Collaborative Mixed-Reality Platform for the Design Assessment of Cars Interior

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Abstract. The paper describes a collaborative platform to support the development and the evaluation of cars interior by using a Mixed Prototyping (MP) approach. The platform consists of two different systems: the 3D Haptic Modeler (3DHM) and the Mixed Reality Seating Buck (MRSB). The 3DHM is a workbench that allows us to modify the 3D model of a car dashboard by using a haptic device, while the MRSB is a configurable structure that enables us to simulate different driving seats. The two systems allow the collaboration among designers, engineers and end users in order to get, as final result, a concept design of the product that satisfies both design constraints and final users' preferences. The platform has been evaluated by means of several testing sessions, based on two different scenarios, so as to demonstrate the benefits and the potentials of our approach.

Keywords: Collaborative design, Mixed Reality, Virtual Prototype, Haptic modeling, Ergonomic assessment.

1 Introduction

The development process of cars interior includes the execution of several evaluation tests necessary for the optimization of the final product. Specifically, the feedback acquired during the evaluation tests performed with end users will determine the commercial success of the product. The data concerning the evaluation with end users are generally acquired at the final phases of product development, since a physical prototype of the product is necessary for the execution of such kind of tests. Consequently, these data cannot be used for deeply modifying the shape of the car interior and, they will be used only for design restyling.

Automotive industries are strongly interested in performing evaluation tests early in the design phase. These tests involve different experts, who have to collaborate for defining a solution that simultaneously satisfies design constraints and end users' preferences. Interior car design, in fact, is not focused only on aesthetic values and safety requirements, but it is also strongly related to ergonomic aspects, which obviously require the study of interaction between the user and the dashboard components.

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Our research has aimed at developing a collaborative platform based on Mixed Reality (MR) technologies that enables designers to assess and refine the shape of a car interior in a more natural and interactive way while enabling other experts (engineers and ergonomists) to perform some evaluation tests with end users with the objective of getting users' acceptance without the need to build several physical prototypes, and thus reducing the product development time.

This paper is structured as follows: section 2 presents an overview of related works, in section 3 we describe the collaborative platform architecture and the hardware and software implementation. Section 4 reports about the usability of the platform assessed by performing different tests related to two different scenarios deriving from typical ergonomic issues of car interiors. Finally, in section 5 and 6 we discuss some considerations and present our conclusions.

2 Related Works

It has become accepted practice the use of the term "collaborative systems" for describing the computer systems that support distal communication between designers [1]. The design activities, in fact, involve several professional figures, who have to collaborate for defining the final product. These activities range from modeling to numerical simulations, evaluations with end users and so on. Therefore, the issues related to the collaborative environment are very complex and several authors propose different approaches to overcome them. Madsen [2] identifies some of the common collaborative barriers such as language differences, time zones, miscommunication, ambiguity in requirements, misunderstandings of design intent and proposes a collaborative strategy to overcome these barriers in particular for supporting distributed teams in CAD systems integration. Li et al. [3], highlight that, due to the complexity of collaborative design activities, a collaborative system cannot be a simply set-up obtained through equipping a stand-alone CAD system with IT and communication facilities, but it needs several innovations or even fundamental changes such as infrastructure design, communication algorithms, geometric computing algorithms, etc. For this reason, the role of VR technologies [4] and in particular of Virtual Prototypes (VPs) [5] is fundamental in this context and several examples demonstrate their effectiveness during the product design process [6-12]. However, the use of VPs arise many issues related to the interaction, in particular during the modification or the evaluation phases of new products. MR technologies can enhance the interaction with the VP by providing a more realistic visualization and by adding the haptic feedback. For instance, Mixed Prototyping (MP) approach, which consists in creating a prototype partially real and partially virtual can be effectively used for the rapid design assessment of new products, as described in [13].

The evaluation of car driving seats with end users, instead, needs systems, named seating bucks, which simulate the car interiors. Many research groups and industrial research centers use this kind of systems. The ELASIS research group [14], for example, has developed a system based on a parametric driver's seat simulator, which supports automatic configuration of steering wheel, driver seat and pedals, coupled with an immersive VR environment [15]. H. Salzmann et al. developed a two-users virtual seating buck system [16], which enables two users to take the function of the driver and co-driver respectively. However, these seating bucks are developed by using VR immersive environments that reduce the perceived realism of the scene: in fact, several users, especially when they have to wear a Head Mounted Display, complain about an unnatural perception of space. Also in this activity, MR technologies can improve the users' interaction with these systems. Ohshima et al. [17], for instance, describe how a MR system can improve the perception of the distances than when the only the visual sense is available, as happens in the VR environments. We have also proposed, in a recent work [18], an innovative MR seating buck system, which enables us to easily compare, with end users, different car interiors.

