Exploring the Benefits of the Virtual Reality Technologies for Assembly Retrieval Applications

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Exploring the benefits of the virtual reality technologies for assembly retrieval applications

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Abstract. Virtual reality technologies offer several intuitive and natural interactions that can be used to enhance and increase awareness during the different phases of the product design, such as the virtual prototyping or the project reviews. In this work, we focus on the benefits of virtual reality environments for assembly retrieval applications, which usually are employed to reuse existing CAD models by operating minor modifications. The retrieval system adopted to evaluate the different similarity among CAD assemblies is able to detect three different similarity criteria (i.e. shape, joint and position) at different levels (globally and locally). Considering the complexity of assembly models, conveying these different types of information simultaneously is quite difficult, especially through the traditional desktop systems. Hence, this paper presents a system for the visualization and the inspection of the results returned by a retrieval system with the aim of easing the analysis especially when the retrieved objects to analyze are complex. The proposed tool exploits the 3D space to represent and communicate the different types of similarity and gestures as well as voice commands to interact in the VR environment. Finally, the usability of the system has been tested over a sample of interviewers, who used the system and the different functionalities provided and then expressed their judgment filling out a questionnaire. The results indicate that user are able to interpret the different similarity criteria and that the gestures help acting in a natural manner.

Keywords: CAD inspection · VR natural interaction · Assembly retrieval browsing

1 Introduction and motivations

The application of immersive virtual reality (VR) environments has been proven beneficial in numerous applications (11) (38), thanks also to the quality enhancement and cost reduction of technologies that allow interacting with the 3D space.

The large use of VR systems is due to the capabilities offered to have a better interaction and comprehension of the digital objects at their real size. Moreover, they also allow better visualization of multidimensional information than 3D screen. For instance, they are used in design and manufacturing applications to evaluate the final product at the real size, to facilitate engineer reviews (34) or to simulate and monitor complex systems (21). These characteristics make VR an attractive choice to visualize in an efficient and communicative way the results of content-based retrieval of 3D assembly models. Experiences of using VR for content-based retrieval exist for images, e.g. (29), and 3D objects (18). As for images, the difficulties behind CAD assembly model retrieval are due to the multiple criteria characterizing the similarity. Indeed, as explained in (27), the similarity concept is affected by the objective of the user, which may be interested in different assembly characteristics such as the shape of its components, their mutual relationships or the assembly structure. In addition, the ability to present properly the ranked results of a given query according to specific criteria becomes even more challenging when the retrieved objects to analyze are complex.

In this work, we propose a VR application exploiting the 3D space to collect and organize the results of the assemblies retrieval system proposed in (27) and to support their browsing and exploration. The evaluation of the 3D assembly similarity is facilitated by visual hints and by the possibility of inspecting the assembly components using voice commands and gestures that have metaphoric meanings and have become part of the daily life thanks to smartphones use.

The rest of the paper is organized as follows. Section 2 reviews the most pertinent related works. Section 3 illustrates the adopted methodology, while section 4 and 5 report details on the proposed system. Finally, section 6 shows the results of the experimentation carried out with end users using our prototype. Section 7 ends the paper providing conclusions and future steps.

2 Related works

VR applications have received a notable amount of attention in manufacturing engineering and section 2.1 provides an overview of related academic/industrial research. In addition, with the aim of understanding how VR could support designers and engineerings during product development, section 2.2 presents some works that analyze human natural interaction.

2.1 VR in the product development process

Examples of the use and the advantageous of adopting virtual reality applications in manufacturing processes are illustrated and discussed in several works (e.g. (7), (10), (22), (28) and (33)). From their analysis, it follows that nowadays VR technologies are mature enough not only to visualize information or highlight problems over a digital model but also to interact with the environments modifying data related to a product and solving issues. Indeed, they find room in several phases of product development. Indeed, VR technologies enhance the virtual simulations (11) by replicating physical mock-ups, (6); improve the collaborative design reviews on digital mock-ups (32) and the decision making on the manufacturing plan as well as on the assembly plan (22); and support engineering education and training by reproducing learning situations (2). In addition, they suggest that the VR visualization with the possibility of fulfilling interactive modification on the simulation input parameters can improve the decision-making capabilities of engineers thereby improving quality and reducing the development time for new products.

