Toward an Evaluation Model of User Experiences on Virtual Reality Indoor Bikes

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Abstract

This paper deals with deriving a model or framework to evaluate user experiences (UX) of virtual reality (VR) systems, especially, VR indoor bikes which are under construction. Recently, VR is one of the most appealing areas attracting people's interests around the world. Many products armed with it increasingly emerge on the market, and it is expected that the use of VR systems will continue to increase sharply in the future. However, UX of such products cannot be evaluated appropriately at the moment due to a lack of proper evaluation models.

In a broad sense, UX that may stem from human machine interface in ergonomics covers affect, usability, and user value in spite of some differences in definition among the researchers. While evaluations of UX on the–products without VR have been overall justifiably performed, UX has been evaluated neither systematically nor strictly on the products with VR.

Through the analyses of expert reviews, we newly identify an additional component and its elements, and modify some elements of the three existing components for evaluating UX on the VR systems. As a result, we propose a comprehensive evaluation model of UX, which consists of four factors: usability, affect, user value, and presence feeling. In addition, we determine the components and their elements for specific VR indoor bikes similarly through the analyses of expert surveys and focus-group discussions, which results in developing a questionnaire for users. Finally, along with the questionnaire, we propose a specific evaluation model for VR indoor bikes.

Keywords: User Experience, Virtual Reality, Bike, Evaluation

Introduction

Recently, virtual reality (VR) is one of the most appealing areas attracting people's interests around the world. A lot of studies have been conducted on technology of VR and its integration with existing products or industrial fields such as game, golf, education and so on. As a result, we can easily see the VR products such as head-mounted displays (HMD), HMD-based games, VR museums, VR education systems, etc. Probably HMD plays a very important role in facilitating the proliferation of virtual systems.

However, the virtual systems are totally different from the traditional products from the perspective of user satisfactions including efficiency and effectiveness. Incidentally, in order to maximize user satisfaction, so many guidelines have been developed on the traditional products. It is unfortunate that we cannot apply these guidelines to the virtual systems directly and completely. We suggest that there are two reasons for this. One is that users tend to value their complicated feeling or experience rather than just satisfaction. The other is that virtual systems have unique and complex features such as presence feeling or motion sickness unlike the traditional products.

It seems that the first reason is closely related to the history of man computer/machine interface or user interface. User interface issues have been changed to the area of usability or usability engineering even if their terminologies are used interchangeably (Shneiderman & Plaisant, 2005). As the level of people's living is getting higher and products have a shorter life-cycle due to new technologies, usability seems to be evolved into the area of user experience (UX). UX broadly describes all aspects of interactions between a user and a product (Kuniavsky, 2007; Marcus, 2006). Even though UX has not been defined clearly, it covers affect, usability engineering and user value (Park et al., 2013). As many researchers make their effort on UX and identify its value or importance, its concept has been applied to designing real applications. For example, most corporations in the Korean mobile industry have established UX departments or groups.

However, it is relatively hard to find studies related to the usability or user experience on the virtual systems because of their short history. Even if Gabbard (1997) comprehensively introduced taxonomy on usability of VR, he did not explain UX. Recently, attempts have been made to evaluate UX of the virtual systems (Allen, 2015; Chu, 2014). However, most of the researchers are trying to improve the technology rather than to focus on user experience or usability. For example, Chu (2014) claims that the stereoscopic effect will be lost if objects are placed further than 20 meters away from the user. In that sense, the studies on the matter are technology-oriented, which suggests a lack of comprehensive or systematic studies on the evaluation of UX. That is why we need to develop a model for evaluating user experience of the virtual systems.

The second reason is that primary success factors of VR systems depend on presence feeling and simulator sickness. Additionally, these factors should be reified or refined in more detail for the purpose of evaluating them. Thus it is necessary to modify existing taxonomy of UX (Park et al., 2013) for evaluating UX of virtual systems.