The above-presented overview has shown several systems for supporting collaborative design and the evaluation of cars interior; however, none of these systems enables performing these two different activities collaboratively. Our work intends to demonstrate how MR technologies can support these activities by creating a collaborative platform based on Mixed Prototyping approach.

3 The Collaborative Platform

The main purpose of our work is to provide an effective system for easily and interactively modifying CAD models of cars interior in real scale and for verifying in real time the modifications with the end users. Usually, these two activities are carried out in two different phases of the car interior development and are often performed by two teams working in two different locations. The Collaborative Platform aims at fostering the concurrent performance of these two activities in this particular situation. For this reason, we set the two systems in two different locations during the testing sessions and the participants were able to communicate by using commercial video-conference software. The designer can modify the 3D model through the 3DHM system while other experts assess the goodness of the modifications by means of the MRSB with an end user. If the user is not satisfied with the results of the modification, the designer is able to further modify the model, according to the comments of the user and of the other experts. Subsequently, the modified model is proposed again to the user, who can express a new judgment. The evaluation test is considered finished when all the participants judge positively the final model.

The Collaborative Platform mainly consists of two different systems: the 3D Haptic Modeler and the Mixed Reality Seating Buck.

(a) (b)

Fig. 1. The Mixed Reality Collaborative Platform: a) 3D Haptic Modeler, b) Mixed Reality Seating Buck

The *3D Haptic Modeler* (3DHM) is a workbench integrating stereoscopic visualization and haptic interaction (Fig.1a). The display system consists in an original solution that we have named Direct Visuo-Haptic Display System (DVHDS), based on mirrors and screens for projecting a 3D image over the haptic workspace [19]. Such solution allows us to visualize in real scale the area of a car interior, which has to be modified. For the haptic interaction, we have used the MOOG-HapticMaster (HM) haptic device [20]. This device is able to render very high rigidity with low friction and, above all, its workspace is large enough to guarantee an appropriate working space. Using a haptic device with a small workspace, as for example the Sensable Phantom device [21], would not allow covering the whole area of a car interior visualized in real scale. Unfortunately, the HM device does not allow users to haptically render any kind of surface. The HM, in fact, can only render haptic effects, such as dampers and springs, and spatial geometrical primitives can be defined, such as spheres, cones and cubes [22]. In order to solve this problem, we have implemented an original algorithm.

The *Mixed Reality Seating Buck* (MRSB) is a system that allows us to simulate different driving seat set-ups for performing different tests enabling the users to see and interact in a natural way with the Mixed Prototype of a vehicle (Fig 1b). The MRSB mainly consists of a configurable hardware structure, which simulates the driving seat, an Optical See-Through Head-Mounted Display (OST-HMD) that enables the user to visualize the virtual representation of the car interior and the real environment at the same time, and a robotic arm, which allows us to interactively change the position of some physical components of the dashboard (for example, buttons, sliders, and knobs). Finally, an optical tracking system equipped with 6 cameras tracks some elements of the structure, the user's point of view and the user's hands for aligning virtual components to the real ones.

The software application, developed for the collaborative platform, consists of five modules: the MainLoop module, the OpenSG module, the ThinkCore module, the HapticMaster module, and the Kuka module, as shown in Fig. 2.

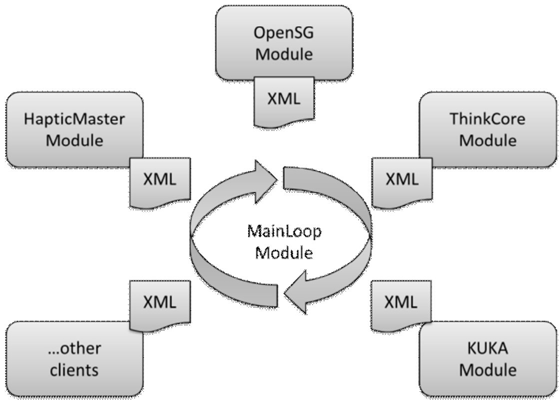

Fig. 2. Software architecture

The core of the system is the MainLoop module. It is based on a publish/subscribe paradigm for interprocess communication based on XML messages sent over a TCP/IP connection [23]. Thanks to that, the 3DHM and the MRSB systems can be placed in different locations and easily connected by Ethernet communication. The MainLoop manages the exchange of data within the other modules of the platform and permits the definition of a specific behavior for each module using a finite-state machine approach. The MainLoop module is also able to connect other clients, which extend the platform in order to provide other workstations in different locations.

