SIMULATION OF THE INTERACTION WITH INTERFACES OF INDUSTRIAL PRODUCTS IN A MULTIMODAL ENVIRONMENT

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Several testing activities on industrial products are today performed on Virtual Prototypes (VPs) because of their flexibility and reduced cost compared to the physical ones. The very first activities on VPs were limited because based mainly on visualization devices. Now the availability and the evolution of haptic and sound technologies have opened new scenarios and offered new possibilities to perform tests on VPs. The paper describes an attempt to exploit VPs to test human interaction with the interfaces of industrial products. The user is able to see in 3D the prototype, hear realistic sounds from it and interact through the sense of touch with the interface of the product. We have performed some experiments with the VP of a commercial washing machine in order to prove the concept and understand the limits we can reach with commercial hardware and software devices. The results of the preliminary users' tests are reported and discussed in the paper.

Keywords: Virtual Prototyping, Virtual Testing, Multimodal Interaction, Haptic Interaction, Haptic and auditory interfaces.

1. INTRODUCTION

The use of Virtual Prototypes (VPs) in the product development process is more and more becoming a diffused practice. This is mainly due to the fact that once created, the VPs are easy to modify, share, represent in different ways, and to enrich with additional information. These tasks have a reduced cost if compared with the same ones performed on physical prototypes.

The initial use VPs was constrained to the available devices, which were mainly devoted to visualization. Today, despite the availability on the market and in the research context of technologies that would allow user interaction through multiple sensory channels, a large number of virtual prototyping applications is still based on the sense of vision, and on the visual representation of information. For example, VPs are used to show different variants of the same product, in terms of textures, colors, geometries, and so on.

In order to effectively substitute physical prototypes with virtual ones and use them in various testing activities — for example, ergonomics and usability tests-, we should explore additional ways for representing product information to humans.

In this paper we explore the benefits of the integration of two additional senses to the interaction with the VPs: the sense of touch and the sense of hearing. Our research is focused on a typical activity that is performed today exclusively by using physical prototypes, i.e. the evaluation of ergonomic and usability issues, and of the perceived quality of the interface of consumer products. In particular, our aim is to understand if the kinds of tests that we can perform using Virtual Prototypes of consumer products are good enough and comparable with the ones carried out with the corresponding real products. In addition, we wanted to test the limits of today's technologies when used for the simulation of interaction

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with virtual products (for example, the limits of haptic devices). In order to do this, we have selected a reference product, i.e. a washing machine, we have built a virtual replica, and we have performed some experiments, including some comparisons of the virtual washing machine with the real one.

The paper is organized as follows: Section 2 compares the work presented in this paper with similar research activities, Section 3 describes the implementation of a study case, and in Section 4 we describe the results of preliminary users' tests. Finally, in Section 5 we draw some conclusions and shortly discuss of future developments.

2. THE USE OF VIRTUAL PROTOTYPES IN THE PRODUCT DEVELOPMENT PROCESS

The use of virtual prototypes for product design evaluation instead of physical ones may positively influence the time required for the overall product design activity, and also the cost of the entire product development process. This mainly because the modifications of the digital information included in the VPs are faster and less expensive than the corresponding modifications performed on a physical prototype, that may also require that a new prototype is built.

In order to effectively perform design evaluation in virtual environments, it is necessary to have a virtual model that has the same characteristics of, and behaves like the corresponding physical one, for what concerns the aspects we are interested to simulate and validate. In this paper we present an example of activity performed in a multimodal environment that can be used for the preliminary stages of conceptual design evaluation, that is a crucial phase of the design process [1]. Several research activities have tried to push the design review activities toward the use of VPs, like for example in [2] where Santos *et al.* explore the possibility of using an immersive visualization system for creating a collaborative design review environment. These review activities are done on static prototypes that cannot be modified. This example, like several other research activities [3], shows a limited types of review tasks that can be performed when visualization is the unique available information channel.

In [4], Bordegoni *et al.* explore the possibility to use a multimodal approach based on the combination of vision, sound and touch in creating a design review activity on continuously evolving shapes. In this application, industrial designers, who are manually skilled, have the possibility to interact with the evolving shape of the product using their hands, and to continuously evaluate and modify the model.

Sometimes, the design review activity involves multiple users that can be geographically dislocated and may require different perceptual representations of the same digital information. In this case a multimodal approach helps in exploiting the potentialities offered by VPs in terms of easiness in creating different variants and performing modifications, and in terms of sharing and transferring of information [5].

From the analysis of literature on design review it results that a multimodal approach, i.e. the use of the combination of more sensory channels, in the interaction with VPs is beneficial in order to get an evaluation model that really allows us to test and effectively and accurately validate the various characteristics of future products.