Conversely, design CAD models directly in VR application deserves a separate analysis. Although immersive CAD would convey many benefits, its achievement is tricky. A first complication arises from the different aims, CAD applications create detailed models and define product manufacturing plan, while VR responds to a need for visualization and uses simplified models. In addition, the complexity of the CAD models increases the difficulties of real-time interactions. A step forward the integration between CAD and VR systems has been performed by Bourdot et al. (8). In this work, the authors propose a framework to combine VR and CAD allowing an intuitive and controlled modification of CAD models in VR environments. Hence, to overcome the bottleneck for the use of VR technologies in design activities, they suggest to label the B-Rep elements of a CAD model according to their design feature history; in this way, a parametrization of the CAD model is performed and it is used to guide the user in the possible modifications and render them in real-time. Jezernik and Hren (19), to share CAD models among different peoples without accessing a CAD workstation, propose a framework to import CAD models into VR and draw back to CAD the modification made to the model in VR. The authors explain the main weakness of the current VR systems and why so far it is not possible to modify CAD models in the VR system directly. Their proposition uses VRML format to represent the geometry data of the virtual models and an XML schema to store the assembly configuration. More recently, Okuya et al. (31) propose a system to modify native CAD data through a shape-based 3D interaction allowing the user to manipulate some parametric constraints of CAD parts by grabbing and deforming the part shape.

2.2 Natural interaction

A selling point of VR applications is their ability to embed virtual objects in the 3D space replicating closely the physical environment. This performance can be even improved by allowing natural and intuitive interaction of the user with the virtual environment surrounding him. Hence, the development of devices to track and analyze hands movements has been encouraged in the last years. Two main types of devices can be identified: haptic or wearable based and vision based.

Wearable devices include data gloves and the Myo Gesture Control Armband. The latter is especially used in medical applications, but it still needs to be improved (4). Instead, more established and widespread wearable devices are the data gloves. VR Glove by Manus, Cyber Glove System or Noitom Hi5 VR are some of the devices available on the market, but all of them are quite expensive. This kind of technology is very accurate and with fast reaction speed. Moreover, it avoids hands occlusion problems or loss of tracking, which are typical visual based devices issues. However, using gloves requires a calibration phase every time a different user starts and not always allows natural hand gestures because the device itself could constrain fingers motion (1; 17; 24).

Consequently, in the last few years, vision-based sensors have received increasing attention. These devices, in general, are easy to install and no calibrations are needed; even if in a limited range of space, they allow free-hand natural interactions. Kinect and Leap Motion Controller (LMC) are the two most commonly visual based devices used. However, LMC is more suitable for hand gesture recognition because it is explicitly targeted to hand and finger tracking, while Kinect is a depth sensor tracking full-body movement. Gunawardane et al. (17) point out the high repeatability and potential of Leap Motion compared to gloves devices in particular applications. In spite of its limitations, the controller has been evaluated with an overall better performance against other competing devices in various application domains (4).

LMC has been highly exploited in static and dynamic hand gestures recognition and 3D objects manipulation. The controller, used alone or together with a Head Mounted Display (HMD), in fact, offers the possibility of interacting with virtual objects by means of mid-air interactions. In the last few years, free-hands interactions and Virtual Reality (VR) have been involved in several research fields. For example, applications for medical purpose are described in (23) and (37). An immersive archaeological environment is developed in (41) to simulate the creation of a statue. (25) provides an interactive application for virtual flower and plant manipulation. Beattie et al.(5) provide the manipulation and inspection of a CAD mechanic model and its individual parts first. However, in their work, interactions do not seem to be completely realistic since the only way to select parts is to break up by default the assembly.

