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Design in context of use: An experiment with a multi-view and multi-representation system for collaborative design

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ABSTRACT

The current trend of product design leads to a change in the collaborative working style. To find the most efficient way to exchange information on the digital mock-up of a product, a synchronous co-located collaborative design environment with recent technologies is in needed. A new groupware of multi-view system allows multiple users to have individual visual information of a domain-specific representation of digital mock-up. In this paper, we propose a case study for the development and testing of a co-located multi-view system in collaborative virtual reality, aiming at enhancing the multidisciplinary early collaborative design. An ergonomic method of Personas is introduced to the evaluation of the tool, considering various user performance. With a multidisciplinary mug design scenario, experiments are presented, validating the benefits of the proposed system.

1. Introduction

Designing is a complex activity, and failure of support can be expensive in terms of time, people and money and can have a large effect on practice [1]. For years, rapid product development (RPD) is relying on the use of new knowledge-based systems such as haptic systems and virtual reality (VR) [2]. There is an increasingly strong need for immersive visualization and interactive tools that may be used in industrial applications [3]. Recent developments in the use of multi-view technologies allow multiple point-of-views and multiple representations of an object. More precisely, with the development of computer–human interaction (CHI) and VR technology, the approach of displaying multi-representation of a digital mock-up (DMU) through a multi-view system can be used in product design. Moreover, concurrent engineering has changed design habit from traditional sequential engineering to a parallel mode to reduce the overall product development time [4]. In the early stages of design, stakeholders involved tend to propose a collaborative tool that is suited to the concurrent design style [5]. Finally, prospective ergonomics is nowadays a key factor in innovation, of prior importance in product design, lifecycle and especially in its use [6–8]. Thus, extracted motivations for this paper are:

- To simulate virtual product design situations with a multi-view system and prove the efficiency of the method.
- To mix ergonomics analysis and early product design on an industrial use-case to validate the proposed method.
- To validate the multi-view system on a use-case and measure the benefits the design team could have when using this technology applies in the consumer goods industry.

Using design research methodology (DRM) approach [1], the following descriptive study is aimed at understanding collaborative design with multi-point-of-view. We follow a comprehensive descriptive study, which involves a literature review and an empirical study. After reviewing the literature of multi-view systems in industry, we determine our research focus (Section 2). Then, we develop our research plan based on a multi-view system for early collaborative design (Section 3) and undertake an empirical study to evaluate it (Section 4). Finally, the results are then discussed (Section 5) before drawing overall conclusions.

2. Review of the literature

The literature on the use of multi-view is to be discussed here first with the definition of multi-view system, followed by the general applications in the field of virtual reality and multi-representation display. We focus then on an introduction of Personas method and an innovative future collaboration style in early design through multi-view system.

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2.1. Multi-view system

The traditional computer supported collaborative design is basically based on several mono-view systems for communication in distance and special software platforms for product information sharing in client/server mode [9–11]. However, multi-view system is a co-located and simultaneous solution of sharing information and working collaboratively.

Multi-view system is a visual–perception interface which allows humans to see simultaneously multiple images through a unique shared medium. The mechanism of multi-view system is: several images are emitted simultaneously from the display medium and then received respectively by human vision, as shown in Fig. 1. In [12,13], multiple views are described as frames with view-dependent pixels. These views can be displayed as an output package simultaneously. To create multi-view system, various technologies exist in the literature and they are classified into three modes: passive, active, and automatic.

2.1.1. Passive mode

The emitted images are projected in the different subspaces of colorimetry or polarization of light through passive filters. Anaglyph images are created by putting images in different anaglyphic color channels, then these images can be seen separately with red/cyan filters. Polarizing filters restrict the light in opposite vibration directions before projection. Using suitable receiving filters for each corresponding projecting filter, images can be encoded with a separation.

2.1.2. Active mode

Within a very short period, images are actively displayed one after the other in sequence. The mechanism is to synchronize the emitter and the receiver. E.g. shutter glasses, which is a receiver, can change the transparency alternately, synchronizing with the refresh rate of the emitter, which is usually from a projector or a screen. As known in human visual system (HVS), 60 Hz is the lowest frequency for human to have a reflection of continuous images without flick fusion [13]. Modern optoelectronic displays with their supporting receiving devices can operate much higher refresh rates, thus multiple views more than two can be created [13]. E.g. a 120 Hz projector and the supporting shutter glasses can create two views in sequence that each has a 1/120 s period.

2.1.3. Automatic mode

Automatic mode does not need any equipment (e.g. Glasses) at image reception. Images can be seen separately from different positions in spatial dimension beyond the same screen. E.g. A display is placed behind a parallax-barrier, which is an opaque sheet with patterned holes stamped out of it, or behind a lenticular sheet, which is composed by an array of magnifying lenses. Light from an individual pixel in the display is visible only from a narrow range of viewing angles. Thus, the images seen through each hole or lens will change according to vision spots [12]. With advanced screen technologies, multiple spatial views more than two can be realized and the combination of the mechanisms above can produce the system with even more views [14].