As far as evaluation is concerned, it is important to consider the trend that users value their experiences on the product and services and the characteristics of the virtual systems at the same time. The objective of this study is to develop a loosely-coupled framework or model to evaluate UX of virtual systems and a specific model to evaluate UX of virtual bikes.

The frameworks are derived from existing studies, expert reviews and expert surveys. Existing studies are described comprehensively in the next chapter. Expert reviews include heuristic evaluation, guideline review, consistency inspection, cognitive walkthrough, and formal usability inspection (Shneiderman & Plaisant, 2005). We asked a few experts to analyze virtual systems in terms of user experience. They analyzed a family of interface heuristics and guidelines on general products, virtual systems, and bikes, and then verified their consistency. A new group of experts were chosen to obtain a tightly-coupled framework or model to evaluate a specific VR product, which helped us build user questionnaire items which reflect UX of the VR product. Detailed process and its contents that experts are involved are introduced later.

VR Systems and their Usability

As we mentioned earlier, human computer/machine interface issues may be melted into usability engineering. ISO standard 9241-11 describes usability as the extent to which a product can be used by specific users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. Unlike the first two goals, satisfaction is quite subjective for most of the practical evaluations and measured simply by interviews or by written surveys that include satisfaction scales. Every designer would like to achieve all of the goals, but there are often forced tradeoffs. Even if the standard is criticized due to the fact that it does not tackle all aspects of security and learnability, it considers the importance of specificity of users, users' goals, and environment in establishing usability.

Usability was originally defined as the efficiency and effectiveness of user interface (Hix & Hartson, 1993). User interfaces are mainly concerned with displays and controls in designing products and systems. Guidelines for visual and auditory displays and those for making various controls have been successfully applied to design products for a long time (Huchingson, 1981; McCormick & Sanders, 1982). The guidelines are too enormous to enumerate them all here. Instead, let us exemplify more fundamental and abstract principles than guidelines related to the interface. The eight principles called "golden rules" derived from experience and refined over two decades are applicable in most interactive systems, even if these are not complete and need tuning for specific design domains (Shniderman & Plaisant, 2005). These principles include striving for consistency, catering to universal usability, offering information feedback, designing dialogue to yield closure, preventing errors, permitting easy reversal of actions, supporting internal locus of control, and reducing short-term memory load. Another principle is very well known as Nielsen's 10 usability heuristics (Nielsen, 1994). The heuristics include (a) visibility of system status, (b) match between system and the real world, (c) user control and freedom, (d) consistency and standards, (e) prevention of errors, (f) recognition rather than recall, (g) flexibility and efficiency of use, (h) aesthetic and minimalist design, (i) helping users recognize, diagnose, and recover from errors, and (j) provision of help and documentation.

As far as interface is concerned, VR systems are totally different from traditional products. They should consider issues such as physiological factors, immersion and stereoscopy, navigation and orientation, and so on (Gabbard, 1997; Kaur, 1998; Stanney et al., 1998). Many guidelines and principles are adapted and modified for appropriate and usable designs of VR systems. Gabbard (1997) and Gabbard et al. (1999) provided us with an informal set of 195 usability guidelines. These guidelines were organized as taxonomy of usability characteristics in virtual environments (VE). It consists of users and user task in VEs, the virtual model, VE user interface input mechanism, and VE user interface presentation components. Interesting to see is that the taxonomy is very similar to an ergonomic model consisting of user, task/product, display and control.

Another study is Steed and Tromp (1998) in which they have adjusted Nielsen's heuristics. They added the interpretation that flexibility is needed in navigating the virtual environment for user control and freedom among the heuristics. They also stated that focus should be on efficiency of use rather than flexibility for their project, and that excessive minimizing would impair the experience of that environment regarding aesthetic and minimalist design. Finally they added that awareness of other participants may be important on virtual environments where various participants meet in a virtual world. However, Steed and Tromp's (1998) modifications are rather specific to their project which makes wider application of them seem difficult.