Other works focus their attention precisely on studying and improving manipulation techniques. One of the challenges is to allow users to manipulate virtual objects in the most natural way and reaching a high level of accuracy. In (13) and (14), the authors investigate which mid-air gestures people prefer to complete different virtual manipulation and deforming tasks. Caggianese et al.(9) face the problem of canonical 3D manipulation (selection, positioning, and rotation) in VR proposing two different techniques: direct or constrained to a single dimension. The first is more natural, but the latter is heavily preferred for accomplishing complex tasks, such as the rotation. Also, Cui et al.(15) investigate the problem of deforming virtual objects' shape with natural free-hands interactions. They come up with a "steering wheel" visual metaphor to improve the precision of manipulation. Three handles are fixed along the three principal axes to guide the user during the deformation tasks. The experiment received overall positive feedbacks: users state that the process of manipulation is easy to learn and remember. Using virtual handles is intuitive but not really natural, however, it is a good way to increase the controllability of interactions, which is affected by Leap Motion's limited tracking. Later, the same authors propose in (16) a new "musical instrument" metaphor for 3D manipulation tasks, trying to achieve naturalness and avoid problems relative to hand tremor, jump release and occlusion. The idea is to distinguish between a non-dominant and a dominant hand. The first triggers events and controls precision, while the latter is tracked for the 3D object manipulation or deformation tasks. Tests' results point out that the proposed technique is easy to learn and apply, it effectively minimizes the problems relative to hands. However, mid-air interactions, compared with the use of a standard mouse, do not show significant advantages in time, learnability and comfort. Finally, also in this work, the naturalness has to be a little compromised to achieve reliable tracking.

3 Methodology and usability

Assembly models are compared and retrieved through the system proposed by Lupinetti et al. in (27), where the user specifies a query model and sets the similarity criteria to be fulfilled. To take into account the multiple aspects characterizing an assembly, the retrieval system evaluates different criteria of similarity, as well as multiple levels of similarity (global, partial and local). In fact, assemblies can be similar in their whole or only in some parts. Specifically, the criteria of similarity include the similarity of components shape, their reciprocal position and the type of contacts with the allowed degree of freedom. Then, the similarity among assemblies is computed combining three different measures related to shape, position and joint, whose weights can be modified according to the user objectives. We refer to (26) for details on their computation.

Highlighting the diverse similarity levels between assemblies according to the different criteria clearly turn out to be tricky and challenging, especially when the assembly models are complex and made up of numerous parts. Rucco et al. (36) proposed a first effort in a desktop view to browse retrieved models according to their level of similarity and then to analyze 3D assemblies highlighting the matched parts in the query and in the target models and tuning part fade-out to allow the visualization of internal components. This approach is suitable for assemblies containing a relatively small number of parts (approximately 10 parts), anyhow in real industrial examples the results visualization is not able to provide the right level of information.

To overcome these limitations, we propose an immersive system to exploit the 3D space to increase the understanding of associated information by using metaphors. The methodology to visualize the results of the retrieval system (27) considers two important aspects: (i) how the information is communicated to the user and (ii) how the user can interact with the system and in particular with the 3D models. Each assembly model is located in a specific point of the 3D space and the more a model is close to the query, the more similar it is. In this manner, we take advantage of profundity and prospective perception of 3D space against a poorly communicative desktop representation. In addition, the proposed VR environment allows a realistic and natural interaction, where users do not need to know how CAD systems work to analyze models and their similarity. The interaction is as much natural as possible thanks to the use of gestures that have become part of the daily life because of the smartphones use. In addition, it provides a more realistic feeling by analyzing the models from the inside and in their real dimensions and evaluating also aesthetic and ergonomic proprieties. Finally, it is accessible easily and a CAD workstation is not required.