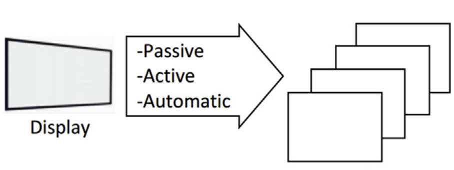

Fig. 1. The mechanism of multi-view.

2.2. Multi-view applications

The applications of multi-view can be categorized into two aspects: multiple point-of-views in VR and multiple representations.

2.2.1. Multi-view in VR

A point-of-view (POV) of an object is generated from a certain spatial position, e.g. in Fig. 2, a DMU of an airplane has several POVs seen from different space positions. Multi-view system can be applied to display the multiple POVs of an object, especially when these multiple POVs are used to create the feeling of stereoscopy in VR.

Becoming a new way for visualization and interaction, VR is widely used in product design and manufacturing, especially in automotive industry [15,16]. This virtual prototype of the product can help evaluate its design by simulating the usage (driving), manufacturing (assembly), etc. Compared to the activities using physical prototype, VR may help in saving time and cost.

To transfer a 3D virtual world to computer graphics, 2D images are calculated as snapshots of 3D world according to a point of view. Binocular vision is natural for humans. For each eye, visualizing from a 3D world is like taking snapshots. The human brain can merge the two snapshots taken from the two eyes to create stereoscopic representation.

Thus, any VR device for creating 3D images belongs to multi-view systems. The three mechanisms of multi-view system also work with VR devices, e.g. passive or active mode multi-view system: 3D glasses, including anaglyph, polarized [17–19], and shutter glasses [20]. In a two-user VR application [15] or a multi-view table [18], the multi-view system, a combination of passive mode and active mode, has 4 POVs for four eyes. Autostereoscopic displays [12,21] also work as an automatic mode multi-view system to receive two POVs for each eye following different spatial positions of the eyes.

2.2.2. Multiple representations

In addition to showing multiple POVs, multi-view system is used to displaying multiple representations. A representation is a perception of an object. People have different representations of an object and they make statements to influence the opinions or actions of others. The users of a multi-representation application choose the representations according to their different roles, different interests, and different preferences. In engineering design shown in Fig. 2, an airplane DMU is a package of data of all the

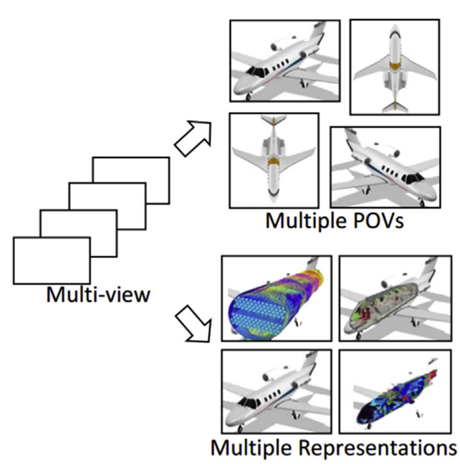

Fig. 2. The applications of multi-view: multi-POV (space transforms of DMU) and multi-representation (domain data of DMU).

domains gathered around a 3D model of the product. Considering his/her own domain, e.g. airplane exterior design, user will choose one representation of the DMU to work with. To display each aspect of a multi-presentation object or application to everyone involved, a multi-view system can be used.

Literatures with the applications of multi-view system in displaying an object's multi-representation are reviewed. In [19,20], a multi-view system is used to show two representations of a text paragraph. Sentences with same meaning are presented to two users with two different language representations.

A photo album with two representations is displayed by a multi-view table for two users in [18]. Each representation follows the user's interest, e.g. architecture structure. On a street map between two cities, users can see separately two different representations on this multi-view table: distance representation and traffic representation.

Seen from different angles, a skeleton representation of a human body and an organic representation of the same body are displayed separately to two users on an autostereoscopic multi-view system [13].

Different from multiple representations, the application of multiple POVs (discussed in Section 2.2.1) may be presented with only one representation. E.g. in [15,22], two or more users have their own POVs of a car from different spatial position in a CAVE system, but the representation of this car is always an assembly view. Multiple representations may also be presented in a single POV. E.g. from a certain POV, the different representations of an object are overlapped.

Different from single user, multiple users emphasize problems of collaboration among stakeholders. In the literatures, very few applications have addressed the use of multi-view system on the multi-representation of a product during its design activities. This paper focuses on the product design collaboration with different representations of a product. The collaborative product design with multi-view system will be discussed in next part.

2.3. Collaboration product design

For years, changes in design teams prone the importance of synchronous physical co-location to solve design problems. Thus, members are operating in physical proximity which is the most efficient way to exchange information on the product (in Fig. 3). When using the DMU as a means of collaboration, design stakeholders from different backgrounds must collaborate on a single representation of the product. However, it could be useful for them to have the ability to display, through new technologies such as multi-view system, their own “in field” representation to facilitate decisions.

