Application of Virtual Reality Technologies in Consumer Product Usability

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Abstract. Users of consumer products have benefited from companies' growing interest in seeking technological innovation to improve their competitiveness and business performance. In this context, interface design represents an essential task in the product process development to directly influence customer satisfaction and, consequently, the success of the product in the market. Usability is about the product ease of use so it is necessary first and foremost to know who are the user / consumer and what their levels of requirements to serve them efficiently, this research has come to play an important role in interface design. Virtual reality (VR) technologies provide novel and enhanced modes for human computer interaction that can be used as a potential tool to provide product user experience and usability evaluation are more efficient, even in the early stages of the product design. This paper presents a conceptual approach to virtual reality technologies application in the evaluation of usability in consumer product design.

Keywords: Product design, product development process, usability testing.

1 Introduction

as a developing technology, has mainly been investigated and applied to advance in the fields of medicine, engineering, education, design, training and entertainment, analyzing their advantages and benefits [10] [11] [20] [42] [47]. The automotive industry, for example, adopted commercial applications and has benefited from the possibilities of VR and virtual prototyping [16] [52]. According to Sherman and Craig [48], Virtual Reality is defined as:

"A medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world)".

In this paper, consumer product has been used just like any three-dimensional object configuration, intended for personal, family or household application in both a home and social environment, and that has gone through a process of conception, design and development project for an industrial manufacturing mode.

Product development is the transformation of the market opportunity to a product available for sale [27]. It takes several stages during the design process to ensure the

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final product success in the market. In order to systematize the development process, each company adopts itself a workflow, with the objective to organize and coordinate all project activities.

According to Acosta et al [1], companies identify everyday usability as a strategic factor in competitiveness, efficiency, differentiation and good practice in due to integrate in all different processes of the product development cycle. Usability is about the product ease of use so it is necessary to know who are the users/consumers, their needs and requirements so as to serve them efficiently.

During the product design development, usability tests are usually performed in the prototyping phase that corresponds to process of construction, modification and testing of prototypes until the final volume production starts. Corresponds to a fundamental activity to structure innovation, collaboration and creativity to design and can make the difference for the product launch in the market [31].

However, during the usability tests, many assessment tools are limited as they do not provide the means for detecting problems that may occur in real world usage because laboratory tests are only simulated use cases of the product. Therefore, extensive research is needed to investigate the efficiency and effectiveness of assessment tools based on up-to-date advanced computer technologies, in order to provide better support for product design throughout the development process [51].

To meet current needs, virtual reality (VR) has emerged as an option to reconcile the advantages of field and laboratory studies because it enables the user to interact with the product in a context similar to the real situation, while allowing the researcher to have full control over the variables and safety conditions [39]. Mahdjoub et al [33], point out the need to integrate these technologies with a designer's knowledge in order to be more efficient in promoting the usability of the product even at the early stages of the design process.

Driven by this challenging statement, this research gives an overview of the application of VR technology to evaluate the usability of consumer products. Aimed to investigate new possibilities that VR offers the product development process. First, the concept of virtual reality is presented along with its contribution to product design, as well as it advantages and drawbacks. Second the concept of usability and usability testing are presented.

2 Virtual Reality

The technologies that incorporate Virtual Reality began to be developed in the sixties, however, only the late nineties became available for industrial use. From the multiple peripheral devices, such as motion capture systems and haptic interfaces, provides an immersive work environment with different ways for interaction between the user and the system. Virtual reality is a high quality computer-user interface that involves simulation in real-time and interactions through multiple sensory channels. These sensory modalities are visual, hearing, tactile, smell and taste [9].

According to Thalmann [46], VR represents a technology able to transfer a person to a different environment without the need to move it physically. For this purpose, the user's sensory organs are manipulated such that the perception is associated with the desired virtual environment. A computer model based on physical descriptions of the virtual environment controls the manipulation process.

