

Assessment of Presence in Augmented and Mixed Reality

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Alexander Toet

TNO, Soesterberg, Netherlands, lex.toet@tno.nl

Tina Mioch

TNO, Soesterberg, Netherlands,
tina.mioch@tno.nl

Simon Gunkel

TNO, the Hague, Netherlands,
simon.gunkel@tno.nl

Omar Niamut

TNO, the Hague, Netherlands,
omar.niamut@tno.nl

Jan B.F. van Erp

TNO, Soesterberg, Netherlands,
jan.vanerp@tno.nl

While the sense of presence in VR has been extensively studied, there are currently no scales available to measure the sense of presence in AR and MR. Here we propose a general Holistic Presence Questionnaire (HPQ), that measures presence through the sense of telepresence, internal and external plausibility and perceived behavioral and cognitive affordances in the mediated environment. The HPQ is sufficiently general to measure presence experienced in any type of multi-sensory (visual, auditory, haptic and olfactory) setting (including VR, AR and MR systems). By using single items to tap into each of the relevant psychological

processing levels the HPQ is comprehensive and efficient. Individual items are sufficiently concise so that their (repeated) application minimally interferes with the experience.

CCS CONCEPTS • Human-centered computing~Human computer interaction (HCI)~Interaction paradigms~Mixed / augmented reality

Additional Keywords and Phrases: augmented reality, mixed reality, virtual reality, presence

1 INTRODUCTION

Next to virtual reality (VR), mixed (MR) and augmented (AR) reality are gaining importance in science, education, training and entertainment, affording new ways of interaction and engagement with real and virtual worlds. While VR environments typically replace the real world with a virtual one through immersion of the user's senses, AR and MR supplement the real world with digital information, affording users real-time interaction with co-existing real and virtual elements. The development of effective immersive AR and MR systems requires efficient and reliable measures to assess their user experience (UX).

A key characteristic typically used to quantify the UX of VR is presence: the extent to which one feels situated and able to act in the VR environment. Various methods have been developed to measure the sense of presence in a mediated (possibly virtual) environment [1, 2]. They can be classified as objective (instrumental) and subjective (perception based) measures. *Objective measures* include biomarkers (e.g., heart rate, EEG and EMG measures, skin conductance and skin

temperature), behavioral measures (e.g., gaze behavior, reflexive responses, postural sway), or measures related to social behavior and task performance in the mediated environment [3]. Objective measures are generally costly and complex and have methodological limitations that do not allow their application in all conditions, while their interpretation is not unequivocal. *Subjective measures* include questionnaires, self-report ratings or interviews. Although post-experience presence questionnaires are typically lengthy, intrusive and time consuming, they are still the preferred method of investigation since they are cheap and easy to administer [1, 4]. However, post-experience questionnaires do not capture state changes during the experience. This may be remedied by using single-item presence scales [5, 6], that afford a less disruptive assessment of presence and may therefore be more suitable to be administered during exposure [7]. Single-item presence scales can effectively combine excellent test-retest reliability and sensitivity with good convergent validity (correlation) with more elaborate multi-item questionnaires [5].

While various scales have been developed to measure the sense of presence in VR, there are currently no scales available that generalize across AR and MR. Next to being relevant, sensitive and reliable, such scales should also be convenient and minimally intrusive, to afford repeated application during the experience without breaking the presence illusion [8].

Here we propose a comprehensive general Holistic Presence Questionnaire (HPQ), that uses a single item to tap into each of the relevant processing levels in the human brain: sensory, emotional, and cognitive, behavioral and reasoning. The HPQ measures presence through the sense of telepresence, internal and external plausibility and perceived behavioral and cognitive affordances in the mediated environment. The

HPQ is sufficiently general to measure presence experienced in any type of multi-sensory (visual, auditory, haptic and olfactory) setting (including VR, AR and MR systems).

2 RELATED WORK

Research on UX in AR/MR typically only addresses the degree to which virtual objects are experienced as actual objects in the user's physical environment [9, 10]. However, next to its sensory aspects, the sense of presence also significantly depends on the affective, behavioral, and cognitive aspects of the experience [11]. Most existing presence questionnaires only address the sensory components of a mediated presence experience. An exception is the Virtual Experience Test (VET) [12] that measures both the sensory (audio, visual, haptic) and affective (the user's internal and external perspective), cognitive, active and relational dimensions of a presence experience. However, the VET is designed for the development of VR environments and is not sufficiently general for the evaluation of AR/MR systems. The Augmented Reality Immersion (ARI) questionnaire [13] is specifically designed for AR applications and measures immersion on the levels of engagement, engrossment and total immersion, with subscales of interest, usability, emotional attachment, attention, presence and flow. However, the scale is rather lengthy (41 items), while only few items implicitly tap into each of the relevant psychological processing levels that mediate the sense of presence.