Indeed, in the case of collaborative product design, project stakeholders are requested to work together and interact to reach an agreement and make shared decisions. The level of decision coupling assesses the degree of collaboration here. Designers from the whole group work together to design product, following the customers' requirements. The project leader, as well as the project group (a group of designers from various companies who have competences and skills in various fields), attempt to solve the design question together. Collaborative activity is synchronized and coordinated throughout the collaborative process.

When dealing with the future use of a product, the visualization in 3D is a good means to simulate the behavior of a customer facing this product. Thus, it helps designers to formalize the “design in context of use” of the product. Meanwhile, displaying the multiple representations of this product for both customer and designer in real time can improve efficiency of the design activity in a collaborative way. Both multi-POV for 3D visualization and multi-representation for collaboration can be realized by using a multi-view system among the collaborators. Next chapter is presenting the Persona method that is commonly used to define models of users in early product design.

2.4. The Personas method

The Persona method was created by Cooper [24] and it was mainly used in the field of product design. Personas are an archetype of users that take the form of a card with a photograph of the persona, his/her name, sociological, demographic, and psychological information which can be embellished with storyboard to promote realism [25]. The Persona method is a tool for design process. As models of users, with behavior, attitude, personal motivation, and intentions, they allow designers to understand the needs of future users as to the use of a technology [26].

Personas are commonly created at the beginning of the design process and are used during the entire design process. Ideally, they are built through the participation of a team, because the creation process is enriched by the debates of the members of the team [27]. They can be used in different manners, depending the nature of the project and the designers' preference [28,29]. They are materialized based on ethnographic research, interviews, and user observations [30]. Following the collection of data on the users, an analysis is realized. A list of behavioral data and demographic variables is drawing up to determine the main trends. From this behavioral pattern emerge, which will determine the construction of different Personas, which will be described in narrative form, to create representative representations of users that are representative of a whole target population [31,32].

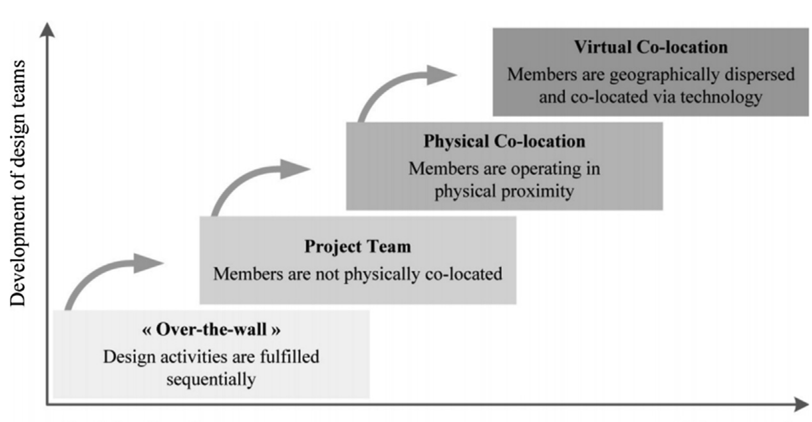

Fig. 3. Changes in design teams adapted from [23].

The entertaining aspect of this method allows designers to stimulate their creativity and encourage the development of innovative ideas [33]. Indeed, they allow them to distance themselves from their way of apprehending the system since they no longer reason from their point of view but from that of the personas [34]. In the design process, they improve the generation of ideas which are more numerous, more original and more flexible than a condition without personas [7]. Personas are commonly used with scenarios to help designers think and act like end users. But the method is also criticized because of the designers' lack of familiarity with this method [35], the abstractive nature or the impersonality [29]. To overcome these drawbacks, we used the method of persona as role play.

Role-playing is a method applied to understand the context of use and the point of view of the users [36]. Role-play simulation are interactions of several participants who adopt the role of stakeholders with varying points of view. Raijmakers et al. [37] have used this method as a co-creation tool to explore different perspective and possible roles for multiple stakeholders. In their study, they ask participants to embody a stakeholder role and to think as if they were in their shoes during workshop sessions. This method allowed the designers to feel closer to the users and to project on future uses.

2.5. Research focus

As we discussed in Section 2.3, VR is widely used for the preliminary test and pre-evaluation. However, there is little work to systematically evaluate the user experiences such as usability, natural and intuitive interaction between human and physical objects, and usefulness [38]. Multi-view VR system could be used to present multiple POVs of an object, as well as multiple representations of a content. In our study, the aim is to test the interaction between end-users and designers in a multi-disciplinary point of view. The main advantage is to include as early as possible the end-user in the design loop. It also prevents from creating a physical mock-up that is cost-full and time consuming.

