Presence Factor Scale (PFS): a Method for Assessing Presence in Immersive Virtual Environments

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Abstract. *The effectiveness of a Virtual Reality (VR) experience is strongly affected by the sense of presence of the users involved. The methods already proposed to measure presence rely on user experiments specifically designed. Regardless of the effectiveness of such studies, carrying out user evaluation is extremely costly since it requires expert planning, adequate volunteer recruitment, compliance with ethical standards, long application periods, and statistical analysis of the results. As an alternative, this work presents a lower cost, faster and highly applicable presence evaluation method, the Presence Factor Scale (PFS), which eliminates the need for user evaluations and can be used as a set of guidelines in the design of new VR experiences.*

1. Introduction

The sense of presence is the feeling of being somewhere else, a virtual place different from the physical place where the user really is, which is strongly related to virtual environment (VE) effectiveness [Meehan et al. 2002]. In recent years, many research works related to presence have been developed, especially involving methods to measure it and the VEs characteristics that contribute to increasing the user's sense of presence.

The methods to measure presence are commonly divided into subjective and objective methods. The subjective ones are the most used, especially post-questionnaires. Apart from scale questionnaires, there are also some subjective observation techniques [Riva et al. 2014]. The objective methods use non-invasive capture of physiological data, such as heart rate, skin conductance, eye movement, and surface electromyography, obtained during the use of the VE [Riva et al. 2014]. In addition, some techniques have been proposed that use neurological measures [Clemente et al. 2014]. Because of this large range of approaches, there is still vigorous debate about how to best measure presence.

This PhD thesis presents a lower cost and highly applicable presence evaluation method, the Presence Factor Scale (PFS), which eliminates the need for user evaluations and can be used as a set of guidelines in the design of new VEs. The method was developed from an extensive systematic literature review [Souza et al. 2021], in which we identified many factors that affect presence. These factors are organized into three categories: Engagement, Personal Characteristics, Interactive Fidelity, and Sensorial Fidelity. We validated the PFS method following the recommendation of the Standards for Educational and Psychological Testing, which establishes that the evidence of validity can be based on test content, response processes, internal structure, relations to other variables, and testing consequences.

2. Methodology

This work was carried out in two major methodological stages, the first being the adequate understanding of the problem and the second the generation of a solution to the problem.

As sub-steps of understanding the problem, a systematic review of the literature was carried out (see Chapter 2 of the thesis and reference [Souza et al. 2021]), which allowed a complete understanding of the concept of presence in VR, as well as the identification of the different methods already proposed to measure it. In addition, it was possible to identify how such methods have been used in recent years, as well as their potential and limitations. As a contribution of the literature review stage, we identified 29 impact factors on the sense of presence. In the second stage of understanding the problem, five studies with users were carried out, involving more than 320 hours of user experiments, in which the main methods proposed to measure the sense of presence in VR were applied and evaluated (see Chapter 3 of the thesis). Such steps were essential for an adequate understanding of the concept of presence, and the potentialities and limitations of the methods already proposed to measure the sense of presence in virtual environments.

The next big step, solution generation, started with the development of a new method to assess the sense of presence in VR, which was based on the impact factors identified in the literature review. The next sub-step was the evaluation of the proposed method by specialists in the area, who made important contributions to the generation of the version that was then applied in the studies carried out in the stage of understanding the problem, with the objective of starting the validation of the proposed method. Then, the other validation steps were carried out, which made it possible to conclude that the proposed method is valid.

3. Presence Factor Scale

Different studies have reported both the characteristics of the system and of the users as the main impact factors of the sense of presence. For Schubert [Schubert et al. 2001], the system is only the raw material for the mind that constructs a mental world. Regarding the system characteristics, many aspects were pointed out as affecting the presence, such as field of view, update rate, feedback, stereoscopy, pictorial realism, image motion, visualization device (monitor, CAVE (Cave Automatic Virtual Environment), HMD (Head-mounted display), large screen, projector, etc), interaction (gloves, controllers, gesture, etc), spatial sound, tactile or olfactory cues and body tracking. On human factors, it is necessary to consider that people differ in a variety of ways, including psychological factors such as personality, cognitive abilities, cognitive style, domain-specific knowledge, and demographic factors such as gender and age. Thus, there are several ways in which the individual factors can influence presence experiences.

In this work, through the extensive literature review, we identified and classified 31 factors that influence user presence sensation. The correlation of these factors with presence was investigated and organized in four categories: Engagement, Personal Characteristics, Interactive Fidelity and Sensorial Fidelity.

Each factor identified in the literature has been thoroughly investigated for proper understanding and definition of its description and its possible variations in a virtual environment. Subsequently, for each variation, a score was determined, on a scale of 1

