii)* avoid discussing and sharing the experience gained in the study with their classmates, and *(iii)* not use smartphones to take pictures and movies while performing the tasks. We did not have any control over the second point. However, the study supervisor took pictures of all the participants when performing the tasks and then shared these pictures with them when the study was concluded.

5.3.2 External validity

This type of threat is always present when students are used as participants. The participants were sampled by convenience from a population of students at the University of Basilicata. Therefore, generalizing the results to a different population (e.g., actual shopping customers) poses a threat of interaction of selection and treatment. That is, the use of students in Computer Science could lead to doubts concerning their representativeness. Indeed, this type of student could be more comfortable with new technologies than could other types of participants.

Regardless, the tasks to be performed did not require a high level of experience with augmented reality and the utilized technologies.

5.3.3 Construct validity

The utilized questionnaires could affect the construct validity. To address this type of threat to validity, we designed pre- and post-questionnaires using standard methods and scales [23].

5.4 Study context

The participants in the study were 47 undergraduate students. They were sampled by convenience among the students in Computer Science at the University of Basilicata. Among them, 30 were 3rd-year students from a course on the design and implementation of information systems, and the remaining students were 2nd-year students from a course on algorithms and data structures.

The answers to the mentioned pre-questionnaire are summarized in Table 1. In particular, for each statement, we show how many participants responded to each of the possible answers. In addition to the answers that admitted closed answers (the greater part of the questionnaires), there were some statements that admitted open-ended responses (e.g., Q12), and others could have had one or more answers. In other cases, one statement (e.g., Q14) was administered to a participant only based on his/her answer to the previous statement.

We can observe that the greater part of the participants (i.e., 21, corresponding to 44.7% of the participants) strongly agreed that they like to play with video games. Only a few participants did not like to play video games (1 and 5 participants responded *strongly disagree* and *disagree* to Q1, respectively). The greater part of the participants (i.e., 17, corresponding to 36.2% of the participants) declared having average experience with video games, and 12 and 3 participants asserted being experts in playing video games. The remaining participants

Table 1 Summary of the responses to pre-questionnaire

Q1	Strong Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree
	1	5	8	12	21
Q2	Strongly Agree	Disagree	Neither Disagree nor Agre	Agree	Strongly Agree
	6	9	17	12	21
Q3	Less than one hour	Between one and seven hours	Between eight and fourteen hours	Between fifteen and twenty-one hours	More than twenty-one hours
	15	14	11	6	1
Q4	First-Person Shooter	Adventure	Role-Playing Games	Strategy/Tactics	Sports
	8	11	5	6	11
	Fighting	Dance/Rhythm	Survival Horror	None	Other
	0	0	3	2	1
Q5	Mouse/keyboard	Kinect	Joypad	PlayStation	Other (Volante)
	27	0	7	9	1
	None				
	3				
Q6	Yes	No			
	30	17			
Q7	Myopia	Astigmatism	Far-sighted		
	24	4	2		
Q8	Yes	No			
	30	17			
Q9	Inexpert	Beginner	Competent	Sufficiently Expert	Expert
	0	6	17	23	1

Table 1 (continued)

Q10	Yes	No			
	41	6			
Q11	Inexpert	Beginner	Competent	Sufficiently Expert	Expert
	23	17	5	2	0
Q12	Kinect	Leap Motion	PlayStation	Wii	None
	11	0	4	8	27
	Other				
	1				
Q13	Yes	No			
	40	7			
Q14	Inexpert	Beginner	Competent	Sufficiently Expert	Expert
	25	11	9	0	2

believed that they did not have sufficient experience with video games. More than half of the participants reported that they either played between 1 and 7 hours per week or between 8 and 14 hours per week. However, the greater part of the participants (i.e., 15, corresponding to 31.9% of the participants) indicated that they played less than one hour per week. A small part of the participants (i.e., 6) asserted that they play between 15 and 20 hours per week. The greater part of the participants (27, 58.75% of the participants) play video games with a PC/Laptop using a mouse and keyboard. A part of the participants play with a joypad and console, namely, 7 and 9 participants, respectively. Many participants (30) had poor eyesight, and myopia is the most widespread vision problem among the participants. In particular, 24 participants suffered from myopia, while 4 were astigmatics. Only 2 participants were far-sighted. Vision problems were always corrected with glasses.

A part of the participants stated that they have adequate knowledge of information and communications technologies (ICTs) (Q9). In particular, 23 participants stated that they were effectively experts, and 17 stated that they were neither expert nor non-expert. This allows us to assess how our solution is perceived by both users with and without experience with ICTs.

Almost all the participants had heard of the term augmented reality (i.e., 41, corresponding to 87.2% of the participants); however, they did not have experience with this type of technology. We observed a similar trend for the Kinect sensing input device. Specifically, a greater part of the participants (85%) had heard of the Kinect device before the study, but only a few of them had any experience with it, namely, 9 and 2 participants declared having average and good experience, respectively. Summarizing, we can postulate that participants had a good level of technical maturity that made them suitable for the study presented in this paper. Indeed, the participants in our study could be more familiar with new technologies than possible shop customers. We can then assert that they represent the present and future generation of shop customers.