Based on the above factors, VR is both interactive and immersive, which are also known as the two *I*'s. In addition, for a proper simulation performance, required a good human imagination, which corresponds to the third '*I*'. Burdea & Coiffet [9] suggest that VR is the integration of three vertices (I^3) - immersion, interaction and imagination. The imagination portion also refers to the mental capacity to realize things that do not exist. Gutiérrez et al [17], point two main factors to describe the experience in VR from the physical and psychological user point of view: immersion and presence.

2.1 The VR Vertices

Immersion is a key issue in VR systems, because it is fundamental for the paradigm where the user becomes part of the simulated world instead of the simulated world being a characteristic of the real world [46]. The first "immersive VR system" was the flight simulator, where immersion is achieved through a subtle blend of real hardware and virtual image. Gutiérrez et al [17] have classified the types of immersion based on the physical configuration of a VR user interface: fully immersive (head-mounted displays - HMDs), semi immersive (large projection screens), and no immersive (desktop – based VR). The level of immersion is measured by the ability of users to interact and communicate with the object in virtual reality in a similar way how he/she interacts and communicates with objects in the real world. Thus, with the less perception (see, hear, touch) of the real world, the level of immersion in VR will raise [17] [49].

In this context, several devices can be used for visualizing VEs. A HMD (Head-Mounted-Display) is used in an immersive manner. To capture users' movements and actions (user inputs) devices are used such as motion trackers and sensing gloves. These devices have built-in sensors that enable the computer to measure the position of the user's hand in real-time and to record the flexion of the fingers to enable natural gestures to be recognized.

Bochenek and Ragusa [5] highlight the need to select an appropriate VR system, since aspects like the feeling of immersion have an important role in design activities. The semi-immersive system is relatively easy to use and more accessible, but the degree of immersion can be low. On the other hand, immersive VR systems (e.g. HMD devices or CAVE) has a greater degree of immersion. However, depending on the level of quality required, the equipment can be expensive and, in the case of the CAVE, require adequate space, being more utilized by large corporations.

Interaction is connected with communication between user and VR system. It is defined for the capacity of detecting user motions and actions (user inputs) and refreshing virtual environment. Some of the main devices used for real-time interactivity are motion trackers and haptic devices (sensing gloves). The gloves are mainly required for tasks involving the manipulation of objects.

Imagination is related to the user's capacity to perceive nonexistent things and the will to believe that he or she is in the VE, even while knowing he or she is physically situated in another environment [9]. Thus, the interactivity and immersion levels experienced by the user directly affect his or her imagination, which in turn is dependent on the type of equipment used, the degree of realism of the VEs, the tasks to be performed while in the VE, and the user's motivation to participate in the simulation [40].

Presence corresponds to the subjective concept that the user perceives there is in a Virtual Environment (VE). Presence is achieved when the user, deliberately or not, becomes conscious of being in a VE. For this, is necessary that multimodal simulations (images, sound, haptic feedback, etc.) are processed by the user brain and understood as a coherent environment in which he or she can perform some activities and interact [17].

Witmer & Singer [50] defined the sense of presence as "the subjective experience of being in one place or environment, even when one is physically situated in another." The authors also developed a Presence Questionnaire (PQ) to measure the sense of presence in a VE. This PQ consists of 32 questions measuring the qualities of different sensory interfaces (e.g. auditory, haptic and visual interface) as well as the ease of manipulating objects inside the VE. Slater [45], argued that the PQ was only measuring the qualities of immersion and not the sense of presence.

Slater [45] defined the sense of presence as "the belief that they (participants) are in a other world than where their real body are located. A comparison between Slater's and Witmer & Singer's definition indicates a difference in the use of 'belief' rather than 'subject experience' to describe the sense of presence.

Involvement is related to the user's concentration inside the VE. Thus any external factor distracting the user can affect his or her involvement [40].