PRESENCE FACTOR SCALE

Category	Factor	Description	Variation	Score
Engagement	Inclusiveness	The extent to which physical reality is shut out	Select	0.0
	Narrative	History designed to be virtually experienced by the user	Select	0.0
	Attention	The extent the VE is holding the attention of the user	Select	0.0
	Emotion	Emotions (Anger, Sadness, Happiness, Disgust, Surprise, Fear) experienced by the user in the VE	Select	0.0
	Task	Action of doing something in the VE	Select	0.0
	Copresence	Feeling of being with another in the virtual environment	Select	0.0
				0.00
Category	**Factor**	**Description**	**Variation**	**Score**
Personal Characteristics	Personality	The characteristic way of thinking, feeling, and behaving	Select	0.0
	Cognition	The way individuals think, perceive, and remember	Select	0.0
	Imagination	Ability to imagine yourself in a not real place	Select	0.0
	Concentration	The ability of focusing one's attention or mental effort	Select	0.0
	Domain Knowledge	Similar experience in the task and environment simulated	Select	0.0
	VR Experience	Previous experience in virtual reality	Select	0.0
	Game Experience	Previous experience in digital 3D games	Select	0.0
				0.00
Category	**Factor**	**Description**	**Variation**	**Score**
Interactive Fidelity	Selection / Manipulation	Ability of the VE to be modified from user actions	Select	0.0
	Travel	Manner of traversing space in the virtual environment	Select	0.0
				0.00
Category	**Factor**	**Description**	**Variation**	**Score**
Sensorial Fidelity	Device	Body-mounted devices	Select	0.0
	Proprioception	Sense of self-movement and body position	Select	0.0
	Body Ownership	Sense of body ownership in the VE	Select	0.0
	Latency	Delay between action and reaction in the VE	Select (Select / Above 20 ms - Greater than 20 ms / 10 - 20 ms - Between 10 and 20 ms / 0 - 10 ms - Up to 10 ms)	0.0
	Transition	State change between the real and virtual world		
	Synchronization	Coordination between user actions and all VE outputs		
	Plausibility	The extent to which VE is considered acceptable or admissible		
	Visual Realism	To what extent the VE looks visually real	Select	0.0
	Field of view	The extent of observable virtual world at any given moment	Select	0.0
	Resolution	Number of individual dots that can be placed in a 1 inch line	Select	0.0
	Frame rate	Number of unique images shown per second	Select	0.0
	Audio	The way that the sound travels through the user's head	Select	0.0
	Haptics	Sense of touching or be touched by something in the VE	Select	0.0
	Olfaction	Sense of feeling the smells of the VE	Select	0.0
				0.0
			PRESENCE :	0.00

Figure 1. Presence Factor Scale Form

to 7, whose final average will indicate the sense of presence provided by the VE. The same scale as the SUS [Slater et al. 1994] questionnaire was used, as this is the most used method for measuring presence, which contributes to the preliminary validation of the proposed method. The initial score was determined empirically, based on the literature review, which was later calibrated in the method's validation steps. For the method application, an online form was created in which, for each of the factors, one can select the variation corresponding to the characteristics of the VE being analysed (see Figure 1). After selecting one range for each of the factors, the final average between the factor scores is calculated and presented, indicating the sense of presence provided by the VE (see Chapter 4 of the Thesis for more details).

According to Hutz, Bandeira and Trentini [HUTZ et al. 2015], to consider a subjective test valid, some requirements need to be met. Currently, the Standards for Educational and Psychological Testing is already in its fifth edition, and it states that evidence of validity can be based on the Test Content, Response Process, Internal Structure, Relations with Other Variables, and on the Consequences of Testing [AERA et al. 2014]. In this work, the validity were based on the content of the test, the response process, the internal structure, and the relationships with other variables. In addition, reliability validation was used, which refers to the stability with which scores are preserved in alternative applications of the same test or in different equivalent test forms [Urbina 2014] (Chapter 5 of the Thesis).

4. Results

The main contribution of this work was the development and validation of a new method for evaluating the sense of presence in virtual reality environments that does not involve user tests, is low cost, and can be widely used both for evaluation of existing VEs based on its characteristics, and for the development of new VEs, offering design guidelines for the VE to provide the desired sense of presence.

In addition, three important contributions emerged from the systematic review of the literature: the updated identification of all available methods for the assessment of the sense of presence – the mapping of how these methods were used over the last 20 years –, and the identification of 29 risk factors that impact on the sense of presence.

Regarding the user experiments carried out in this work, it was possible to highlight the potentialities and limitations of the main methods for evaluating the sense of presence, as well as evaluating the effectiveness of different virtual environments. Applications and its target audience were different so that it was possible to inspect with greater breadth the practice of the main methods for presence. The results of all these experiments were published in vehicles of the area.

As for the use of the SUS questionnaire exclusively for the presence evaluation, its cost-effectiveness was evidenced, given that it is short and, consequently, quick to apply and analyze. However, it was confirmed that a clear explanation of the concept of presence to the participants is necessary in order to obtain reliable results. It was evident that carrying out evaluations with users is extremely expensive, as it requires planning, adequate recruitment of volunteers, a long period of application, on average 40 minutes per session, and statistical analysis of the results.

5. Conclusions

In this work, we proposed and evaluated PFS, a factor scale to measure presence in virtual reality environments. The final version of the PFS method is composed of 23 factors that impact the sense of presence in the VEs, which were grouped into three categories: Engagement, Interactive Fidelity and Sensorial Fidelity.

The user experiments carried out in this work, were extremely valuable for a better understanding of the methods for assessing presence already proposed, and it was possible to observe in practice their potential and limitations, which contributed in a very important way, together with the systematic review of the literature, for the development of the method proposed in this work.

The limitation of the proposed method is the non-guarantee that all impact factors in the sense of presence are considered, as well as all current and future variations for each one of these factors, given that the technologies and, consequently, the different uses of VR are in constant evolution. Therefore, the PFS should evolve continuously to accompany the development of the area. Besides, according to the Standards, there is no single evidence of validity for a method and, therefore, establishing validity must be a constant task that involves accumulating relevant evidence that provides a safe basis for the interpretation of results. Thus, it can be said that validation is something that is constantly under construction, always in search of evidences that allow the conclusions about the test scores to be progressively more valid.

New applications for the PFS method must be carried out, in different contexts, involving different profiles of applicators and virtual environments, such as in the design phase for existing VEs. For each new application, evidence of validity must be examined and adjustments must be suggested so that the method becomes increasingly accurate in assessing the sense of presence in immersive virtual environments.

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