5.5 Instrumentation

The empirical evaluation was performed on a PC equipped with an Intel Core i7-3820 @3.60 GHz with 16 GB of RAM, a Nvidia GeForce GTX Titan 6.0 GB video card, and Windows 8 as the operating system. The utilized monitor was an Asus ROG PG278Q 27-inch LCD with a 2560 $\times$ 1440 resolution. The monitor was rotated vertically to provide something similar to a dressing room mirror.

6 Results and discussion

In this section, we present and discuss the results observed based on the answers participants gave to the statements to the (final) questionnaire. The presentation of the results and their discussion are organized with respect to the defined research questions. Answers to the statements are summarized using pie charts.[1] We conclude this section by discussing possible practical implications related to the use of our virtual dressing room and to the obtained outcomes.

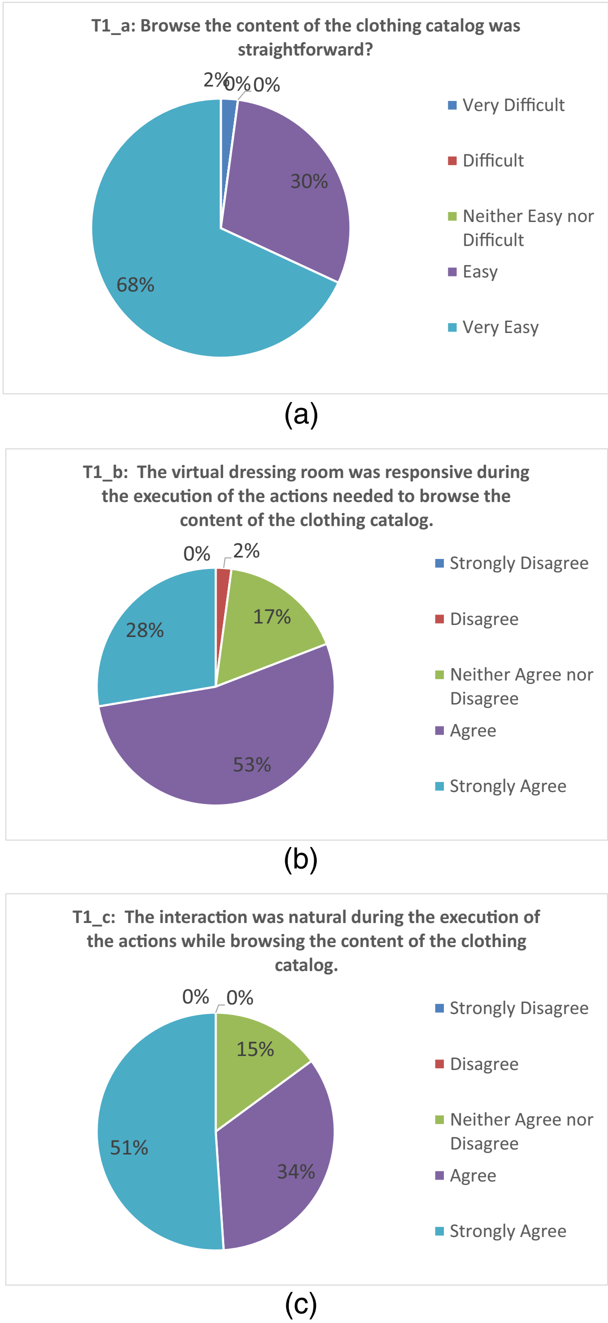


Fig. 5 Summary of the answers to T1_a, T1_b, and T1_c

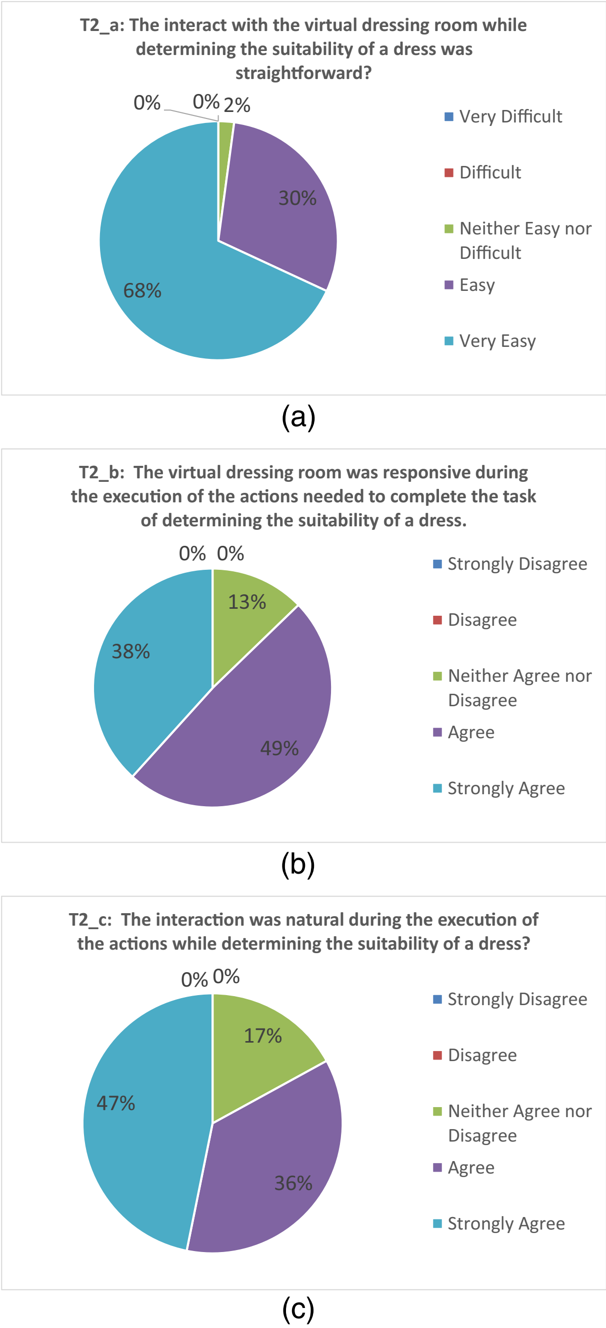


Fig. 6 Summary of the answers to T2_a, T2_b, and T2_c

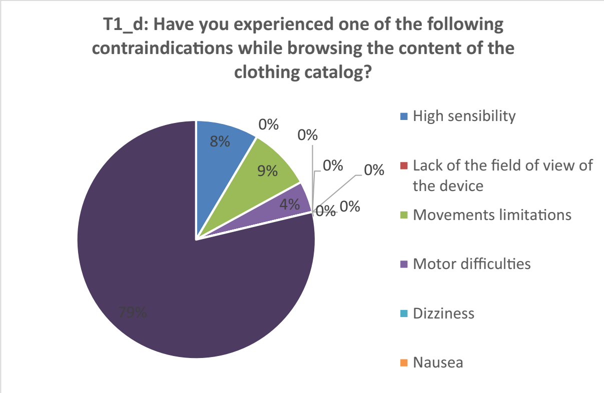


Fig. 7 Summary of the answers to T1_d

6.1 RQ1 - interaction with the clothing catalog and dress suitability

Participants found the content of the clothing catalog straightforward to browse (see Fig. 5a). In particular, 68% and 30% of participants strongly agreed and agreed that the content of the clothing catalog was straightforward to browse, respectively. Only 2% of participants disagreed on the straightforwardness in browsing that catalog.