One of the causes of the low perceived quality of a large number of Virtual Reality-based applications, and sometimes the failure, is related to fact that several developers do not consider human factors as the center and the focus of the interaction design. Actually, human factors in VR environments design are crucial for the development of successful applications, especially when the users are people with highly developed manual skills [6]. In our work, we aimed at developing an application that simulates at best in a virtual environment the physical interaction with a corresponding real product. Therefore, we were not interested in precisely simulating the physical phenomena, but rather in representing phenomena that are perceived as real by humans.

3. DESCRIPTION OF THE STUDY CASE

In this section we describe the application we have developed in order to demonstrate the potentialities of VPs when also the sense of touch and hearing channels are used.

Before affirming that a particular activity that is today performed on physical prototypes, can be successfully run on VPs, we have to compare VPs with real ones, in order to understand the fidelity of the representation and the consequent reliability of the test. These limits are related to the technologies used, but sometimes can be also related to a n inappropriate approach taken to simulate the interaction with the virtual prototype.

The study case presented consists of the simulation of the human interaction with the interface of an industrial product, and in particular of a domestic appliance. One of the parameters that is evaluated by potential buyers of an industrial product, and in particular of domestic appliances, is the perceived quality of the product, that sometimes does not correspond to the real quality, or to the quality that designers had in mind. For example, when choosing among different products with similar performances and cost buyers may prefer the one that seems to be more “robust”, or more “stable”. These parameters are often evaluated through a direct interaction with the product. In fact, it is not unusual to see buyers playing with doors, buttons and so on for evaluating the characteristics of a product.

The use of VPs can help designers in testing these characteristics with end users since the very beginning of the design process and possibly changing the product design specifications. Through haptic devices we can simulate the touch and physical interaction, through sound devices we can reproduce realistic sounds, and with the technologies available for the visualization channel we can return to the user a realistic and 3D representation of the product.

3.1. Main requirements for the application

The application we have developed was meant to satisfy the following two requirements:

1. give the user a perceptual feedback as much as possible similar to that she can experience while using a physical prototype of the same product. This feedback should be based on the combination of three sensorial channels: visual, haptic and auditory. Other sensory modalities have not been considered because of minor importance in this kind of simulation and because enabling technologies are still not so evoluted so as to provide realistic perceptions;
2. allow us to exploit the benefits regarding the flexibility of the digital nature of information included in VPs, in order to allow actions that cannot be performed on real prototypes, as for example easily and quickly changing the force feedback of a component of the interface according to users’ preferences thanks to the use of a programmable haptic device. These parameters about force feedback can then be reproduced by the engineers in the real prototype, by manipulating or mixing the components that affect the force feedback, like for example the material of colliding components, spring constants, superficial roughness of sliding parts, etc.

The first requirement, once completely satisfied, would allow us to perform ergonomics and usability tests like completely on VPs, with an accuracy of results that is comparable with that obtained with physical prototypes. The second requirement demonstrates the real advantage of performing tests on VPs instead of on physical ones.

Regarding the first point we have observed and analyzed the way users interact with the real product, that in our study is a washing machine provided by Whirlpool Company, and we have concentrated on the interface and on moving and interacting components that are: the knob, the drawer, the door and buttons. We have recorded the sounds that are generated by colliding parts, and in particular the click generated by these four components, and we have analyzed the forces that are returned to the hand of the user when interacting with these components.

In order to reproduce in the VR environment a perceptual feedback that is as much as possible similar to the one occurring in the real world, we have decided to concentrate only on the way information is perceived by the user, and not on the way information should be produced in order to replicate in the Virtual Environment exactly the real phenomenon. Therefore, this has simplified the implementation of the application, allowing us to concentrate only on the effect on users at the perception level.

3.2. Hardware and software architecture of the application

The application we have developed is based on the use of commercial devices such as:

— a rear-projected wall display by Cyviz that creates a stereoscopic visual effect thanks to the use of two projectors equipped with linear polarizers and a pair of lightweight glasses worn by the user;
— an optical tracking system by ARTrack made of three infrared cameras, used to detect head position and orientation;
— a six DOF haptic device Haption Virtuose that detects the hand position and returns to the user forces and torques along three axis;
— a set of speakers to convey sounds to the user.

Figure 1 shows two users while interacting with the virtual washing machine, after they played with the real one (that is on their right hand side). They are seeing the virtual product represented on the wall display, they hold the haptic device in their right hand for interacting with the product components, and move their head to see the product from different points of view.