Considering existing works in literature, the proposed looks to be innovative. In fact, if on the one hand VR (and AR) has been exploited to allow the browsing and sorting of large collection of images (20; 29; 35), to support web pages content comparison and retrieval (38), or to provide virtual interfaces for retrieval typically associated with research in the physical books (12); on the other hand the browsing and inspection of CAD models in an immersive virtual environment is a field little explored up to now.

An important difficulty to consider is that representing CAD in VR is not a standard so far. The integration of two different virtual words (CAD and VR) requires to manage heterogeneous data, such as the design history, semantic information, kinematic characteristics and all the elements defining the mobility of the assembly model. Unfortunately, most of this information is not embedded within CAD models (8) especially using standard formats for the exchange of CAD models. In the proposed application, the input CAD models are created with traditional CAD systems and stored in STEP format (AP 203-214). The models are then processed to obtain a standard graphics object format, more precisely an STL representation is stored for each part of the assembly model. Since this application does not require to draw back in the CAD files the potential editing performed on the models in the VR environment to inspect and analyze the different similarities, the proposed application recovers the hierarchical structure of an assembly, i.e. how the parts are gathered into sub-assemblies and the relative position of the single parts in the entire assembly model. The adaptation of the CAD models in a suitable format for VR applications is performed once for all the models present in the dataset used by the retrieval system of (27). How these models are used in the VR environment and their possible interactions are described in the sections 4 and 5 respectively.

4 Virtual environment set up

The proposed system adopts Unity 3D as graphical engine to visualize and perform model transformation operations. The user accesses the VR environment by wearing an HTC Vive head-mounted display (HMD), where, to allow as much natural as possible, gestures motions and vocal instructions are guaranteed.

To make more communicative the results rendering, we designed a *results browsing scene* (see Fig. 1), where each assembly is located in a specific point of the 3D space according to three similarity measures $\overrightarrow{\mu} = (\mu_{shape}, \mu_{joint}, \mu_{position})$. In this way, the Cartesian coordinates x, y and z of a general point will reflect respectively the three measures of similarity (shape, position and joint). Thus, the position $\overrightarrow{P}$ of the barycenter of each model is expressed in the equation (1), where ρ and ω indicate the radius of the sphere containing the model and the measurement accuracy respectively.

$$\overrightarrow{P} = 2\rho\omega\overrightarrow{\mu} \tag{1}$$

In this way, to avoid overlapping situations, two models whose similarity measures differ less than ω are collapsed into a sphere, on which the number of included models is drawn. The models represented with a sphere can be visualized either opening the sphere or increasing the value of the measurement accuracy ω.

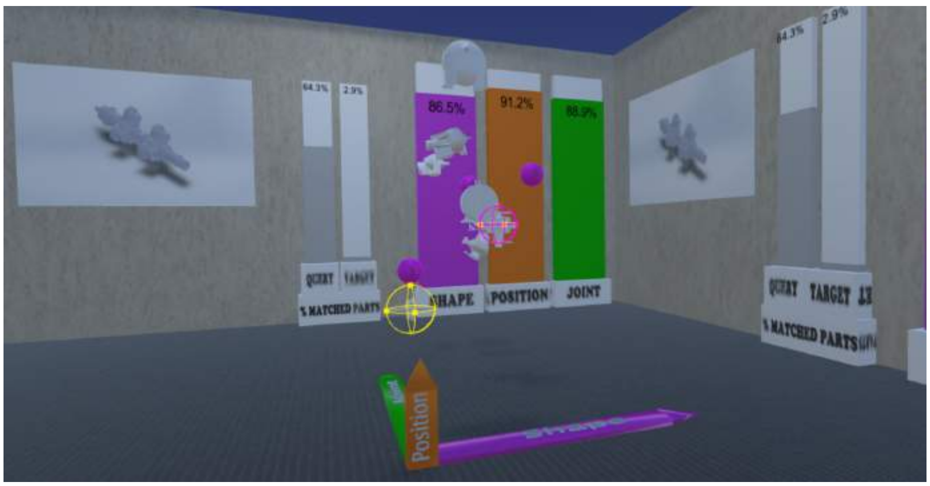


Fig. 1. Results browsing scene. The query and the gazed models are ringed in yellow and in purple respectively.