As for the responsiveness while browsing the content of the clothing catalog (see Fig. 5b), we observed that 53% of the participants agreed on the fact that the virtual dressing room was responsive, whereas 28% strongly agreed on this point. Neutral participants represented 17% of the total. These participants neither agreed nor disagreed with the question concerning responsiveness. Only 2% of participants provided a negative judgment.

We observed that the greater part of the participants either strongly agreed or agreed that the interaction with the virtual dressing room was natural during the execution of the actions for browsing the content of the clothing catalog. As shown in Fig. 5c, 51% and 34% of participants answered *strongly agree* and *agree* to T1_c, respectively. The remaining 15% answered neither *agree* nor *disagree* to that question.

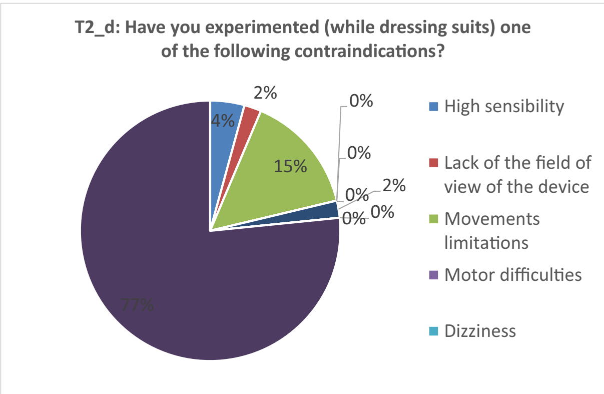


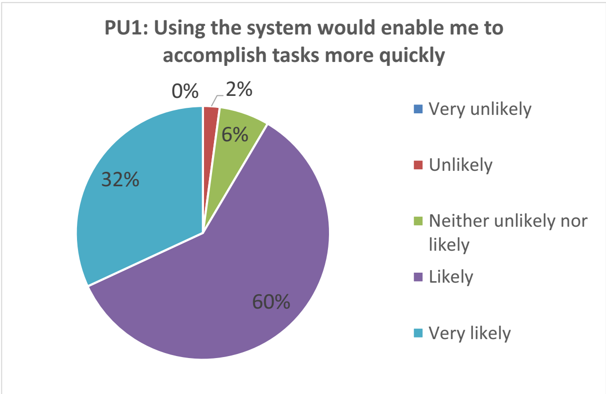
Fig. 8 Summary of the answers to T2_d

Concerning the interaction with the virtual dressing room when wearing clothing, we obtained nearly the same results as browsing the content of the clothing catalog (see Fig. 6a). In particular, 68% and 30% of the participants strongly agreed and agreed that the suitability of a dress was straightforward, respectively.