Kalawsky (1999) presents the method of VRUSE, which is an adaptation of the MUSiC framework for usability evaluation, for evaluating VR systems. The tools that MUSiC offered were found to be suitable for 2D text and point-and-click desktop applications, but not applicable for a VR system. VRUSE itself is a ten-part questionnaire in which each part addresses a key usability factor in an interface. Ten VR usability factors include (a) functionality, (b) user input, (c) system output (display), (d) user guidance and help, (e) consistency, (f) flexibility, (g) simulation fidelity, (h) error correction/handling and robustness, (i) sense of immersion/presence, (j) overall system usability. It is natural that the factors partly overlap with the standard usability heuristics of Nielsen.

It is observed that most of the studies in VR systems depend on project or tasks to evaluate their usability. Thus we need to concentrate on VR bikes to identify factors affecting their usability. The effort we made is given in the next section. Through the review of existing studies, however, we found that they fail to consider UX of VR systems, which is very valuable in selecting them from the user's point of view.

User Experience

UX has been widely studied in a recent decade even though it still has not been generally accepted by researchers (Chamorro-Koc et al, 2009). The concept of UX includes affect or usability engineering (Hassenzahl & Roto 2007). ISO standard 9241-210 describes UX as users' perception and response that has resulted from the use or the anticipated use of a product, a system, or a service, but its definition is not clear (Law & Van Schaik, 2010). Several attempts have been made to define UX universally. Hassenzahl et al. (2006) found that UX is an outcome reflecting the user's internal state, the system's characteristics, and the context of use. Law et al. (2009) found that UX is something individual that emerges from interacting with a product, system, service, or object. Most researchers agree with these two studies, but its concept clearly covers more than usability and affect (Horn & Salvendy, 2009; Law & Van Schaik, 2010). Park et al. (2013, 2014) indicate that there are two limitations for evaluating UX. One is not to identify additional factors that may directly influence UX, and the other is a lack of systematic methods for evaluating UX.

Incidentally, factors that contribute to UX have rarely been systematically addressed in UX research. Park et al. (2013, 2014) considered user value one of the most important elements that influence UX. They developed a framework, which includes usability, affect and user value, to evaluate UX of the mobile phones. We found that even if it is based on the specific product, it includes considerably general or comprehensive UX.

There is no doubt, so far, that many researchers are mainly concerned with usability among these three factors. Usability focuses on effectiveness and efficiency of the three major dimensions that ISO stipulates in order to match service quality dimensions. It is necessary, however, that satisfaction, the last of the main dimensions, should be elaborated for affect and user value that users are recently more interested in. Affect and user value should be reified or refined in terms of UX in order to evaluate them more strictly and accurately.

Park et al. (2013, 2015) made great contributions in that they interpret these factors from the perspective of UX. As far as usability is concerned, it consists of simplicity, directness, efficiency, informativeness, flexibility, learnability, and user support. While affect consists of affective words representing customer’s feeling, user value may be related to how meaningful and significant the user thinks the product is in his or her life. Incidentally, affect includes elements such as delicacy, simplicity, texture, luxuriousness, color, and attractiveness. User value includes elements such as self-satisfaction, pleasure, sociability, customer need, and attachment.

UX of VR to date has received very little attention in VR literature. While awareness of the need for UX evaluation of VR appears to be on the rise, the techniques needed to perform efficient, meaningful UX evaluation of VR are not yet available. With the recent release of head-mounted displays (HMD) and VR sets such as Oculus Rift, Samsung Gear VR, and Google Cardboard, VR may make a big leap in VR applications. ICAROS at CES 2017, which is a system to fly through virtual worlds, play games and exercise the body at the same time, attracted a lot of attention. A Virzoom bike has been even successfully commercialized after showing at CES 2016. As the fundamentals of UX in VR, Allen (2015) found that for the proper user experience, VR systems need more elaboration on comfort, interface, sound and music, movement, interaction, normal maps, and so on. However, Allen’s description is not so specific, but it helps us to derive specific elements of VR systems.