In addition, to help the understanding and to increase the communicability, the virtual room is furnished with several elements. Three arrows are set on the floor, under the query model, to indicate the directions along with the three measures of similarity decrease. Two groups of columns are projected on the walls and, once the user gazes an assembly, some data are displayed on them. In particular, the first group is made up of two gray columns and provides information relating to global/local similarity, showing the percentage of matched elements in the query and the target model. The second group consists of three colored columns, where the exact values of shape, position and joint similarities are visible.

This approach helps to have a first intuitive view of all results, where the VR system allows the user to move within the scene and explore them. To have a better understanding of the results, the user can select a model and then the comparison mode is automatically activated into the *inspection scene*. Here, only the selected model and the query are visualized and the components identified as similar by the retrieval system are shaded with the same color in the two assemblies (see Fig. 2). This phase allows examining deeply the similarity between the 3D objects because the user can manipulate the entire assembly or disassembly it by manipulating part by part with realistic hands-free interaction. Indeed, it is possible to choose whether to manipulate the assembly or the single elements by means of a three buttons menu. The menu is available when the user opens the left hand with the palm facing his gaze. Notice that all the provided operations do not change the geometry of the object and can be always undone.

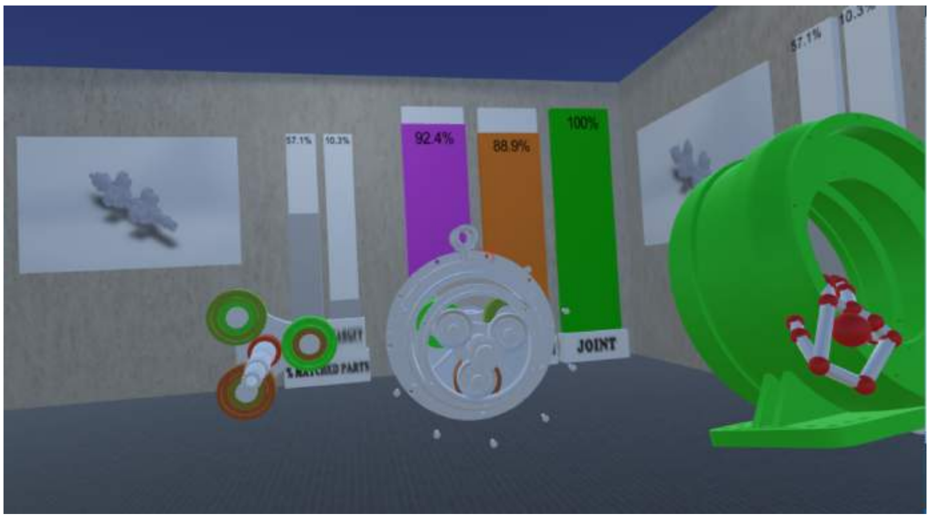


Fig. 2. Inspection scene. The user can manipulate the selected model; the matched parts are of same color.

5 Interaction behaviour

To comply as much as possible with the fundamentals of a Natural User Interface (NUI) (40), the interaction in the 3D space must be intuitive and simple and possibly without using controllers for input specification, such that user can act with the most natural behavior and the least training. In general, this involves two main problems: (i) specification of practical and natural object selection methods (3); (ii) inaccuracies in hands tracking and difficulties in keeping hands motionless when using gestures without external controllers (30).

5.1 Selection

A suitable selection functionality in VR has to provide the selection of objects in dense environments and of occluded parts (39). Many techniques have been studied (3).