The OpenSG module manages the visualization both of the 3DHM and of the MRSB through two stereo viewports that support the active stereo and the passive stereo modalities. OpenSG is an open source portable scene-graph system able to create real-time graphics programs by supporting all the modern computer graphics features.

The ThinkCore module, instead, is based on a subset of the think3 COM API [24]. This module allows us to use the functionalities of ThinkDesign CAD system with the aim of developing applications working with CAD models. The ThinkCore module manages the CAD model by generating a tessellated representation of the model and by providing the haptic objects stored in the model. The tessellated representation is sent, through the MainLoop module, to the OpenSG module for the stereoscopic visualization while the haptic objects are sent to the HapticMaster module for the haptic interaction. The haptic modifications, in fact, are made directly on the CAD model while the ThinkCore module deals with the updating of the visualization. In addition, this module provides us with two powerful CAD modification modalities of ThinkDesign: the Interactive Solid Modeling (ISM) and the Global Shape Modeling (GSM). Such modification modalities enable us to directly modify the CAD model by using the haptic interaction modalities, which are simple and intuitive.

The HapticMaster module manages the haptic behavior of the HM devices and enables us to acquire data from the end-effector position and to generate the objects used for the haptic integration. Since the HM is able to interact only with simple primitives, we have implemented a procedure that enables the user to touch the general surfaces of the CAD model. The procedure creates a Haptic Virtual Plane according to the end-effector position with the same normal of the selected surface. The virtual plane moves according to the end-effector position, while the ThinkCore module elaborates the new normal in respect to the surface in real time, and gives the user the feel to touch the surface. This tangent plane is determined by a normally oriented spring that is calculated in the position of the HM end effector. Finally, through the HapticMaster module, we have created a sort of magnetic point, named Snap Point (SP), which helps the user to haptically select a specific feature of the CAD model. We had to implement such haptic object because similar objects do not exist in the HM API. The SP is a haptic object made up of three haptic springs with the same application point but different stiffness and deadband.

The Kuka module manages the communication with the robotic arm. In particular, the module sends to the robot the position that has to be reached by its end effector. These positions are obtained directly from the modification made on the CAD model.

4 Evaluation Tests

The case studies, which we have chosen for the evaluation test, have been carried out by using two typical ergonomic issues of car interiors. The first one consists in the evaluation of the reachability relating to the position of the climate control system knob on the car dashboard while the latter one is based on the visibility assessment of the left A-pillar. In the automotive field, such issues are considered very useful to improve the quality of the final product and the level of satisfaction for costumers.

The repositioning of the knob has been made by using the ISM modification modality. The expert user moves one of the three knobs to a new position according to his preferences by using the 3DHM. During the modification, the haptic feedback link the knob to the surface of the dashboard and a “ghost” representation of the knob help the user to define the final result of the modification. Simultaneously, the new geometry is sent to the MRSB and the physical prototype of the knob is moved by the robot in the new position. Therefore, the user seated on the MRSB can evaluate the new position of the knob both visually, by means of OST-HMD, and haptically, by touching the real knob. Fig. 3 shows the modification of the model during the knob repositioning.

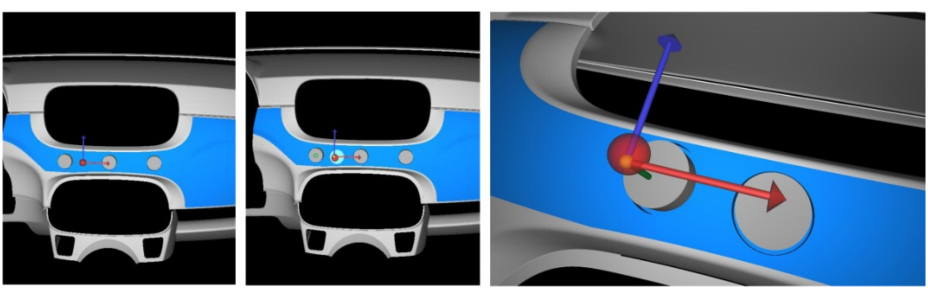

Fig. 3. ISM modification applied during the knobs repositioning

The second case study, instead, concerns the A-pillar restyling and the modification is done by using the GSM modification modality. During the modification, the haptic feedback simulates the surface deformation and a graphical representation of the result is updated in real time. These feedbacks help the user to define the final result of the modification. At the end of the modification phase the user seated on the MRSB can evaluate visually the goodness of the modification. The test ends when the user is satisfied with the achieved A-pillar modifications. Fig. 4 shows the main steps of the dashboard restyling.