Even if there are general characteristics for evaluating VR systems such as FOV, sense of depth, frame rate, and so on, which are technology-oriented rather than UX, it is found that UX tends to be dependent on the specific product. Consequently, we have to concentrate on both UX and VR bikes. Although the Virzoom bike was recently commercialized, it may expose a lack of presence, which is very important for UX, by focusing on game-oriented features such as no leaning motion, various control buttons around the grip of handles, and so on. To make it worse, related articles on the bikes are rarely found. Kim et al. (2002) investigated the influencing factors of balancing posture by measuring the parameters such as path deviation, driving velocity, center of pressure, and average weight shift.

They found that continuous visual feedback by weight shift was more effective than no visual feedback in the postural balance control. Even though the study was executed on a monitor-based VR bike simulator without HMD and was focused only on effectiveness of the bike, it gave us a great amount of clues to define UX of VR bikes along with the Virzoom bike.

A Proposed Model for Evaluating UX of VR Indoor Bikes

Many in-depth studies have been carried out on UX of products without VR. Among them Park et al. (2013) shows a hierarchical structure on it even if the research focuses on the mobile phone. We consider it very valuable because it also includes most of UX for different products. UX structure consists of three main elements of usability, affect and user value, and their sub-elements.

On the other hand, it is observed that VR systems have characteristics of unique UX while partly sharing those of UX of products without VR. It is worthwhile to note that primary success factors of the VR systems depend on simulator sickness, which belongs to affect, and presence feeling. Thus it may be necessary that the two important factors be reified or refined for the purpose of evaluating UX of the two in more detail. Simulator sickness represents symptoms very much like those associated with motion sickness such as dizziness, postural disequilibrium, and even vomiting.

As far as presence feeling is concerned, Waterworth et al. (2015) define it as the feeling of being located in a perceptible external world around the self. It is inferred that as we process more abstract, conceptual information, we can consciously sample fewer concrete aspects of the present situation, and so our **s**ense of presence diminishes. We can share external worlds in which we feel present, but we cannot share imagined worlds in the same way (Waterworth & Hoshi, 2016). Immersiveness, the state of consciousness where an immersant's awareness of physical self is diminished or lost by being surrounded in an engrossing total environment, may be related to the latter.

Through the analysis of expert reviews, we propose a loosely-coupled framework combining UX of products without VR with that of specific products with VR. As the framework implies, it has two important characteristics: sufficiency and flexibility. It is sufficient enough to comprise detailed experiences of both Non-VR and VR systems. Being more general, the framework is also flexible enough to accept unique experiences of different VR systems. In the case of a specific VR product, it is natural to fill the detailed elements of the general structure, which are specific and unique experiences for the product. At least a domain expert is needed to fill the elements into the loosely-coupled framework. Through the evaluation of expert surveys on a questionnaire based on the specific VR system, it may become a tightly-coupled framework or model, which helps us develop a questionnaire for users.

Incidentally, three experts who have expertise in the fields of ergonomics, bikes, and VR were employed to find the basic elements of the loosely-coupled framework, which becomes a basis to develop a questionnaire for experts. They intensively reviewed design guidelines, heuristics, principles, and taxonomy derived through the studies on VR, UX, and different products and then tried to reorganize them into a framework. Note that these results were validated comprehensively through existing research. As a result, the framework initially contains presence feeling and its sub-elements as well as usability, affect and user value, and their sub-elements. While adopting the sub-elements of usability and user value as they are, we newly added immersiveness and sickness of affect, and presence feeling. Note that presence feeling, unlike usability and user value, consists only of displays, controls, and environments without defining their respective sub-elements. The sub-elements of presence feeling should be elaborated by a domain expert(s) before executing expert surveys. Figure 1 shows the loosely-coupled framework elaborated with a few domain experts. Of course, their UX elements may not be mutually exclusive, and it is hard to separate them from each other.