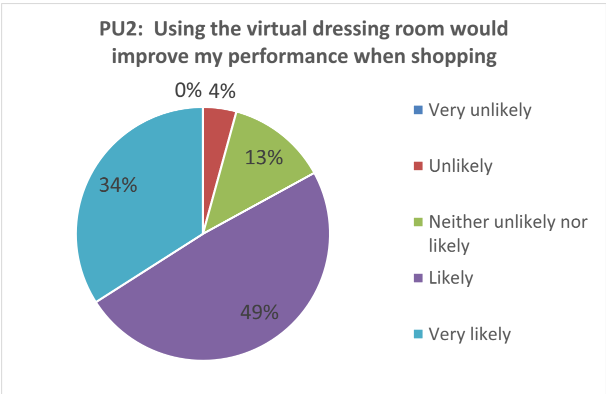
The participants expressed a positive judgment on the responsiveness of our virtual dressing room when performing their actions to complete the task of determining the suitability of a dress (see Fig. 6b). In particular, 38% of participants strongly agreed on the system responsiveness, and 49% agreed on this point. The other participants (13% of the total) were neutral; specifically, they answered neither *agree* nor *disagree*.

The judgment on the naturalness of the interaction while determining the suitability of a dress is positive (see Fig. 6c). In particular, 47% and 36% of participants answered *strongly agree* and *agree* to question T2_c, respectively. The remaining participants (i.e., 17%) answered neither *agree* nor *disagree*.

The greater part of the participants (i.e., 79%) did not experience any of the contraindications listed as the possible answers (see Fig. 7). Among the experiment's contraindications,



(a)



(b)

Fig. 9 Summary of the answers to PU1 and PU2 when browsing the clothing catalog, the participants experienced High sensibility (8%), Movement limitations (9%), and Motor difficulties (4%).

In Fig. 8, we summarize the answers to question T2_d. As the chart shows, the greater part of the participants did not experience contraindications when determining the suitability of a dress. A small number of participants experienced movement limitations (i.e., 15%) and high sensibility (i.e., 4%). A lack of the field of view of the device (i.e., 2%) and tennis elbow (i.e., 2%) were the other two experienced contraindications.

Based on the responses to questions from T1_a to T1_d and from T2_a to T2_d, we can assert that participants in the study did not have any particular difficulties in browsing the content of the clothing catalog and did not manifested any particular issues in the suitability of dress. More importantly, the participants found the interaction with the virtual dressing room to be natural when performing the tasks on the catalog and on those to determine the suitability of a dress.

According to the obtained results, we can positively answer RQ1.