Regarding the software, the application has been developed using 3DVIA VirTools, which is a development system for creating interactive 3D applications. We have decided to use such tool because it offers a building block interface, which is quite easy to use also for non-expert programmers.

3.3. Implementation of the visual environment

The visual environment includes the digital model of the washing machine. The moving components have the same degrees of freedom (DOF) of the real ones. The environment contains also an additional element that is the visual avatar of the human's hand (see Figure 2). The virtual hand is used to give visual feedback to user's actions. In fact, it changes its shape according to the component the user is grasping, and reproduces the shape it takes in the interaction with the real washing machine. The representation of the hand in the visual environment improves the quality of the overall interaction with the prototype. In fact, even if the user holds in her hand the generic end effector of a haptic device, she is visually guided by the visual avatar of her hand. The fact that in combined haptic/visual applications the user is visually guided in searching the targets has been demonstrated and described in [7].

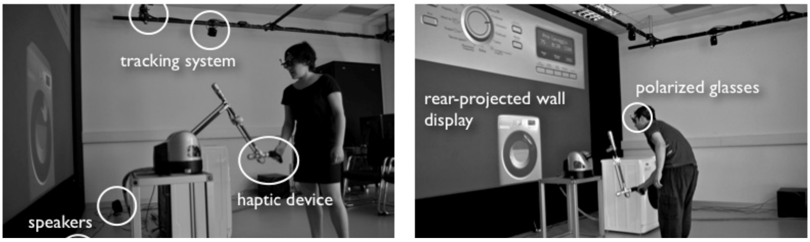

Figure 1. Hardware environment used for the implementation of the study case.

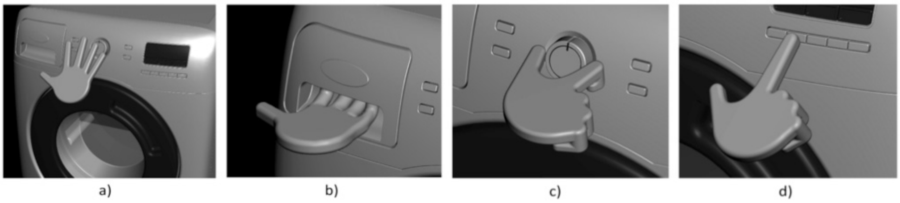

Figure 2. The avatar of the user's hand during: (a) free exploration; (b) handling of the drawer (and the door); (c) rotation of the knob; (d) interaction with the buttons.

Figure 3. The visual environment: zoom in of the control panel.

Figure 3 shows a screenshot of the visual environment as it has been implemented in our application. After some preliminary tests with users, we have also added a representation of a zoom in of the control panel of the washing machine in the top part of the screen. This allows the user to read the text labels, which due to the resolution of the projectors of the wall display cannot be read. This part of the visual representation can be also hidden depending on the kind of simulation we want to run on the prototype. It has been judged fundamental by the users during the following tests.

3.4. Implementation of haptic and sound interaction

The haptic interaction of the application is implemented throught the use of the Haption Virtuouse haptic system. This system is a commercial 6DOF point-based and general-purpose haptic device that is particularly suitable for our application, since it is equipped with an ergonomic handling tool and allows the force feedback rendering of manual operations based on movements along the three axes, and also torques.

The software tool that we have used, 3DVIA Virtools, is easy to use also for non programmers but has not been designed specifically for haptic simulations, and so it does not offer all the functionalities that are usually available in haptic libraries, such as CHAI3D or H3D. Therefore, the haptic effects that we have reproduced are obtained as the combination of a limited number of low-level force controls.

Figure 4 illustrates the concept of the implementation of the force-feedback effect of the moving components of the washing machine. We have obtained the force effect by combining three main effects:

1. we have included into the environment some small blocks that are not visually represented. These blocks are used to reproduce the rotational limits of the door hinge, or the translational limits of the drawer by returning a collision;
2. in order to reproduce the clicks of the opening/closing we have used some local effort gradients. The same approach has been used to reproduce the rotational clicks of the knob, and the force returned by the buttons;
3. in order to reproduce the weight of the door and of the drawer, we have used the dynamic friction of the hinge and of the rail.