Personas could also efficiently be used in a virtual environment. Buisine et al. [39], have experimented the use of persona through avatar in virtual environment. The goal was to make engineers embody persona to make them think as users. The experiments were made using "Second Life" as a virtual world of collaborative design. Results show that idea production was closer to the user needs. Engineers produced more ideas to anticipate user experience. The embodiment of an avatar in a virtual world was appreciated and helped them to feel closer of the users. The Persona method seems interesting to create a situation of interaction between the designers and the users. Designers mainly use the method to consider user needs, but users are not necessarily present during the design process and decision making. In our study, we show the interest of personas during a user case in a virtual environment. We pushed this method to involve real users playing the role of personas and interacting with the designer, through a multi view system.

3. Research plan: a multi-view system for early collaborative design proposal

According to the literature review, multi-view system can improve the designing of multi-user interface, e.g. multi-user virtual reality environment. Also, multi-view system may help in the field of collaborative design where several experts are working in multi-disciplinary activities with multi-representation of a DMU.

To enhance the early collaborative design among experts from different domains to communicate, Personas method allows end-users to participate in the design process and provide practical feedback to designers. Building personas from the earliest stages of design was very important for designers to familiarize with end users. We wanted to make them more aware of users' point of view, by giving life to the personas. For that purpose, we ask real users to embody the Personas profiles during a collaborative design session, in interaction with a multi-view system.

In this paper, a multi-view system tool is integrated in an early design activity. It aims at developing a multi-view collaborative system prototype and evaluating the usability of CHI system and performance of collaboration through experiments. To solve this scientific problem, the following scheme of the approach is proposed in Fig. 4:

The proposed approach is a method for evaluating the contribution of a multi-view system and the multiple users' experience based on a multi-view collaborative design module which is composed of a multi-view hardware/software system and an early collaborative work scenario:

- Define an early collaborative scenario considering the special representation that is adopted by each Personas.
- Establish a virtual immersive multi-view system which consists of stereoscopy, head tracking and hand tracking.
- Evaluate the usability of the system and the performance of collaboration by Personas methods.
- Analyze the evaluation results of a multi-view system and discuss the contribution on collaborative product design.
- Define recommendations to improve the system regarding users' point of view.

The details of these steps will be discussed in the following section of experiment.

4. Empirical study

4.1. Setup

4.1.1. Define an early collaborative design scenario

An experiment of early collaborative design is conducted between two collaborators. One of them is a Persona who has a typical character setting, such as age, profession. Another collaborator is a designer who can control the functional parameters in design. A multi-view system on DMU's multi-representation is used to allow two people to collaborate in real time.

The interest of the personas is to propose to the users to embody an end user profile, which acts according to a given scenario. We have created 2 different personas for the study:

- A 34-years-old woman who likes drinking tea during the day, mainly in her car between two consultations.
- A 42-years-old man, head of a company, mug user in public transportation and in his office.

The product to design is a mug that can be filled with water, tea, coffee, etc. The idea is to join two users in one scene collaboratively to design a mug. One user, a real end-user who plays the role of the persona, is testing the mug in virtual environment by moving the mug to a preferable position. Another user, the designer, is more interested in design analysis data, e.g. size, thermal analysis, etc. If the size of the mug is changed, both users will see this tightly related element. Since both users have other individual elements that only each one himself can understand, a mixed coupling style of this multi-view system will be applied.

This application involves two representations of a mug DMU. As displayed with 3D VR system, each representation has two POVs to

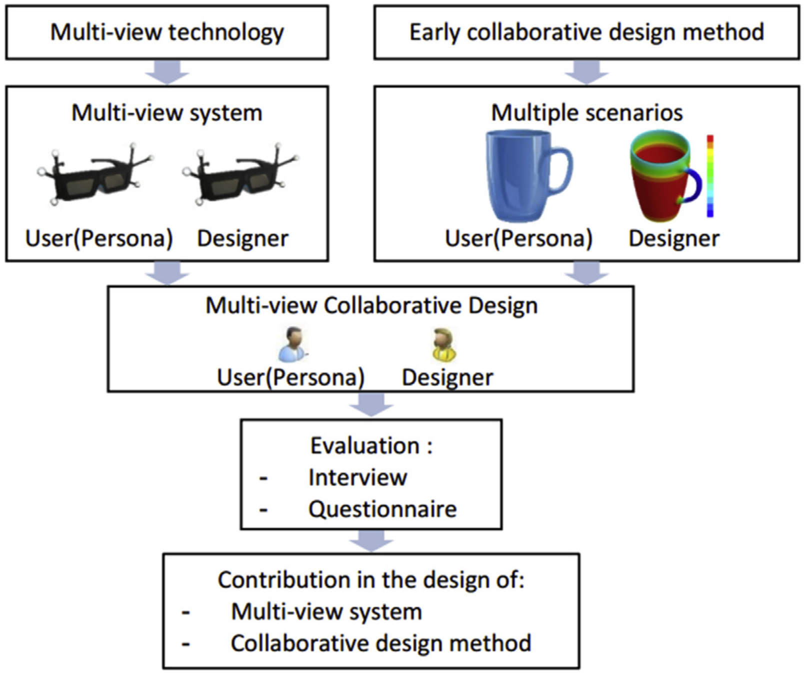

Fig. 4. Proposed scientific approach.

form stereoscopy, 4 views are needed for this multi-view system. It was chosen with the following criterions: well known by end users, multi-contexts of use, simplicity to design, time to implement in a 3D.