Through the analysis of the expert surveys based on a specific product, however, a final version of a tightly-coupled framework on the product was constructed, which results in developing a questionnaire for users. Figure 2 shows a VR bike that we use for our experiment (HMD and the screen not included in the figure). In order to obtain the tightly-coupled framework, we need a domain expert(s) for the bike to refine or elaborate sub-elements of displays, controls, and environments that belong to presence feeling, which may be a bottleneck for various VR systems but can be helpful by using the loosely-coupled framework. As a result, it leads to form an initial version of the tightly-coupled framework, which results in developing a questionnaire for a group of experts. 12 experts who have expertise in the field of ergonomics, bikes, and VR were given the questionnaires developed by the initial version of the framework. They expressed their ideas freely by adding and deleting items while marking down their validity on each question item. Focus-group discussions are valuable to ascertain the universality of the user's comments (Kuhn, 2000). After we conduct the discussions on the modifications they made, the tightly-coupled framework is finalized except a validity test regarding expert opinions.

For the purpose of the validation test, content validity ratio (CVR) developed by Lawshe (1975) was used to judge the most effective factors or elements.

Table 1 exemplifies CVR values of affect and presence feeling with the cutoff value of 0.56 for validating question items. Similarly, through the review of those of usability and user value, Figure 3 shows the final version of the tightly-coupled framework or model for the VR indoor bike. Through the comparison of Figures 1 and 3, we can notice that there are some modifications on all of the components. As a result, Figure 3 helps us derive a user questionnaire very easily. Suppose, for example, that we would like to obtain a user's UX for a sub-element 'Attractiveness' of affect. Then simply ask the user to answer how valid the question is as to 'User's perception that a product/service is pleasing, arousing, interesting, and attractive' on a 5-point scale. This way makes it possible to evaluate the UX of VR systems very easily and systematically.

In summary, the processes from which this study seeks to derive the user questionnaire consist of expert reviews (general classification and refinements), expert surveys, focus-group discussions with experts, and a validity test.