To our aim, the selection by virtual hand is not recommended, even if it would be a very natural interaction. In fact, CAD assembly models are made up of many small nested parts and touching one involves colliding its neighbors too. An expensive disambiguation mechanism would be required to guess the object the user aims to select. Hence, we suggest the use of gaze: a ray is cast from the user's viewpoint and the first hit assembly/part is highlighted and becomes the selectable one. In this way, the user is guided during the gaze selection and disambiguation is easier. The voice command "select" confirms the choice. To reach the innermost occluded components, the user has to disassemble the model part by part using the gestures described in section 5.2. This may seem tedious, but it is certainly the most realistic and natural method.

5.2 Gestures and Voice Commands

NUI can be achieved maintaining a connection to real-life, for instance, by allowing to choose operations using different gestures instead of selectable menus (15). Thus, we propose a multi-modal system supporting gesture and voice interaction.

In the browsing scene, the user can move the whole assemblies' system in order to bring a result of interest near. This operation is achieved performing a uni-manual scrolling gesture constrained to one direction at a time (horizontally, vertically or in depth). Once selected a 3D object, it can be directly grasped and manipulated with the user's virtual hands. Three specific extra operations are allowed: translation, rotation and uniform scaling. Each of them is associated with a specific dynamic gesture: uni-manual drag, hands open with facing palms and bi-manual pinch. Table 1 shows all the gestures with a brief description. Before executing an operation, except the grasping one, the user has to maintain the hands in the correct position, until audio feedback occurs. This delay permits reliable gesture recognition and better disambiguation. These gestures have been chosen according to their use in VR (14) and in everyday life to achieve the required naturalness in a NUI.

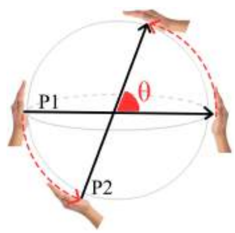
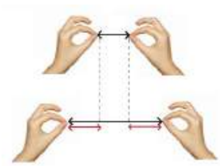
Finally, few additional voice commands have been included as confirmation or shortcuts for specific actions. The commands are:

- *zoom (de-zoom)* to change the unit of measure in the results browsing scene,
- *select* to confirm gaze selection,
- *undo* to cancel the last performed transformation,
- *restore (restore all)* to reassemble the selected (all) disassembled model(s),
- *show matching parts* to highlight the matched parts between query and target models and put in transparency the not matched parts,
- *show assemblies* to undo the show matching parts voice command,
- *return* to come back to the previous scene.

6 Users validation

To validate the approach experimentation has been carried out with users. In particular, the testing phase was conceived with the aim of evaluating the two

Table 1. Gestures description

Operation	Gesture	Description
Scroll the browsing scene in one direction		Keep one hand opened with the palm's normal parallel to the chosen direction. Scroll the scene by moving the hand in that direction.
Grasp the selected object		Grasp the selected object with the left or the right hand. Move the grasped object by moving the hand.
Translate the selected object in any direction		Keep the right hand with the index extended and the other fingers closed. Move the selected object by moving the hand.
Rotate the selected object in any direction		Keep the hands opened with the palms facing each other. Rotate the selected object by rotating the hands.
Scale uniformly the selected object		Keep the hands with the thumb and the index pinched. Scale the selected object by bringing your hands closer and further.

main aspects of our VR system: the naturalness and intuitiveness of interactions and the communicability of the proposed environment. In the following, the evaluation method and the achieved results are described.