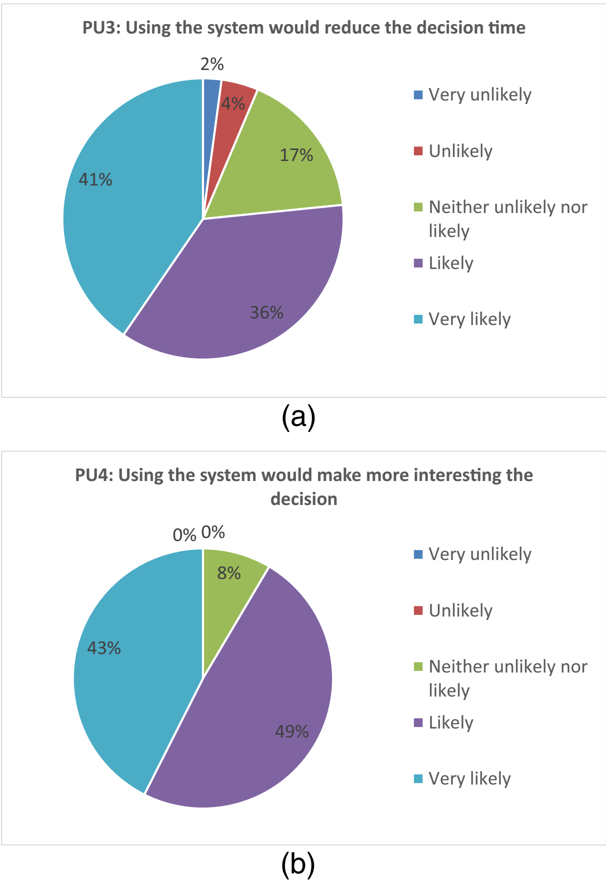


Fig. 10 Summary of the answers to PU3 and PU4

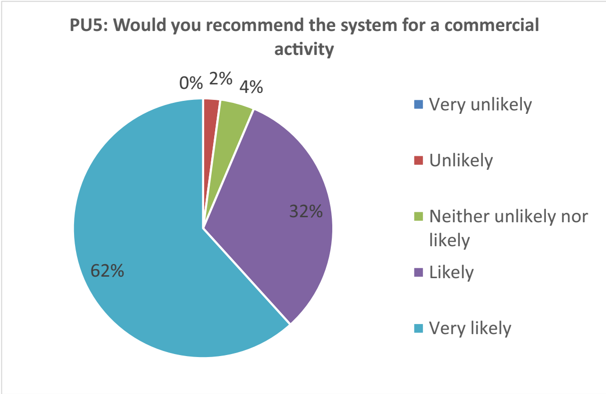


Fig. 11 Summary of the answers to PU5

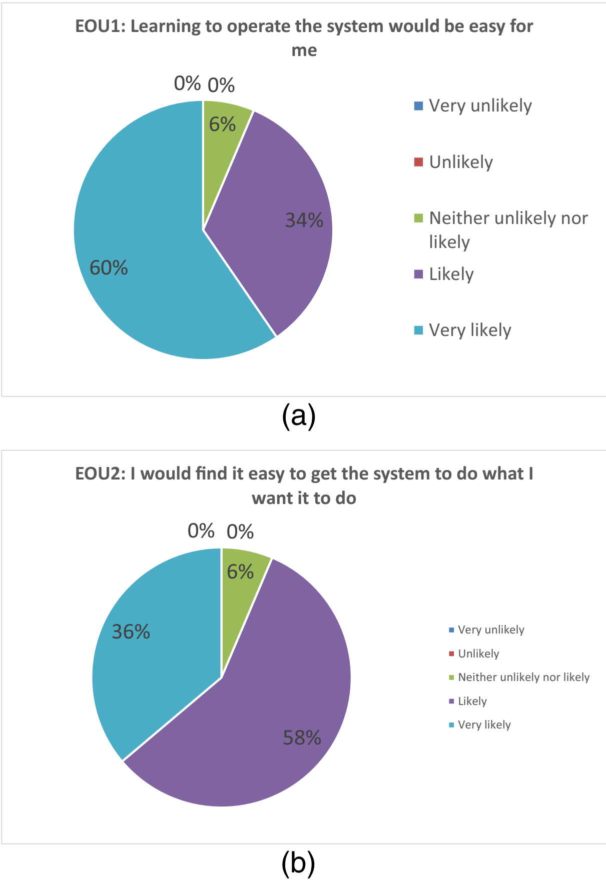


Fig. 12 Summary of the answers to EOU1 and EOU2

6.2 RQ2 - perceived usefulness

The greater part of the participants believed that the use of our virtual dressing room would enable them to accomplish dressing tasks more quickly (see Fig. 9a). The most spread out answers were very likely (i.e., 32% of participants) and likely (i.e., 60%). Only 2% of participants answered unlikely to PU1. The remaining participants expressed a neutral judgment.

Even more interesting, 34% and 49% of participants believed that it was likely or very likely that our participants would have improved their performance in shopping, i.e., more satisfaction related to the possibility of trying more clothes in less time. A neutral judgment was expressed by 13% of participants, while a negative judgment was expressed by 4% of participants. Responses are graphically summarized in Fig. 9b.

In Fig. 10a, we can see that many of the participants believed that the use of the virtual dressing room in a shop would reduce the decision time to choose clothing. In particular, 41% and 36% of participants answered very likely and likely to the statement PU3.

Concerning PU4, 43% of participants answered very likely, and 49% answered likely (see Fig. 10b). Uncertain participants were 8% of the total.