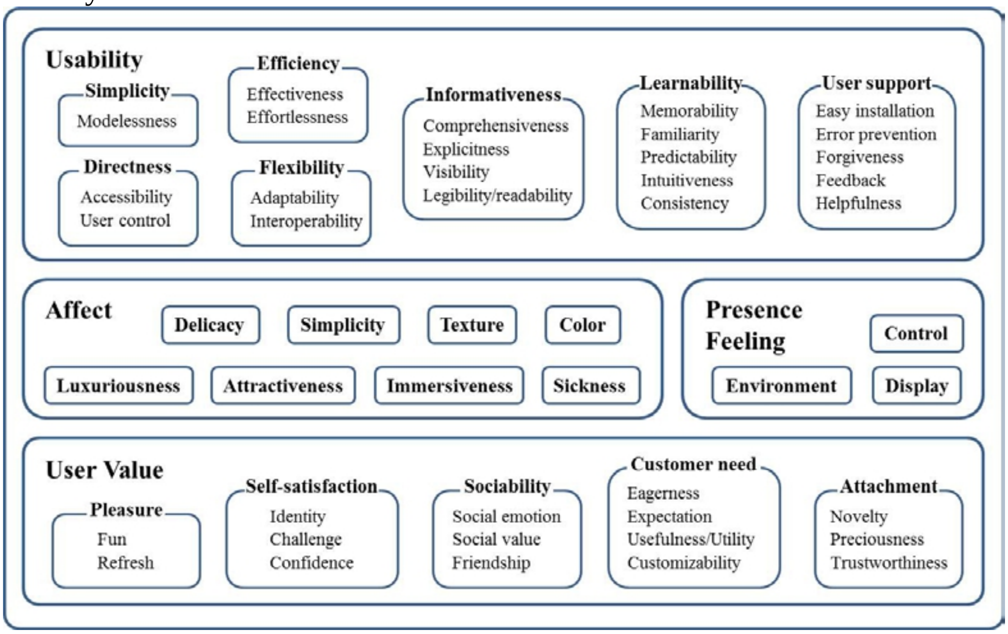

Figure 1. A Loosely-coupled Framework for UX of VR Systems

Figure 2. A Prototype of a VR Indoor Bike

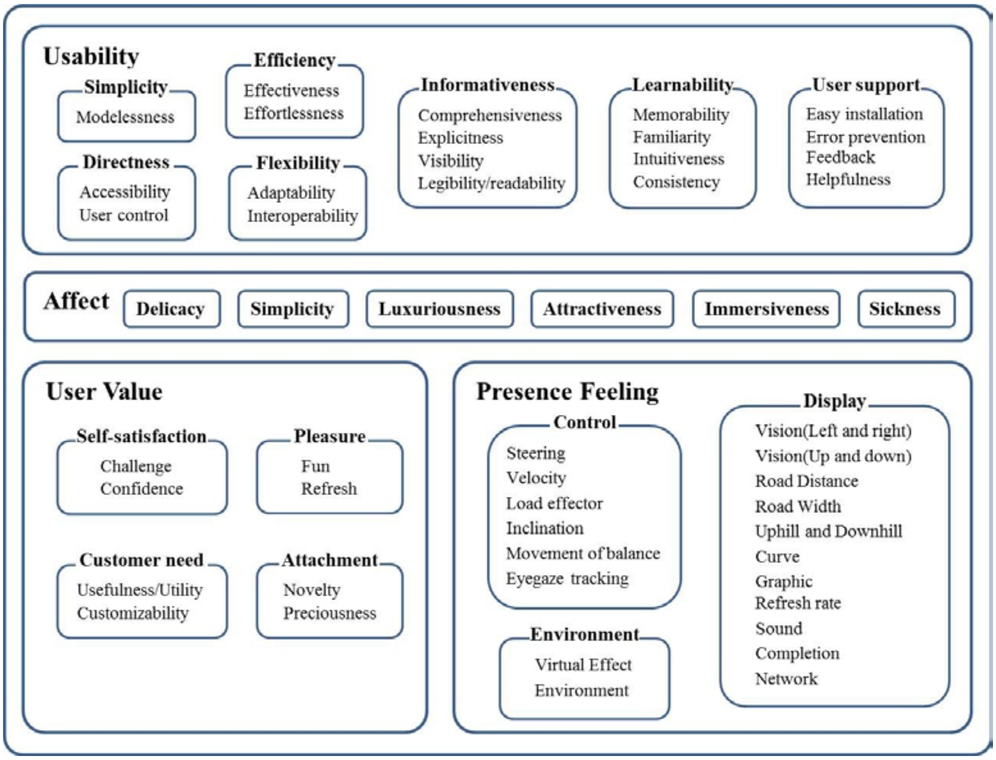

Figure 3. A Tightly-coupled Framework for UX of a VR Indoor Bike

TABLE 1. CVR Values of Sub-elements

(a) Sub-elements of Affect

Element	Sub-element (Before)	Avg	Med	Ne	CVR	Sub-element (After)
Delicacy	Delicacy	4.33	4.5	10	0.67	Delicacy
Simplicity	Simplicity	4.42	4.5	11	0.83	Simplicity
Texture	Texture	3.92	4.0	8	**0.33**	-
Luxuriousness	Luxuriousness	4.58	5.0	11	0.83	Luxuriousness
Color	Color	3.58	3.5	6	**0.00**	-
Attractiveness	Attractiveness	4.25	4.0	11	0.83	Attractiveness
Immersiveness	Immersiveness	4.58	5.0	11	0.83	Immersiveness
Sickness	Sickness	4.67	5.0	12	1.00	Sickness