The specificity of this study lies in the fact that we propose to a designer and a user to collaborate on the design of a product, in real time and with a common tool.

4.1.2. Establish a multi-view system

- Hardware setup:

Two projectors of DIGITAL PROJECTION DLP® TITAN™ 1080p 3D and two shutter glasses of Volfoni® EDGE™ are used in this multi-view system. Each projector can run at 120 Hz. So, one user with shutter glasses can receive two views with stereoscopy, as we described in Section 2.1. Hence, two projectors have four views. Two different representations for different users are displayed through polarized filters. Two linear filters in a same polarization direction are placed before a pair of projector and shutter glasses separately. Two experimental scenes are developed by using 3D game engine and are displayed by two projectors separately, as shown in Fig. 5.

- Software function:

To realize an early collaborative design application, each collaborator has an experimental scene with special functions. As we described in Section 4.1.1, one of the collaborators is a USER (taking the role of a persona), the other is a DESIGNER (Table 1). Different actions realized in this multi-view system for two collaborators are listed in Table 1.

The user of the mug experiments its usage under a specific context (inside a car) in virtual environment (Fig. 6a): manipulate the mug; put the mug into the car mug holder; put the tea-bag into the mug; take the document without overthrowing the mug.

Meanwhile the designer of the mug optimizes the design parameters and analysis data (Fig. 6b), e.g. size, thermal analysis, etc. If the size of the mug is changed, both user and designer of the mug will see. Both have other individual elements that only each one himself can understand. The user has the accessories accompanying the use of the mug. The designer has the tool panel of design that only he/she can see. If user put a teabag in the mug, he/she can design a handle for the mug to tie the teabag. User can ask designer to show the transparent mug to verify the teabag (Fig. 6c). A real time displaying of the size of the mug is shown in Fig. 6d. Designer can use a virtual wand in the scenario to select and control objects. The reflections of objects on the windshield can be so disturbing for users that he/she can ask the designer to follow his/her advices (Fig. 6a).

4.1.3. Evaluate usability and collaboration

The evaluation of usability and collaboration of the system consists two parts. Firstly, ergonomic evaluation methods, such

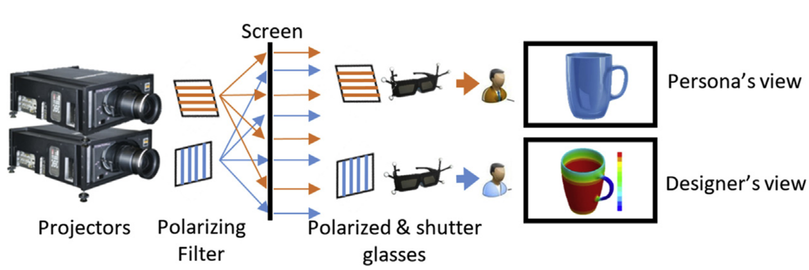

Fig. 5. Multi-view system of 2 3D views (4 views) used in the experiment.

Table 1
Definition of the actions of users (personas) and designers in the scenarios.

USER's actions	DESIGNER's actions
Reachable objects - Highlight objects which can be moved (mug, teabag, folder, cup holder) - Highlight effects (coffee, cup holder)	Synchronous observation: - Analysis result - Thermal analysis - Performance analysis (Teabag)
Personas motion simulation - Move and rotate the mug - Pour water to coffee mug - Grab teabag and drop into mug - Grab folder and open it	Exterior design - Geometry dimension - Color - Part/assembly design (mug lid, handle) - Shape design (change mug form)