6.1 The validation method

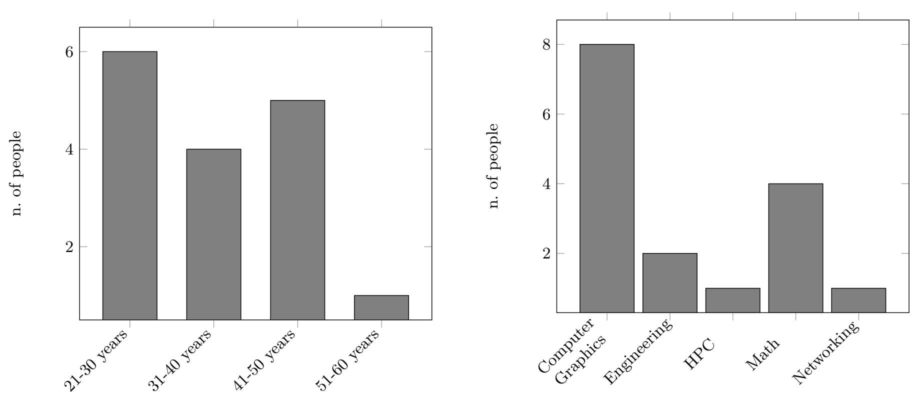
The evaluation process consists of three steps:

– *Explanation and training*
  First, we explain to the users what the proposed application is meant for: it is

a tool for browsing and inspecting in a virtual reality environment the results returned by a retrieval system for CAD assembly models. After summarizing the concepts of local and global similarity between assemblies and the three adopted similarity criteria, the challenges of this study are pointed out. Finally, brief training follows, in order to illustrate all the possible gestures and voice commands.

– *Use of application*
  Users are asked to wear the HTC Vive headset and they can explore the virtual environment freely, move around the results and select assemblies to inspect. We suggest them to think-aloud commenting on what they are observing and remarking the difficulties during the interaction with virtual objects. If necessary, we guide users during their experience to be sure all the functionalities are tested.
– *Questionnaire*
  Finally, users are required to fill in an assessment questionnaire. It consists of three sections: personal information, interaction evaluation and communication evaluation. Each question asks to evaluate a functionality or a feature of the virtual environment with a score from 1 (= Not at all) to 5 (= Totally) points.

16 participants (8 male, 8 female) were invited, with age between 21-60, distributed as shown in Fig. 3(a). All of them are scientific researchers (8 with a master degree, 8 with a Ph.D.) and the main subjects of their study are illustrated in Fig. 3(b). Most of the users have low or none experience with VR/AR environment and 3D CAD system; they are quite more familiar with Video Games. Few users are familiar with applications for 3D model retrieval and concepts of similarity between 3D models.



(a) Users' age (b) Users' study

Fig. 3. Users' personal information

6.2 The validation results

Users have understood very promptly which objects were selectable and also the effective selection of assembly objects has been judged easy. Some difficulties have been encountered in a few cases when selecting individual parts, especially when there are small parts in big objects.

In general, the evaluation of the interaction commands is very positive for the majority of the users. The *grabbing* is judged easy and intuitive; only a few users have considered inconvenient to be obliged to approach the object to be able to take it. A few users have had troubles in distinguishing between the *translation* command (used to move the selected object in any direction) from the *scrolling* one (used to move the whole scene horizontally, vertically and deeply). Some users have encountered some difficulties in the *rotation* and *scaling* operations, mainly because the gestures leave the field of vision of the Leap Motion or because in certain positions of the hands the Leap Motion recognizes the gesture no longer.

A weakness perceived by different users is the slowness of the operation execution with respect to the command. All users agree that the voice commands are extremely useful. Some of them have recommended avoiding similar voice commands that can be difficult to remember and easily confused. Most users have assessed useful the activation of any gesture/operation by specific voice command; some users have suggested having the corresponding voice command for each gesture.

The ability to access a graphic menu showing the palm of the hand has been appreciated by most users, even if a certain difficulty arose in performing the operation of pressure on the buttons.

Regarding the communication of the information to convey to users through the virtual environment and the mutual position of the models, some issues emerged, which need to be addressed. The positioning of the models generally provides a good perception of the measure of similarity of the objects relative to the query. On the contrary, the majority of the users did not immediately understand that the pink spheres are containers of objects with a very close similarity measure and therefore, in these cases, users did not attempt to select and open the spheres.