3 THE HOLISTIC SOCIAL PRESENCE QUESTIONNAIRE

We present a new holistic presence questionnaire (HPQ) that measures the user's sense of place [14] (i.e., telepresence, plausibility and perceived affordances) in a mediated environment by tapping into each of the five relevant (sensory, emotional,

cognitive, behavioral and decision making) processing levels for multisensory environmental stimuli as defined in the conceptual framework by [15]. The HPQ extends most existing questionnaires that typically only measure spatial presence (i.e., telepresence and agency; [16]).

At the sensory level, the relevant quality factor is the perceptual or *sensory fidelity* of the experience, i.e. the extent to which users fail to perceive or acknowledge the fact that (part of) the environment they perceive is mediated (the illusion of non-mediation: [17, 18]). Hence, there should not be any noticeable distortions in the mediated representation: the visual representation should be photorealistic and of high quality, audio should be undistorted, and system factors like jitter and delay that affect behavioral realism should minimally interfere with the sensory activation and integration. Note that the fidelity of an experience can differ largely between the different sensory modalities. Such inconsistencies can lead to a strong sense of presence in one modality but not in another. At this level, quality features are related to individual sensory channels, such as visual, auditory or tactile features, and may also be linked to the perception via multiple senses in parallel (e.g., audio-visual features; see [19]). Example quality features for the visual channel include color naturalness, sharpness, darkness (of black areas), brightness, contrast, flicker, blur, geometrical distortion, and coding and packet-loss induced degradations such as blocking, freezing, and slicing. Examples for the auditory channel include audio-streaming quality parameters like localization and timbre, and speech-transmission quality features like coloration, noisiness, loudness, or continuity. For systems that address multiple sensory channels simultaneously, relevant features are e.g. balance and synchronism, and an experience assessment should address the extent to which one feels like being in direct contact with

the environment (one's impression that one directly sees, hears, feels, or smells the environment). At this level, the experience can be assessed by rating an item like: "*The represented environment feels natural*" (item 1 in Table 1).

At the affective or emotional level, the relevant quality factor is the *internal plausibility* or sensory congruity [20] of the experience, i.e. the extent to which users have the feeling that their multisensory input is coherent [21] and agrees (is congruent and consistent) with their mental model (expectations or memories) of the represented environment [20, 22, 23]. Hence, the relevant quality feature at this level is the semantic consistency and congruency between all sensory signals, and the experience can be quantified by rating an item like: "*My sensations are consistent and agree with the represented environment*" (item 2 in Table 1).

At the cognitive level, the relevant quality factor is the *external plausibility* or environmental and thematic congruity [20] of the experience, i.e. the perceived fidelity [24], realness [3] or illusion that the represented environment is authentic [25] and a place that can actually be visited [26, 27]. At this level, the experience can be quantified by rating an item like: "*The represented environment appears real*" (item 3 in Table 1).

At the behavioral level, the relevant quality factor is the degree to which the all elements in the environment afford natural behavior without any limitations or restrictions, i.e. the feeling that one can interact with the environment in natural way. At this level, the experience can be quantified by rating an item like: "*My interaction with the represented environment feels realistic*" (item 4 in Table 1).

At the reasoning level, the relevant quality factor is the degree of realism of the multisensory representation of the mediated environment. An AR/MR environment with a high degree of fidelity and realism is expected to influence one's

Table 1. The Holistic Presence Questionnaire (HPQ)

Item	Level	Aspect	Question
1	Sensory	Fidelity	<i>The represented environment feels natural.</i>
2	Emotional	Int. plausibility	<i>My sensations are consistent and agree with the represented environment.</i>
3	Cognitive	Ext. plausibility	<i>The represented environment appears real.</i>
4	Behavioral	Agency	<i>My interaction with the represented environment feels realistic.</i>
5	Reasoning	Reasoning	<i>My thoughts in the environment feel natural.</i>

reasoning in a similar way as its unmediated counterpart. At this level, the experience can be quantified by rating an item like: “*My thoughts in the environment feel natural*” (item 5 in Table 1).

4 CONCLUSION

Presence in AR/MR implies the ability to interact directly and in a natural way with all the elements in one’s environment, whether they are real or mediated [28]. Existing presence questionnaires developed for the assessment of VR UX typically do not apply to AR/MR systems [28, 29]. The HPQ is sufficiently general to measure the quality of presence experiences with systems on any position on the reality-virtuality continuum [30]. The HPQ covers all psychological aspects of MR and AR experiences that are relevant to achieve a convincing feeling of presence, like the feelings that the represented environment is plausible (consistent and realistic), that the interaction with the environment is realistic (both on the sensory and behavioral levels), and that it affords natural reasoning and decision making. By using a single item for each of the relevant psychological processing levels the HPQ is comprehensive and efficient. Individual items are sufficiently concise so that their (repeated) application during an

experience will minimally break the experience. Initial validation studies confirm the content and face validity of the HPQ. In future studies we will test its stability, sensitivity, and convergent validity in different multi-sensory (visual, auditory, haptic and olfactory) system (including VR, AR and MR systems) settings.

ACKNOWLEDGMENTS

This project was partially funded by TNO’s Early Research Project ‘Social eXtended Reality’.

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