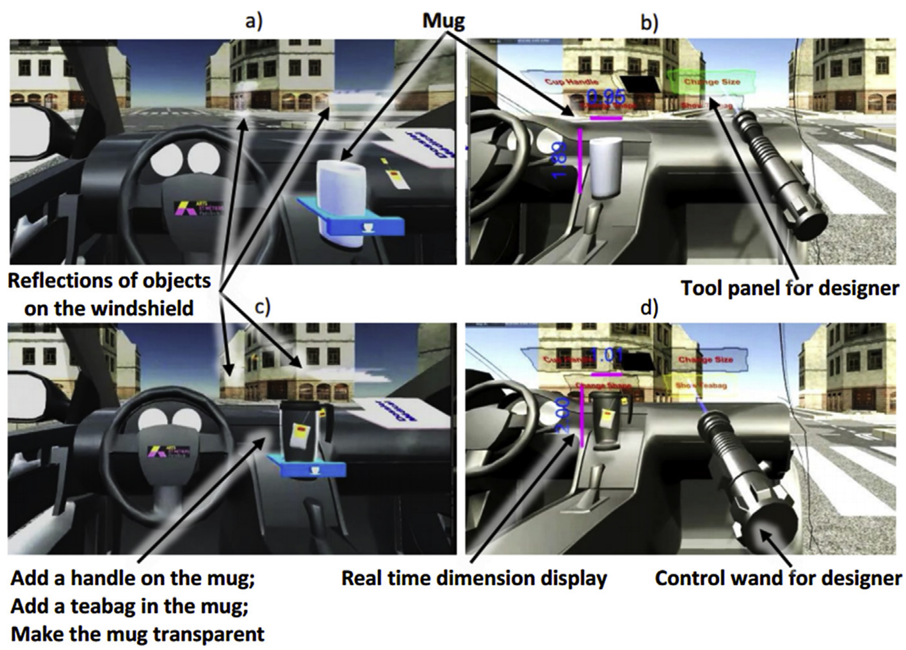

Fig. 6. User's view of a mug in the car (a and c); designer view of a mug in the car (b and d).

as observation, interview, and open questions, are adopted to participants by a professional ergonomist. Secondly, quantitative analysis with a Likert scale questionnaire is used during the experiment. The variables adapted to our research question based on literature [40,41] can be measured from point 0 to point 4:

- Involvement: the participants' feeling of how well they participate in their activities.
- Learnability: the quality that a system offers dealing with the level of ease of learning.
- Satisfaction: user's acceptance of the performance of the tools or system.
- Awareness: the ability to communicate directly, users of shared systems should be aware of each other's presence and activity.
- Collaborative effort: how much work can two collaborators provide to accomplish a specific task in a collaborative context.

Among which, learnability and satisfaction are criteria for the usability of the CHI system, while the performance of collaboration concerns about the involvement, awareness and the effort provided during a collaborative task.

4.2. Collecting data

The experiment requires simultaneously 2 participants (one will play the role of the user and the other will play the role of designer). They are asked to be recorded during the experiment by camera.

10 participants are recruited for the experiment to form 5 partnerships. Participants are students from a school of engineer. They are all men, between 19 and 23 years old. They are novice in product design.

(1) Introduction (5–10 min): They are firstly introduced with the object and procedure of the experiment. Then in a training scenario, they are asked to manipulate virtual objects. They must be taught how to do the following movements: catching an object, moving it, dropping it, returning it, etc. A training task is to be tested several times to make the collaborators familiar with our equipment. As soon as the participants are ready, the experiment starts.
(2) Test phase (20 min): The tasks asked the group of participants to achieve during this “product user/designer” experiment are

listed in Table 2. These 4 tasks are intended to represent situations of the use of a product.

(3) Feedback of experiment (20 min): Participants are asked to fill a questionnaire and a recorded interview to gather their point of views on the experience.

4.3. Processing, analyzing and interpreting data

The main results of this case-study are highlighted in this chapter. From background investigation questions in the questionnaire, we can find out that 50% of the participants have experience in projects with design activities. But only 20% of them have been involved in collaborative design activities with other people. Thus, the opinions and performances of these participants may have practical implications in multi-user system and the way of collaborative design.

From the result, we can explore that this experiment allowed us to identify elements about the co-activity between users and designers related to the use of the multi-view system on the one hand, and elements of improvements of this system on the other hand.

4.3.1. Ergonomics analysis of collaboration activities

The main result of the analyzing the interviews recorded are listed as below:

- Collaboration between users and designers:

From the familiarization phase, spontaneous exchanges between users and designers quickly become noticeable. These exchanges make possible to agreements on the modifications of the model and continue throughout the experiment. Through the observation of the participants during the experiment, as Fig. 6, the user gives directions to the designer "*a little bit*" "*it's ok*" so that he/she can modify the DMU to get the expected results. User guidance allows designers to modify the settings of the DMU as required, but designers can also propose spontaneous changes to arouse user's interest in things they might not have thought of, such as color changes for example "*I didn't know that you could change the color, it's good to be able to do it*".

Users and designers raise the interest of this device for design. Regarding their experience, they express different point of views.

For the users, it is very interesting to be able to communicate with the designer. Being involved in a design project is not common, and it is interesting for them to be able to express their opinion "*speaking with the designer make him closer*". On the other hand, seeing live modifications helps users to express their needs, something generally difficult for a non-expert in the domain "*it's very interesting to see the changes in live, it helps to verbalize the thoughts*". Users appreciate the fluidity of the experiment and the scope of possible modifications "*it's great to see the object changing in live*". On the other hand, the device is also appreciated for putting itself in a situation, users can project themselves in a context of use with the product "*it helps to project*" (Fig. 7).

Fig. 7. A user and a designer collaborate during the experiment.

