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Pervasive virtuality in digital entertainment applications and its quality requirements

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A R T I C L E I N F O

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A B S T R A C T

There is a growing trend of entertainment applications where players wear non-see-through HMD devices (i.e. they see only virtual contents) and move freely in a physical environment, being able to touch physical objects and walls, feel hot air stream on their faces, and interact with other real people, while fully immersed in the simulation. Current definitions of mixed reality situations cannot cope adequately with this new class of experience. In this paper we name this new situation as "pervasive virtuality", which we define as being a virtual environment that is extended by incorporating physical elements as proxy objects, integrating contextual information, and resolving conflicts with the dominance of a particular sense (usually vision). This new mixed reality paradigm is not well understood by both industry and academia. Therefore, we propose an extension to the well-known Milgram and Colquhoun's taxonomy to cope with this new mixed reality situation. Furthermore, we propose Pervasive Virtuality characteristics that represent quality requirements, which help us to understand and design this new type of virtual environment. This paper also presents a brief case study using these characteristics.

1. Introduction

Currently, the world's largest tech companies are intensely exploring virtual reality (VR), which is a fully computer-generated simulation (e.g. Oculus Rift, HTC Vive, and Google Daydream). Also, at the other end of the spectrum, the industry is heavily investing in augmented reality (AR), which is a simulation that overlays the real world with digital content via see-through HMD devices (e.g. Hololens, Meta, and Magic Leap). In this market, virtual reality and augmented reality are basically visual applications. Few applications explore other senses such as hearing and touch. However, recently a new form of virtual reality experience started emerging. The reader is invited to see the video demos by two industry pioneers in this type of experience: The VOID [1] and Artanim [2]. In these cases, players wear non-see-through HMD devices (i.e. they see only virtual contents) and move freely in a physical environment, being able to touch physical objects and walls, feel hot air stream on their faces, and interact with other real people, while fully immersed in the simulation. Current definitions of mixed reality are too generic and cannot cope with this new class of experience. The media have been referring to this new situation as real virtuality [3], hyper-reality [4], or even hybrid reality [5], but presenting no accurate definitions. Even more concerning is the lack of guidelines to assist the conceptual design of this type of application, especially when we have digital entertainment in mind.

To help in conceptualizing and using this new kind of entertainment application more accurately, this paper extends our previous work [6] by detailing the concept of "pervasive virtuality" (PV). We present some important improvements in this paper. Firstly, we clarify the concept of pervasive virtuality and define PV as a new lane in the spectrum of mixed reality, based on proxy elements, context-awareness, and the dominance of one sense (usually vision[1]). We are not presenting an entirely new concept but instead we propose a new taxonomy of mixed reality that is more adequate to product development. Secondly, we extend the original set of quality requirements and revise their names to consider general entertainment applications (the original focus was gaming), and present more details about these requirements referring to current works in the literature. In this second contribution, we do not intend to exhaust the subject, but present a robust set of requirements to assist the conceptual design of this type of mixed reality.

Essentially, we define pervasive virtuality (PV) as being a virtual

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[1] In this paper we use the terms "sight" and "vision" freely. However, when referring to the dominance of the visual perceptual experience we prefer the term "vision", as found in the literature on multisensory perception.

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environment extended with more senses by incorporating physical elements as **proxy objects** and resolving conflicts with the **dominance** of a sense over the others. An important goal in PV is to significantly enhance the "illusion of embodiment" [7], which helps to create a distinct "live-action" aspect (as experienced by the user) in this kind of environment. A *proxy object* is a physical object (e.g. a tactile solid object, a sound, a smell) that acts as an intermediary between the user and a given virtual object in pervasive virtuality, enabling a user to experience multiple senses in the mixed reality environment. Usually, vision is the dominant sense and tactile proxy objects add the sense of touch. At first glance, pervasive virtuality seems to be another name for well-known mixed reality situations. However, this is not the case. A proxy object is more than a simple placement of a real object in the virtual world. Proxy objects change the virtual world pervasively. For instance, a very simple tangible physical object may turn into a more complex virtual object [8] or even into an object of different shape [9]. Also the same simple tangible physical object can be mapped to multiple virtual objects [10]. Locomotion is also transformed. For example, a user may walk in circles thinking s/he is on a straight path in the virtual world [11]. On the other side, from the user's viewpoint, the real world is transformed more deeply than being visually augmented (as in the usual case of augmented reality applications). The above-mentioned effects are possible because of dominance of vision – when sight and another sense are in conflict, sight usually dominates. In the case of locomotion, vision dominates the vestibular sense. In this context, we propose an extension to the taxonomy of Milgram and Colquhoun [12], in which we situate vision as one of the possible examples of sense domination (albeit the most important). This is a new enlightenment (or a different perspective at least) to develop mixed reality applications for physically impaired people. Nevertheless, we need more research and experiments to elaborate this later perspective.