In order to simplify the user interaction we have introduced some haptic snap operators that attract the hand of the user also when its visual avatar is not exactly on the surface of the component the user wants to grasp. In particular we have used two different snapping locations on the hand. In order to push the button or turning the knob, the part of the visual hand that has to be close to them is its fingers, as it happens in reality; in order to grasp the door or the drawer, the part of the hand that is closer to them is the palm. The use of these simple snap operators makes the application easier to use especially for new users, being them able in this way to operate in the virtual environment exactly as they would do in the real one, and so reaching the buttons and knob with the fingers, and the other

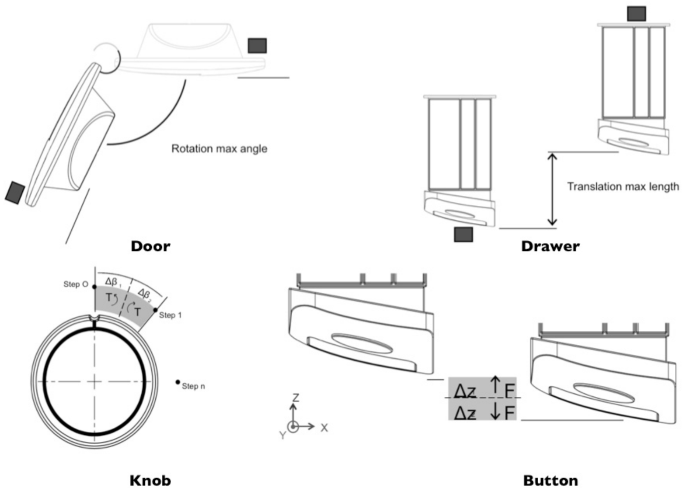

Figure 4. Implementation of the four haptic effects.

components with the palm. One of the buttons of the Haption device end-effector is used to release the grasped components.

Regarding the use of sound, we have recorded the original sounds from the real washing machine, and then we have elaborated them and introduced the possibility of varying them during the use of the application. For example, we have created three different versions of the closing effects of the door by adding some audio effects. We have experimented that in order to make the user feel different effects when closing the door, without changing the force feedback parameters, we can act on sound. The original recorded click sound has been modified: we have used equalizers to obtain a higher frequency sound that gives an effect of lower force, and compression effects and reverbs to reproduce the effect of a tight closure. So, we have proved that the various sounds added to the environment alter the force perceived by the user. This fact is described in literature as cross-modal perceptual illusion [8]. As for most of the perceptual illusions, the tendency is to disappear when they are experienced for long periods, and then also when the difference between the expected effect and the one experienced is too strong, i.e. there is a threshold we cannot exceed before the user understands that the effect is not natural. We assume that our application is not going to be used continuously, but for short periods during the testing activities. Therefore, we can reasonably use these illusions to represent different system behaviors, instead of implementing complex force-feedback effects.

So, we can conclude that the use of sound in a complex multimodal environment has a double effect:

— first it allows us to increase the level of realism of the overall simulation;
— then it gives us the possibility to choose among different solutions for solving the same problem related to technical limitations.

The second effect is particularly useful because the use of more sensorial channels may change the way we design VP applications. In our example we can decide to represent different force effects with a perceptual illusion coming from the combination of auditory and haptic sensory channels without the need to change or re-adapt the force-feedback effect.

4. USERS' PRELIMINARY TESTS

When developing a new kind of application based on VPs it is important to have a feedback from end users since the very beginning. End users of an application such as the one described in the paper have

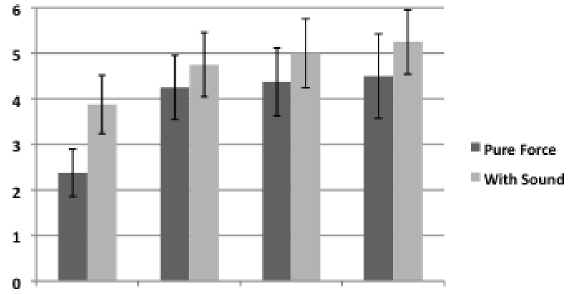

Figure 5. Perceived quality of the simulation of the click effects for each component, with and without sound.

not necessarily to be expert in technologies, and so we have submitted the application to a continuous revision to a large number of students and visitors of our laboratory. So several adjustments, as for example the zoom in of the washing machine panel or the avatar of the hand that changes its shape according to the grasped object, and the haptic snaps, are the results of this kind of informal testing.

Then, in order to have quantitative results we have organized two kinds of structured tests [9] with a group of 16 users, 5 female and 11 male, aged between 23 and 54.

The aim of the first test was to understand the limits of the VP application in terms of kind of information that we are able to represent, and the quality of the representation. In addition, we were interested in understanding how sound may be effectively used to simulate realistic force perception related to the click effect of closing parts of the washing machine.

The participants were asked to perform the following tasks:

1. Interact with the real washing machine for 5 minutes in order to have a subjective evaluation of the different behaviours: open and close the door and the drawer, rotate the knob and push the buttons;
2. Interact with the virtual prototype of the washing machine for 5 minutes: perform the same operations done using the real washing machine;
3. Evaluate the differences in terms of perceived force effect of the two prototypes and fill in a questionnaire.