3 Contribution of Virtual Reality to Product Design

In the product design, VR can be applied in almost all stages of product development, but in prototyping phase greatest benefit can be obtained [6] [30] [43]. However, few studies address consumer products [3] [7] [39], in particular usability tests of the product interface with virtual prototypes. Prototype, or mock-up involves a scale model, often full size, of a product. It is used for studying, training, testing, and manufacturability analysis. As Jimeno & Puerta [22] indicated, Prototypes can be classified according to the way they are generated:

- *Physical prototypes*. Traditionally, material is taken from an initial block by means of a variety of processes. The result of the process is a physical prototype in wood, clay, foam or metal although it does not necessarily posses the same properties as the finished product.
- *Virtual prototypes (VP).* The VP or computational prototype is generally understood to be the construction of product models by computer, frequently in a VE. This makes its assessment in a simulated functional context easier, without the need to manufacture the product first.

In design practice, the product development is based on CAD (Computer Aided Design) for building and automation of three-dimensional models. VP does not have to use VR. But the use of VR technology brings a new paradigm for CAD community. It allows designers to visualize, analyze, optimize and implement product at full size, to change its geometric configurations and modify its characteristics, without physical objects, taking full advantage of VPs; as opposed to the regular tools used by designers such as cross-section views or layout drawings for example [6] [12] [30] [39] [51] [53]. Designers can also put themselves in the place and point of view of future users of the product being designed [3].

Using three-dimensional digital models in immersive environments, with different design alternatives, can be manipulated directly by users, allowing feedback and better creativity of developing concepts. Also customers can make decisions with the help of virtual prototypes in order to avoid development mistakes. In addition, user-typical scenarios can be easily simulated in VR (e.g. the use of the future product in a home or office environment).

Furthermore, the solution and design can be made interactively and easily than if the object were physical, which means more prototypes alternatives can be tested, which would be financially viable [53]. The early representation of future products significantly helps to shorten the time-to-market and thereby to gain competitive advantages. The high complexity of technical products can be simplified by presenting only relevant aspects in virtual models. Thus, Virtual prototyping becomes up-to-date concept in design as it reduces the time and cost in product development cycle [4] [36] [38].

Physical models, which were a common evaluation option in several industries for a long period of time, are expensive and hard to produce. They are nearly invariable so single prototype have to be produced for every design variation even if only few changes in product data have to be visualized. Consequently it can bring negative consequences for the product competitiveness in terms of cost and time to manufacture [12] [39] [51].

Despite the above mentioned benefits, sometimes a virtual prototype is less preferable as compared to a physical prototype. Liu [31] cites some customer's preference to interact with a physical prototype in testing about the ergonomic aspects of a product. Thus, both physical and virtual prototypes have important roles for the design, and advantages/disadvantages in different ways. According to Grimm [15], VR should not be seen as competitive technology, but as complementary. Significant researches have been done in this area but further researches are needed to provide an impact on VR systems development [14] [26] [31] [44].

For interactions with virtual prototypes, the motion and behavior of virtual objects should be realistically simulated besides realistic visual feedback. That involves the human hand, as in the case of performing operations in the real physical world. Dataglove provides the possibility of tracking the user's finger motions [19] [22]. This kind of device is made up of sensors that measure the movement of each finger. It has been used as a main kind of VR input devices [8] [29]. Some of these gloves also work with 3D trackers to find the position of the user's hand.

Although having advantages for the development of consumer products, the VR systems are not free from problems and limitations, this is partly caused by: display devices, such as limited field of view and/or low image resolution offered by some HMDs; as well as the interaction devices, such as haptic feedback, involving sensations of weight and shape [6] [7] [9] [13] [38] [51]. It is supposed that the main problem of these limitations is related to the technology quality and stability, because this sort of devices are commercially available with different degrees of technical sophistication.