(b) Sub-elements of Presence Feeling

Element	Sub-element (Before)	Avg	Med	Ne	CVR	Sub-element (After)
Control	Steering	5.00	5.0	12	1.00	Steering
	Velocity	5.00	5.0	12	1.00	Velocity
	Load effector	4.75	5.0	11	0.83	Load effector
	Inclination	4.75	5.0	12	1.00	Inclination
	Movement of balance	4.92	5.0	12	1.00	Movement of balance
	Eyegaze tracking	4.00	4.0	10	0.67	Eyegaze tracking
Display	Vision (Left and right)	4.67	5.0	12	1.00	Vision (Left and right)
	Vision (Up and down)	4.67	5.0	12	1.00	Vision (Up and down)
	Road distance and width	4.75	5.0	12	1.00	Road distance and width
	Uphill and downhill	4.67	5.0	12	1.00	Uphill and downhill
	Curve	4.58	5.0	12	1.00	Curve
	Graphic	4.67	5.0	11	0.83	Graphic
	Refresh rate	4.50	5.0	11	0.83	Refresh rate
	Sound	4.50	5.0	11	0.83	Sound
	Completion	4.67	5.0	12	1.00	Completion
	Network	4.83	5.0	12	1.00	Network
Environment	Virtual effect	3.67	4.0	10	0.67	Virtual effect
	Environment	3.75	4.0	10	0.67	Environment

Conclusion and Discussion

UX is concerned with experience that occurs when a user interacts with a product or service. First of all, we developed a loosely-coupled framework for evaluating UX on VR systems through the analysis of the expert reviews. It consists of usability, affect, and user value with concrete elements and presence feeling with rough elements. Through experts' reviews, surveys, and focus-group discussions on the framework, we derived the tightly-coupled framework for evaluating UX of VR bikes. It consists of four components with concrete elements, though some of the elements were modified. The model validated through expert surveys helps us to obtain a series of questionnaire for users. The questionnaire provides us with a tool evaluating UX on the products.

We can utilize this evaluation tool in many ways. We can use it to diagnose the strength and weakness of prototypes or products under construction in terms of presence feeling, usability, affect, and user value and then to identify the problems easily. We can also utilize it to evaluate other brands of products comparing them. Additionally, the loosely-coupled framework can be used as a basis to develop a tightly-coupled framework for other VR products to evaluate their UX.

Although our model is a good starting point for evaluating VR systems, it offers no panacea for a thorough analysis. Of course, there may be no problem to evaluate various VR bikes. However, it has to be kept in mind that the loosely-coupled framework, thanks to its flexibility, has room to accommodate differences that various VR products can cause. A domain expert(s) should fill up the sub-elements of the three components of presence feeling, which should be verified by a group of experts. This is very similar to an approach of expert systems in artificial intelligence that was adopted to build them.

To evaluate how realistic the VR bikes are, the elements of presence feeling were reified and refined in detail. Even if our model is sufficiently capable of evaluating reality on VR bikes, it may be exposed to some limitation on the evaluation of other VR systems. It is important to note that the elements of presence feeling heavily depend on the product we want to evaluate. Thus for various VR products, it is better to focus on the presence feeling involved with their displays, their controls, and their environments.

This study stimulates a couple of further studies. First, it seems to be interesting to develop a single UX index for VR systems, which may help decision-makers understand them easily and intuitively. A similar study has been done to derive an overall UX index on the mobile device (Park, Han, Kim, Oh & Moon, 2013) Thus, it may be valuable to study quantification models that aggregate elements of UX of VR systems.

Not only will we need to make sure we have designed environments that make sense from a 3D spatial standpoint, but we need to make sure the VR bikes do not make users sick. When displaying VR with the use of an HMD, one of the most worrying aspects is the common experience of simulator sickness (Serge & Moss, 2015). Safety concern after riding VR bikes may even exist. The sickness is so important that we had better measure it more accurately using, for instance, simulator sickness index considering various symptoms such as headaches, nausea, dizziness, eyestrain and so on.

Finally, our results depend on the subjective judgements (whose accuracy we cannot claim with certainty) that users made for each element on the questionnaire. The judgement was assessed via fuzzy logic questions (Han & Kim, 2017; Kelaher et al., 2001) completed by all of the subjects at the end of each task. The method may help us to improve the quality of evaluation by considering subjective rating scores.

Acknowledgement

This work was supported by Institute for Information & communications Technology Promotion(IITP) grant funded by the Korea government(MSIP) (R0115-15-1003, Immersive VR MTB Game and Interlocking 5D Simulator Development).

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