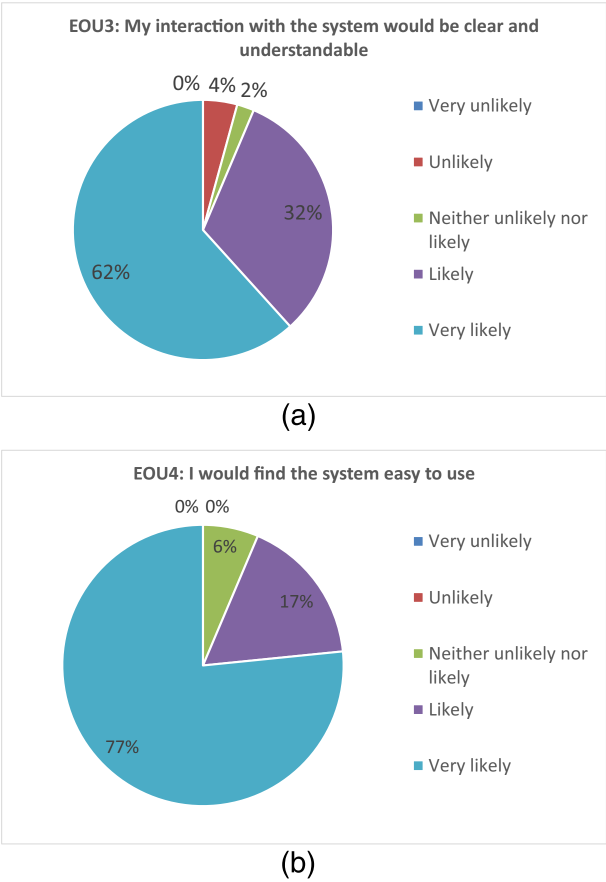


Fig. 13 Summary of the answers to EOU3 and EOU4

Many of the participants (95%) in our study would recommend our virtual dressing room to a commercial entity (see Fig. 11). Indeed, 62% of the participants would very likely recommend this system to a commercial entity, and 32% would likely do so. Only a few expressed either a neutral judgment (i.e., 4%) or a negative judgment (i.e., 2%).

Summarizing, we can assert that the most important outcomes of our study are that almost all the participants perceived our solutions to be useful, and even more importantly, they would suggest the adoption of these solutions to commercial entities. These results are practical implications because they encourage commercial entities to invest in the adoption of augmented reality. Based on the observed outcomes, we can also positively answer RQ2.

6.3 RQ3 - perceived ease of use

In Fig. 12a, we summarize responses to EOU1. In particular, we can observe that 60% of participants answered very likely, while 34% participants likely. Only 6% of the participants answered neither unlikely nor likely.

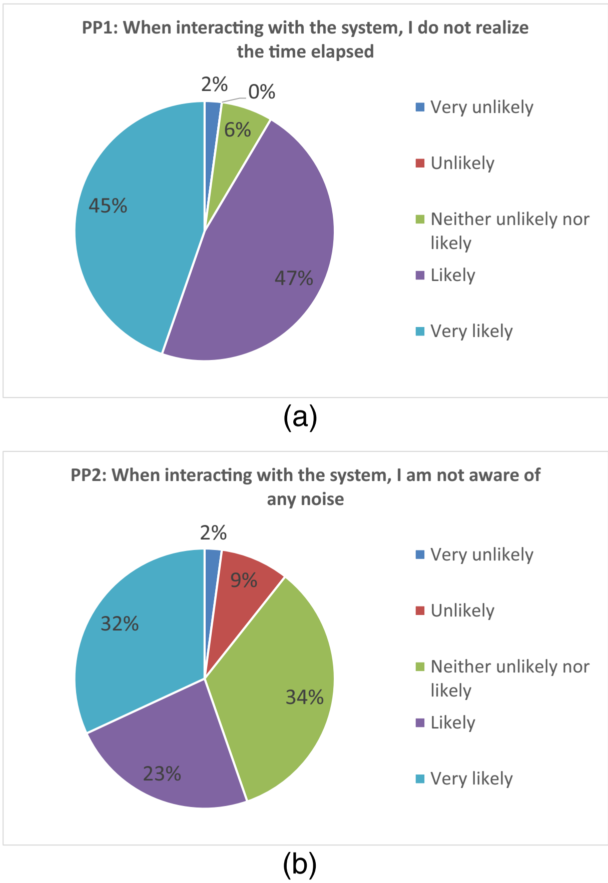


Fig. 14 Summary of the answers to PP1 and PP2

Concerning the statement EOU2, 36% and 58% of participants answered very likely and likely, respectively (see Fig. 12b). The percentage of participants who expressed a neutral judgment (i.e., answered neither unlikely nor likely) was 6%.

The answers to the statement EO3 were positive. In particular, 62% of participants answered very likely to this statement, and 32% of them answered likely (see Fig. 13a). Only a few participants responded neither unlikely nor likely (i.e., 2%). The remaining participants answered unlikely to EO3.

The answers to the statement EOU4 are summarized by the piechart in Fig. 13b. This chart suggested that the greater part (i.e., 77%) of the participants strongly agreed that the virtual dressing room was easy to use. On the other hand, 17% of the participants agreed that this system was easy to use, while 6% expressed a neutral judgment (i.e., answered neither unlikely nor likely).

Based on the answers to EOU1 to EOU4, we can draw the following conclusion: the participants perceived our virtual dressing room to be very easy to use. This was true for all the participants in the study, thus allowing us to conclude that our solutions are viable for a broad range of users, even heterogeneous groups of users with minimal experience with augmented reality applications. Concluding, we can positively answer RQ3.