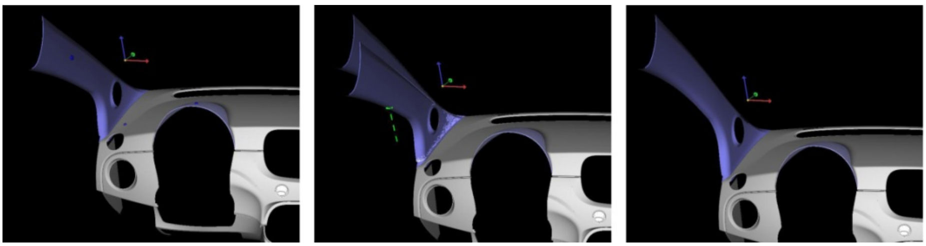

Fig. 4. GSM modification applied during the visibility test of the A-pillar

5 Discussion

In this section we discuss the data collected during the testing sessions in reference to the usability aspects of the collaborative platform. The definition of a protocol for evaluating the effectiveness of our platform is necessary and we have investigated several approaches in order to define the most suitable one. We have decided to adopt the heuristic method proposed by Nielsen et al. [25] that enables us to address the usability issues of the collaborative platform. In particular, during the test we have involved an expert user for assessing the usability of the 3DHM and other 10 users, who are skilled in VR technologies, for the evaluation of the MRSB functionalities. The expert user has a background on heuristic methodology, with 3-years experience in HCI research, so we can classify him as an HCI expert user. The expert user and the other users have been invited to carry out some specific tasks according to the two case studies, which will be described in the following. At the end of the testing session, all the participants have filled a questionnaire that has been elaborated according to the Nielsen's heuristics. Table 1 presents the correlation between the data collected during the testing sessions and the qualitative usability aspects investigated. Some of such data have been collected during the execution of the testing sessions while the remaining ones are the users' judgments, related to some aspects of our collaborative platform, expressed on a scale from 1 (bad) to 10 (good). In this table, we correlated quantitative data collected and qualitative aspects for assessing the usability of our system.

Table 1. Usability Considerations

Measurements	Value	Usability aspects
Misunderstanding	3%	Learnability
System errors	2%	Margin of error
User's errors	10%	
Influence of surrounding environment	8	Efficiency
Influence of the structure	7	
Field of view limitation	4	
Time for tasks execution	9	
Perceived Comfort	6	Satisfaction
Perceived Realism	4	
Global evaluation	6	

At first, we correlated the system learnability of the platform to the times that the user misunderstood some task during the testing session and asked to explain it. This datum is presented as the rate between the number of misunderstandings and the total number of tasks (30 for each testing session) and highlights a good affordance of the platform. Obviously, this datum will be more significant when the sample of users will be wider and more heterogeneous since, in this testing session, the involved users are skilled on VR technologies.

The margin of error is an aspect that we correlated with the errors occurred during the execution of the testing session. We divided such data into two categories: system and user's errors. The first one represents the times that one of the components constituting the system (robotic arm, tracking system, haptic device, etc.) goes in failure mode during the test. In the second category similar kind of errors are collected but only if they occurred when the user interacts with the system. These values are expressed as the rate between the number of errors and the number of tasks in which we subdivided the testing session. We considered the margin of error one of the aspects that can represent the reliability of our system.

The efficiency of the system, instead, has been correlated to users' judgments that relate to some issues, which can limit the interaction and consequently invalidate the assessment. The surrounding environment and the presence of the structure, for instance, can influence negatively the user during the testing session since they are visual noises. The time for task execution is another issue investigated for assessing the efficiency and the effectiveness of our approach. Thanks to the robotic arm, the time needed for changing the layout is very short (few seconds) and thereby the users are able to correctly compare different proposed solutions and the time need to complete all the testing session (about 20 minutes) did not wearied any user.

Globally, the users' judgments have been positive also in relation to the aspects related to the satisfaction in using the system. These results are encouraging and show the effectiveness of our platform that certainly improves the normal activities carried out for evaluating car interiors. Unfortunately, we cannot do a comparative assessment since now there are not similar collaborative platform to compare. However, the traditional procedure, which the automotive industries follow to validate a car interior, is complex and implies a lot of downtime.

6 Conclusion

This paper has presented our MR collaborative platform for the design assessment of the car interiors. The aim of this platform is to improve the decision-make process during the project development by providing the possibility of verifying the design modifications in real time with the end users. The conducted testing sessions confirm the good usability of the platform. However, some technological issues have to be solved for improving the effectiveness of our collaborative platform. In the next future, we aim at improving the system as regards the interface for the user's interaction, and at solving the technological issues arose during the testing sessions.

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