4 Usability and Usability Testing

The usability concept was introduced by Shackel [41], and is well-known and well-defined as to the approach of Human-Computer Interaction (HCI). This aims to develop transparent interfaces, capable of enabling an interaction easy, pleasant, effectively and efficiently, allowing the user full control of the environment without becoming an obstacle during the interaction [37]. These concepts are applied to enhance the software-user interface [37]. The importance of this dimension in product design was first considered in the early 1990's by companies such as Thomson Consumer Electronics, Apple Computer and Northern Telecom [34]. Since then usability has been applied on a large scale for the design of products easy to use, understandable, accessible and comfortable [18] [23] [25] [28] [32] [35].

The definition of usability is sometimes reduced to 'easy to use', but this offers poor information about the user interface. From a concept better known, usability is defined as the ability of a product or system to be used in an effective, efficient and enjoyable way by a specific range of users for tasks that need specific tools within a given environment. ISO 9241-11 [21] sets out the most classic and recognized concept of usability, "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*".

Effectiveness refers to the extent to which an objective or task is reached. Effectiveness measures the relationship between the results obtained and the desired goals, i.e. to be effective is to achieve a given objective. Efficiency refers to the amount of effort required to achieve an objective. The lower the stress, the higher the efficiency.

Satisfaction refers to the level of comfort that the user feels when using a product and to what extent the product is acceptable to the user in relation to achieving his/her objectives. As it is more closely linked to subjective factors, this aspect can be more difficult to measure than effectiveness and efficiency [24].

Barnum [2], indicated that satisfaction was clearly important when the ISO standard was developed and has become the most important measure of usability today. That's because users expect products to be usable, and if the product meets the users' expectations for satisfaction they will not resist, repel, or even rebel against using the product.

In order to measure the level of satisfaction of the user, as well as effectiveness and efficiency, usability testing is needed. This allows the designer to see what people actually do, what works for them, and what doesn't, not what he or she thinks they would do. According Nielsen [37], "*your best guess is not good enough.*" That's why usability testing is essential. Usability testing refers to activity that focuses on observing users working with a product, performing tasks that are real and meaningful to them [2]. The testing can be subdividing into two types, depending on the point at which it is done and the goal for the study:

- *Formative testing* – while the product is in development, with a goal of diagnosing and fixing problems, typically based on small studies, repeated during development.
- *Summative testing* – after the product is finished, with a goal of establishing a baseline of metrics or validating that the product meets requirements; generally requires larger numbers for statistical validity.

Based on what was discussed in the previous section, during a usability testing the virtual prototype should be viewed, listened, and touched by all the actors involved in its design, including the potential users, as if it was a real physical product. This is where VR can play a significant role since it can allow different alternative solutions to be evaluated and compared in quite a realistic and dynamic way, not only visually but also considering other interaction aspects such as sound and forces. From stereoscopic visualization and haptic feedback, VR simulation provides a more realistic interaction with the prototypes than possible with CAD prototypes [38] [39].

5 Conclusion

In the development of a product, usability tests must be part of a design methodology. Physical prototypes are usually used to perform the tests, which are expensive and difficult to modify. The use of virtual prototypes can solve this limitation. VR, when framed in the contexts previously described, has the potential to overcome such problems, allowing a better communication between designers and users.

In sum, when compared with conventional three-dimensional models, VR definitely has many advantages for the usability evaluation of product. The resources of VR technologies are potentially infinite. The application of VR in the evaluation and design of products is vast and can offer benefits in terms of usability and cost savings. It is believed that the continuing exploration of new technologies and their integration with their application to design will result in the further evolution of product design evaluation systems that are more compatible with the needs of designers and users. It is expected that in the near future, product design based on a VR environment may provide better visualization of the product, thus enabling the designer to coexist in the same virtual space and providing a better appreciation of the geometry and aesthetics of the product.

Given the above, this paper was motivated by the studies that been applied in the *New Technologies Laboratory* at Federal University of Pernambuco. The group has been investigating the efficiency and effectiveness of VR evaluation tools based on technological advances, to provide a better designer support throughout the product development process.

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