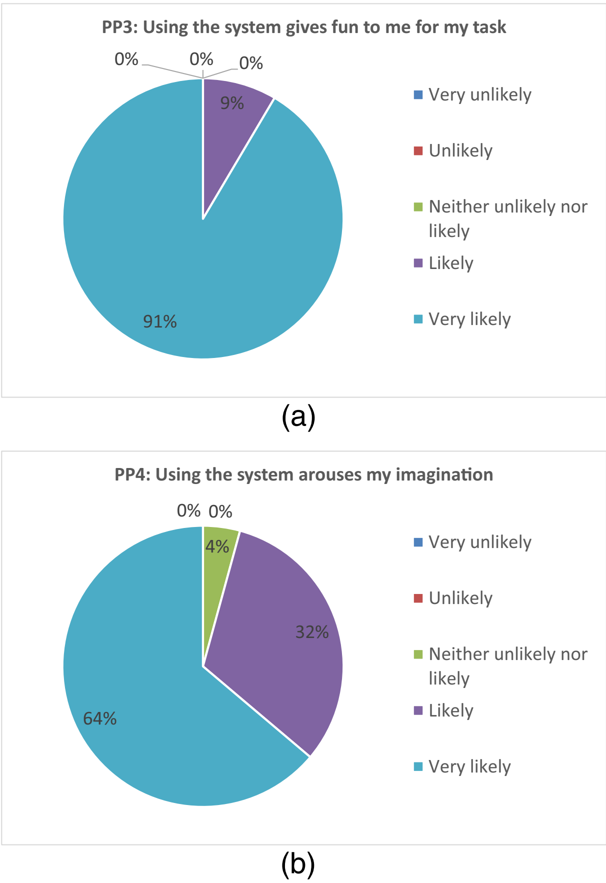


Fig. 15 Summary of the answers to PP3 and PP4

Fig. 16 Some pictures captured during the execution of the empirical evaluation

6.4 RQ4 - perceived playfulness

Answers to PP1 are summarized in Fig. 14a. The chart suggests that the greater part of the participants in the study did not realize the time elapsed when performing tasks. In particular, 47% and 45% of participants answered likely and very likely, respectively. Only a few participants expressed a neutral judgment, answering neither unlikely nor likely (i.e., 6%).

In Fig. 14b, we show the chart for the answers to PP2. We can observe that 55% of the participants were not distracted from noise, thus suggesting that they were concentrated on the assigned tasks. In particular, 32% and 23% of participants answered very likely and likely to the statement PP2, respectively. The percentage of participants who answered neither unlikely nor likely is 34%. The remaining 11% of the participants answered unlikely (9%) and very unlikely (2%).

Most of the participants had fun while using our virtual dressing room (see Fig. 15b). It is worth noting that 91% of participants asserted that the use of this system was entertaining when performing the tasks. Only 9% of participants were less enthusiastic.

Concerning PP4, Fig. 15b shows that many of the participants asserted that our virtual dressing room aroused their imagination (i.e., 64% of participants). Although less enthusiastic, 32% of participants expressed a positive judgment of the capability this system had in arousing imagination. Only a few of the participants (i.e., 4%) expressed a neutral judgment in this respect.

Based on the results presented above, we can conclude that participants perceived high playfulness while using our tool and then we can then positively answer RQ4 (Fig. 16).

7 Conclusions

In this paper, we describe our experience in designing an augmented reality dressing room. We introduce our approach, which combines the visualization capabilities of the game development tool Unity Pro with the position and body tracking capabilities of the Microsoft Kinect 2. The overall system software does not require calibration and is both inexpensive and easy to use. The low cost and ease of use make it accessible to a wider group of vendors who do not have access to a professional augmented reality facility. To assess the validity of our proposal, we conducted a qualitative study with potential users. The results suggest that an augmented reality dressing room could be easily transferred to vendors (with a low access to a professional augmented reality facility) because potential users found this dressing room easy to use, useful, and playful. To increase our confidence in the achieved results, replications of our study with other types of users are advisable despite the attained positive results. Our study can be also considered explorative because it can be considered as a pre-study to a more thorough investigation to assure that important issues are not foreseen. That is, the obtained results can be used to conduct more specific empirical investigations. For example, we could conduct an empirical investigation aimed to ask questions about whether trying clothes in our system would encourage possible customers to buy clothes. Future work will be also devoted to verifying if virtual reality would lead shop customers to choose similar cloths to the ones they would have done when trying out actual cloths. This would indicate that the virtual reality actually saves time and makes the shopping/discovery process more efficient. We could also conduct an experiment to compare our augmented reality dressing room with an actual dressing room. In this case, we plan to use statistical hypothesis testing. To conclude, we can assert that the empirical investigation presented in this paper has the merit to justify and to pose the basis for future research on augmented reality dressing rooms.

Regarding future work, our augmented reality dressing room can be enhanced in some points. First, we will conduct an empirical evaluation of the proposed system to investigate the customer satisfaction in relation to service quality. The illumination of the clothing given the lighting conditions of captured camera images of the real world could be used to enhance the realism of the rendering. Another improvement could be the implementation of a complete 3D scanning procedure for the clothing to quickly and easily add new items to a 3D repository. We would improve physical properties of clothes, such as stretchiness, secularity and more, just as well. Finally, people tend to relate more to their image at the right scale. Therefore, we plan to use a projector to generate a large display and verify if this affect observed results.