Most users perceived well the information projected on the walls of the virtual room concerning the similarity by shape, structure and joints between the looked object and the query; on the contrary, the information relating to whether the similarity is global/local is not correctly perceived by the majority of users. Some users have also encountered some difficulties in looking at the object and seeing the information projected on the wall at the same time. Finally, all users evaluated very useful the highlighting of the correspondences between the parties judged similar between the selected object and the query.

All questions and related evaluations are summarized in Table 2.

Table 2: Summary of users' feedbacks

N.	Question	Evaluation 1	2	3	4	5
1	Was it easy to discern selectable and unselectable?	0%	0%	0%	44%	56%
2	Was it easy to select target assemblies?	0%	0%	0%	63%	37%
3	Was it easy to select target parts?	0%	12%	19%	44%	25%
4	Was the grabbing gesture natural and intuitive?	0%	0%	6%	56%	38%
5	Did the grabbing operation act as you expected?	0%	6%	25%	31%	38%
6	Was the translation gesture natural and intuitive?	0%	0%	31%	44%	25%
7	Did the translation operation act as you expected?	0%	0%	19%	56%	25%
8	Was the rotation gesture natural and intuitive?	0%	12%	25%	44%	19%
9	Did the rotation operation act as you expected?	0%	12%	13%	56%	19%
10	Was the scale gesture natural and intuitive?	0%	6%	13%	50%	31%
11	Did the scale operation act as you expected?	0%	0%	19%	56%	25%
12	Was the scrolling gesture natural and intuitive?	0%	12%	19%	50%	19%
13	Did the scrolling operation act as you expected?	0%	6%	44%	44%	6%
14	Were the voice commands useful?	0%	0%	6%	13%	81%
15	Were the adopted keywords natural and intuitive?	0%	0%	6%	13%	81%
16	Is the gesture to visualize the graphical menu natural and intuitive?	0%	0%	12%	25%	63%
17	Are the menu buttons easy to push?	0%	12%	12%	38%	38%
18	Is the meaning of the buttons easy to understand?	0%	0%	12%	19%	69%
19	To what extent does objects' position help in the perception of the object similarity with respect to the query according to the three similarity criteria?	0%	0%	31%	44%	25%
20	Is it easy to understand that the pink spheres represent a set of close objects?	19%	31%	31%	6%	13%
21	Does the information projected on the walls help you in understanding how much the object you are looking at is similar to the query for each criteria?	0%	6%	13%	31%	50%
22	Does the information projected on the walls help you in understanding how globally/locally the object you are looking at is similar to the query?	6%	31%	19%	38%	6%
23	Is it useful to visualize the matching parts among two similar assemblies(voice command *show matching parts*)?	0%	0%	0%	12%	88%

In general, the experimental results confirm the validity of the approach to visualize and explore in an immersive environment the results of a 3D assembly models retrieval system. Most of the choices made in terms of both gesture and vocal commands and of communication strategy to the user have been appreciated with some exceptions. As far as the interaction with 3D objects is concerned, the perceived limits mainly derive from technological limits that cannot be completely overcome and require revising some interactions in order to reduce the negative effects perceived at least partially. As regards information that are not perceived correctly by most users, i.e. use of spheres as containers of several objects and communication of information on global/local similarity, it is necessary to study and propose alternatives solutions to make the communication more immediate and less ambiguous.

7 Conclusion

In this paper, we present a VR environment for the visualization and inspection of the results of a system for the retrieval of similar 3D assembly models. It exploits the capabilities offered by VR technologies for creating a 3D scene in which the retrieved 3D models are distributed according to their distance from the query model highlighting the characteristics that determine the similarity. Moreover, natural interaction capabilities are provided to explore the models and their correspondences with the query one.

The experimentation carried out with end users provided good indications confirming the validity of the approach and the usefulness and usability of the developed prototype. Moreover, it highlighted some issues to be faced to improve it. Future extension foresees the inclusion of functionality for the modification of assembly components to allow the updating of existing models and the possible combinations of existing components to create new assemblies.

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