On the designers' side, the contribution of the presence of users is undeniable. This allows them to think differently and consider elements they would not have thought of alone, such as the embarrassment of the reflection of the mug on the windshield, depending on the color "*we see things we didn't necessarily see without the user*". Finally, designers appreciate the time saving this tool allows to reduce iterations. The presence of users and live modifications is deemed relevant to save time in design "*this tool gives the opportunity to reduce iterations and to collect user impressions in live*".

Finally, the playful aspect of multi-view system is appreciated and encourages both parties to participate, compared to a test situation without digital support "*it's nice to manipulate an object with virtual reality!*"

Users and designers also mentioned difficulties and improvement points for the device.

- Difficulties and areas for improvement

On the user side, the main difficulty lay in interactions with the virtual model. Indeed, some actions were hardly feasible and not very fluid, like putting the mug on the cup holder "*it falls when it is placed on it*". Tracking latency was also mentioned. An embarrassment also resided in the field of view because the objects to be caught were located behind the user's hand, which did not allow him to see them correctly.

For designers, the major difficulty was the lack of information on the view of users. Indeed, users had a view of the car with all its attributes, while the designers only saw the mug. Therefore, they could not assist users in adjusting the modifications to the object. In addition, designers have offered us to add more parameters to vary, such as more choice of color or shape of the mug.

Table 2
Experimental tasks.

Task	Product user	Designer
Task 1: Put the mug in the cup holder *The user is positioned in the vehicle. His/her mug is on the dashboard. He/she must put it on the cup holder*	Open the cup holder; manipulate the mug and tries to put it on the cup holder, but the size of the mug is not suitable	The designer changes the size of the mug immediately when the user asks him.
Task 2: Put tea bag *The user must grab the tea bag and put it in the mug*	Leave the mug on the cup holder and move the teabag. The user may require the mug to be transparent to see the condition of the teabag.	The designer can make the mug transparent to better see the tea bag.
Task 3: Catch the folder cup holder *The user is asked to grab the folder*	The user must take the folder from the dashboard, but the height position of the mug on the cup holder may block the movement.	The designer changes the size of the mug so that the folder can pass over the cup holder.
Task 4: Color change	The color of the mug is reflected on the windshield	Change the color of the mug so that the reflection stops

4.3.2. Quantitative analysis of collaboration activities

The main results of representative themes of the quantitative questionnaire are shown in Fig. 8 and are listed below:

- Involvement

The questions about the impression of the experiment are asked. The results show positive feedbacks of the general impressions. An average score of "Excellent" and "Interesting" impressions is up to 3.25/4. From the frequency analysis in Fig. 9, over 85% of the participants is beyond a "fair" score in involvement. Thus. During this experiment, participants are highly involved in the collaborative work.

- Learnability

In terms of the ease of learning of the multi-user system, as well as the collaborative scenario, a mean score of 1.8/4 (4 means very hard learnability) is present. In the questionnaire, 20% of the participants think the experiment task is very easy to complete. Half of the participants have some difficulties about the collaborative task or troubles with hardware.

From an analysis comparing users and designers, users appear to consider the collaboration task easy to complete. They achieve an average score of 1.4/4. However, designers usually have trouble with the learnability of the scenario that they got 2.2/4 point.

- Satisfaction

The questions about the concept of collaborative working styles in the experiment scenario receive high marks. Participants seems like the way the multi-user system works. A score of 3.75/4 (4 means very satisfied) has been given for the satisfaction of the usability of the system. In Fig. 9, 75% of the participants are very satisfied with the collaboration style during this kind of design activity, in which collaborators can exchange multi-disciplinary information in real time.

- Awareness

For each participant, the awareness of the collaborator is questioned, as well as the confidence of the collaborator. During the experiment, participants show great awareness of their collaborators. Through frequent communications, the awareness of collaborator reaches a high mark of 3.5/4 (4 means knowing very clearly about one's collaborator) and the score of the confidence of one's collaborator is 3.5/4 (4 means very confident).

- Collaborative effort

The effort that collaborators provide to accomplish the experiment task during the communication between the two of them is questioned. The result shows an average of 3.25/4 (0 means having tough difficulties) for the collaboration difficulty. Participants do not meet terrible communication problems and they have high evaluation of the contributions of their collaborators.

5. Discussion

- Usability of multi-user CHI system

We will first discuss the evaluation of the usability of multi-view system. In both ergonomic interview (Section 4.3.1) and quantitative questionnaire (Section 4.3.2), participants expressed satisfaction on the usability of CHI system for the arranged collaborative task. They felt interested in the multi-view system which presents multi-representation of a product. The score from the questionnaire also has a very positive feedback of the CHI system.