Appendix surveys

We report the questionnaires used in our study.

A.1 Pre-questionnaire

- Q1: Do you like video gaming?
  Strongly disagree◯ ◯ ◯ ◯ ◯ Strongly agree
- Q2: What do you consider your experience with video games?
  Non-expert ◯ ◯ ◯ ◯ ◯ Expert
- Q3: How many hours per week do you spend playing video games?
  ☐ Less than one hour ☐ Between one and seven hours ☐ Between eight and fourteen hours
  ☐ Between fifteen and twenty-one hours ☐ More than twenty-one hours
- Q4: Which types of video games do you play?
  ☐ First-Person Shooter ☐ Adventure ☐ Role-Playing Games ☐ Strategy/Tactical ☐ Sports
  ☐ Fighting ☐ Dance/Rhythm ☐ Survival Horror ☐ Other (Add here which one)
  ☐ None (I do not play any video games)
- Q5: Which [–]type of device do you use when playing video games?
  ☐ Mouse/keyboard ☐ Kinect ☐ Joypad ☐ PlayStation ☐ Other (Add here which one) ☐ None
- Q6: Do you have vision deficiencies?
  Yes ◯ No ◯
- Q7: If you answered ''Yes'' to the previous question, which type of deficiency do you have?
  - Open Question
- Q8: Do you wear glasses?
  Yes ◯ No ◯
- Q9: What do you consider your IT experience?
  Non-expert ◯ ◯ ◯ ◯ ◯ Expert

- Q10: Have you heard of the term *Augmented Reality*?
  Yes ◯ No ◯
- Q11: What do you consider your experience with *Augmented Reality*?
  Non-expert ◯ ◯ ◯ ◯ ◯ Expert
- Q12: With which of these input devices do you have more confidence?
  ☐ Kinect ☐ Leap Motion ☐ PlayStation Move ☐ Wii Mote
  ☐ None (No familiarity with natural user interfaces)
- Q13: Have you heard of the Kinect?
  Yes ◯ No ◯
- Q14: If you answered "Yes" to the previous question, what is your experience with the Kinect?
  Non-expert ◯ ◯ ◯ ◯ ◯ Expert

A.2 Final questionnaire

Browsing the clothing catalog:

- T1_a: Browse the content of the clothing catalog was straightforward?
  Strongly disagree ◯ ◯ ◯ ◯ ◯ Strongly agree
- T1_b: The virtual dressing room was responsive during the execution of the actions needed to browse the content of the clothing catalog.
  Strongly disagree ◯ ◯ ◯ ◯ ◯ Strongly agree
- T1_c: The interaction was natural during the execution of the actions while browsing the content of the clothing catalog.
  Strongly disagree ◯ ◯ ◯ ◯ ◯ Strongly agree
- T1_d: Have you experienced one of the following contraindications while browsing the content of the clothing catalog? Please select all that apply.
  ☐ High sensibility ☐ Lack of the field of view of the device ☐ Movement limitations ☐ Motor difficulties ☐ Dizziness ☐ Nausea ☐ Tennis elbow ☐ Tiredness ☐ Other ☐ None

Questions on dress suitability

- T2_a: The interact with the virtual dressing room while determining the suitability of a dress was straightforward?
  - *Same answer options as* T1_a
- T2_b: The virtual dressing room was responsive during the execution of the actions needed to complete the task of determining the suitability of a dress.
  - *Same answer options as* T1_b
- T2_c: The interaction was natural during the execution of the actions while determining the suitability of a dress?
  - *Same answer options as* T1_c

– T2_d: Have you experienced (while determining the suitability of a dress) one of the following contraindications? Please select all that apply.

  – *Same answer options as* T1_d

Perceived Usefulness (PU)

PU1. Using the virtual dressing room would enable me to accomplish tasks more quickly.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
PU2. Using the virtual dressing room would improve my performance (more satisfaction related to the possibility of trying more clothes in less time) when shopping.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
PU3. Using the virtual dressing room would reduce the time to choose an item of clothing.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
PU4. Using the virtual dressing room would make the decision-making process more interesting/exciting.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
PU5. Would you recommend the virtual dressing room for a commercial activity?
very unlikely ◯ ◯ ◯ ◯ ◯ very likely

Perceived Ease of Use (EOU)

EOU1. Learning to operate the virtual dressing room would be easy for me.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
EOU2. I would find it easy to get the virtual dressing room to do what I want it to do.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
EOU3. My interaction with the virtual dressing room would be clear and understandable.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
EOU4. I would find the virtual dressing room easy to use.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely

Perceived Playfulness (PP)

PP1. When interacting with the virtual dressing room, I do not realize the *time elapsed*.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
PP2. When interacting with the virtual dressing room, I am not aware of *any noise*.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
PP3. Using the virtual dressing room ensures that I have *fun* when performing my task.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely
PP4. Using the virtual dressing room arouses my *imagination*.
very unlikely ◯ ◯ ◯ ◯ ◯ very likely

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