The participants have been organised into two groups. A first group of 8 participants tested the application with visual and haptic feedback only, while for the other 8 participants also the sound effect has been added. The participants were asked to evaluate the quality of the interaction of the component of the virtual prototype with respect to the real one. They were asked to score the effect for each component giving marks from 1 (poor) to 6 (very good), were 3 means acceptable.

The results of the scoring are summarized in Figure 5. The graph shows that the use of sound increases the quality of the physical interaction effects. Specifically, the role of sound has different weight on the different components.

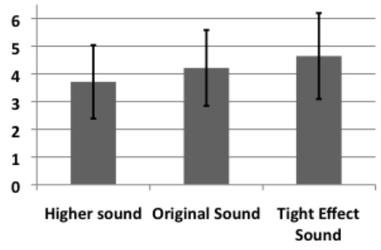

Figure 6. Results of test demonstrating the integration of sound for selecting the preferred closing effect of the drawer of the washing machine.

The aim of the second set of tests was to experiment the benefits of using VPs for proposing variants of a product to users. The participants were asked to compare three different force effects related to the opening/closing of the drawer, that were induced by changing the associated sounds. Then, they were asked to say which one they would have preferred in a potential new washing machine. The results are reported in Figure 6.

This simple test represents one of the key points for evaluating the benefits of virtual prototyping. The digital nature of VPs, and the possibility of implementing multimodal interaction, can extend the number of actions, functionalities and behaviors to test, which can be implemented with a small effort.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

The paper has presented a multimodal application for the simulation of the interaction with the interface of a domestic appliance. We started from the results of some previous research activities on the use of Virtual Prototypes in the product development process, and we have used them to demonstrate how the use of other channels than the visual one can enlarge the number of tests that can be performed, and can also contribute in substituting the physical prototypes, which are in general less flexible and more expensive.

We have developed an interactive virtual prototype of an existing commercial washing machine in order to understand the limits due to the use of current commercial hardware and software devices. We have continuously tested the evolving version of the virtual prototype, which we have submitted for testing to several students and visitors. Once it was considered sufficiently good we have performed some more formal preliminary users' tests in order to measure how the combination of senses impacts on the quality and fidelity of the simulation of complex interaction phenomena. We have then demonstrated with a simple example how the digital nature of the VPs can help in performing additional activities on the VPs with a very small effort.

One of the future developments of the application will concern the implementation of a configurator for industrial products that will allow end users to design their own preferred interaction with the product, as an extension of what is now performed on products shape and colors.

REFERENCES

1. Ulrich K. and Eppinger S., Product Design and Development. McGraw-Hill, fourth edn., 2008.
2. Santos P., Stork A., Gierlinger T., Pagani A., Paloc C., Barandarian I., Conti G., Amicis R.D., Witzel M., Machui O., Jimenez J., Araujo B., Jorge J. and Bodammer G., Improve: An innovative application for collaborative mobile mixed reality design review. International Journal on Interactive Design and Manufacturing 1(2), 115–126, 2007.
3. Schmalstieg D., Fuhrmann A., Hesina G., Szalavari Z., Encarnaçao L.M., Gervautz M. and Purgathofer W., The Studierstube Augmented Reality Project. Presence: Teleoperators and Virtual Environments 11(1), 33–54, 2002.
4. Bordegoni M., Ferrise F., Shelley S., Alonso M. and Hermes D., Sound and tangible interface for shape evaluation and modification. In: Proceeding of HAVE 2008 — IEEE International Workshop on Haptic Audio Visual Environments and their Applications. Ottawa, Canada, 2008.
5. Bordegoni M., Ferrise F., Ambrogio M., Caruso F. and Bruno F., Data exchange and multi-layered architecture for a collaborative design process in virtual environments. *International Journal on Interactive Design and Manufacturing*, 4(2), 137–148, 2010.
6. Stanney K.M., Mourant R.R., and Kennedy, R.S., Human Factors Issues in Virtual Environments: A Review of the Literature. Presence: Teleoper. Virtual Environ. 7(4), 327–351, 1998.
7. Plaisier M.A., Kappers A.M.L., Bergmann Tiest W.M. and Ernst M.O., Visually Guided Haptic Search, *IEEE Transactions on Haptics*, 63–72, 2010.
8. Stein B.E. and Meredith M.A., The Merging of the Senses. The MIT Press, Cambridge, MA, 1993.
9. Tullis T. and Albert B., Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics. Morgan Kaufmann Publishers, Burlington, MA. 2008.