From the quantitative questionnaire, we find the criterion on the usage of the system, learnability, is slightly below the median, which means that participants have problems with the usage of the system. Participants did not think this CHI system was easy to learn due to the technical problem. From the interview responses, there are many recommendations about technical improvements of the tracking system and interaction system. The complex operation of the interaction devices could be a technical problem which affect the user experience. That's also why a long-time training program

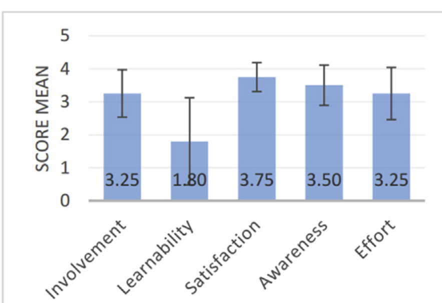

Fig. 8. Score means of the variables in the quantitative questionnaire of the experiment.

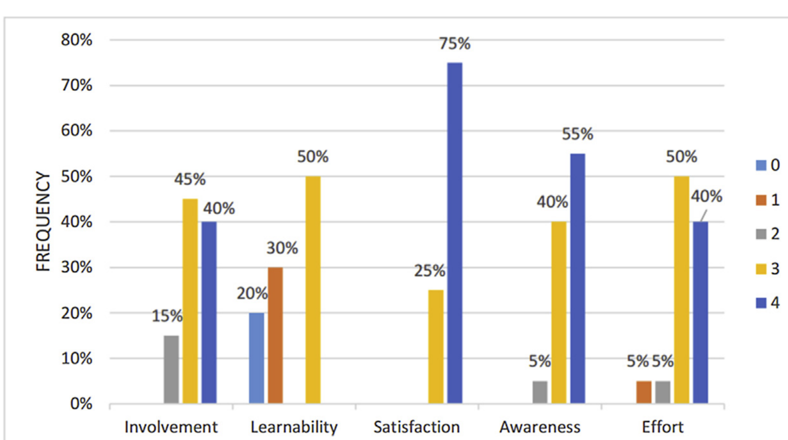

Fig. 9. Frequencies of the scores of variables in the quantitative questionnaire of the experiment.

was set up to keep the participants to be familiar to our devices before the experiments.

- Performance of collaboration

Then we will discuss the performance of collaboration and its evaluation of the experimental task. Since our participants have little experience in collaborative design activities with a partner, they seem curious and interested in the multi-view system and the multi-representation of a product. From the interviews, we can conclude that participants had positive comments on the synchronization of virtual world changes in both view during design activities. One's modification on the product can be synchronized and visualized in real time to the other participant. This reduces the time of checking modifications in another user's view. The time saving in design process can be realized between the user and designer. Compared to traditional design activities, transferring, checking, and re-designing will cause a waste of time.

From quantitative questionnaires, the criteria of the performance of collaboration: involvement, awareness, and collaborative effort, all have a score that is over 3 points (Fig. 8). During the collaborative task, participants felt their independent work got involved in a collaboration. Synchronization on the multiple representations of the same object, e.g. the modification of the cup and its parameters, allows participants to have an awareness of the existence and contribution of their collaborators. Participants also feel that the synchronization of multiple representations of an object leads to a reduction in the effort that each person needs to provide. These results of evaluation of collaboration reveal that our concept of introducing multi-view system into early collaborative design is a feasible solution of presenting multi-representation of a product. Both quantitative questionnaires and ergonomic interviews demonstrated that the advantage of co-located face-to-face communication is obvious during a collaborative task.

- Personas method in collaboration

Personas method lets participants act as some special users of a product. In the collaboration with a designer, a persona tests the product from his/her point of view. At the same time a persona allows the designer to express opinions according to both professional knowledge and user experience. The role playing of two characters needs to practice the requirement of the role in training program. However, in the future development, a way to improve the setup could be: including expert designers into the experiment to make more persuasive and authoritative evaluation.

6. Overall conclusions and future work

Communication can be realized among designers through computer–human interaction technology. Sometimes when experts with different backgrounds want to work collaboratively, the computer human interfaces used by experts become a barrier of transferring, checking, and modifying design data among experts.

Multi-view system is a kind of interface that can support several users to work together but with different visualizations as well as interactions. The aim of this paper is to integrate a multi-view VR system into an early collaborative design case (Section 2). An evaluation is conducted, and the advantage of this multi-view system is concluded.

A research plan has been proposed in Section 3. The mechanisms and techniques to build a multi-view system are discussed. The relationship among multi-view, multi-POV and multi-representation is explained. The analysis of the need of multi-user interaction in early collaborative design has been discovered, followed by the evaluation method of this kind of collaboration.

An experiment using Personas method has been conducted (Section 4). A multi-view system has been developed and integrated into a multidisciplinary mug design scenario. From the results of the experiments that we have conducted, the advantage of introducing multi-view system into early collaborative design is positive. The interviews of participants also have positive comments on the multi-view collaborative design and give some advices on the further improvement of the prototyped multi-view system.

In the future, more improvements on the computer–human interaction techniques in the multi-view system should be considered. Then expert designers will be invited to test in the multi-view experiments for more authoritative evaluation.

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