As far as pervasive virtuality characteristics are concerned, our contribution stems from shedding some light in this new type of mixed reality, by creating a common vocabulary and identifying conceptual aspects and features for designers and developers. Research on conceptual characteristics that help the design of mixed reality applications can be found in other related areas, such as pervasive games [13–16]. Some conceptual characteristics we present in this paper have been inspired by the work in [16], whose authors discuss non-functional requirements (qualities) for pervasive mobile games and provide checklists to assess and introduce these qualities in game projects.

The present paper is organized as follows. Firstly, Section 2 defines and characterizes "pervasive virtuality". Next, Section 3 presents related works. Section 4 presents a two-level map of characteristics, which can describe pervasive virtuality in a more accurate way and help the design of new applications. Section 5 presents a brief case study about how these characteristics apply to a pervasive virtuality game demo. Finally, Section 6 presents conclusions and future works.

2. Pervasive virtuality

Pervasive virtuality (PV) is a mixed reality environment where real, physical, elements are incorporated into the virtual environment as proxy objects, using context-aware devices (e.g. sensors and wearable technology), and solving sense conflicts through the dominance of one sense (usually, vision). In PV, the dominant sense is totally generated by computers. For example, if vision is the dominant sense, users wear non-see-through HMDs all the time, which means that they do not see any real-world contents. We start introducing the concept of pervasive virtuality by extending the taxonomy of reality-virtuality continuum. Then we present the pervasive virtuality quality requirements.

2.1. Extending the reality-virtuality continuum

Milgram and Colquhoun [12] proposed a reality-virtuality continuum that became the traditional reference to mixed reality (Fig. 1). Based on this taxonomy, well-known companies have their own preferences to refer to virtual reality applications: "mixed reality" (e.g. Microsoft), "augmented reality" (e.g. Facebook), or "immersive computing" (e.g. Google)[2]. However, the concept of virtual reality applications and the use of those three terms in the industry should be better defined in the light of the current technology and new possibilities for introducing more senses along with sight. Most especially, we are interested in providing an improved definition of the new experience we briefly describe in Section 1.

At the time Milgram and Colquhoun [12] proposed their taxonomy they were almost certainly considering visual displays only, with no other senses in mind. From the perspective of vision, mixed reality applications simply juxtapose real and virtual objects through the projection of visual artefacts. For instance, a common example of augmented virtuality is a video of a real human face projected on an avatar's head in a virtual world. Essentially, in these applications "augmented virtuality" consists of a virtual world augmented with a real image or video (i.e. not computer-generated) mapped into virtual objects. "Augmented reality" is the same process the other way around. One can think about extending these interpretations by incorporating sounds, or even tactile objects. In this case "augmented reality" would augment the real world with digital objects of any sort. However, this simplified extension cannot cope with situations where real (i.e. physical) objects are transformed into virtual objects, and vice versa (i.e. virtual objects become real objects). The problem here is to make clear how both the real world and the virtual world evolve when they are mixed with more than one sense.

Milgram and Colquhoun's reality-virtuality continuum refers to any continuum between the real and virtual worlds. However this is too generic to give effective support to product development for mixed reality situations. We need to clarify the type and level of immersion we are dealing with.

Nowadays we do not have Virtual Reality technology that guarantees full compatibility between all senses (actually, not even between two of them) in a mixed reality situation. This means that if a sense conflicts with another sense, immersion will be hindered or possibly destroyed. A common solution for this problem is to solve sense conflicts by considering the dominance of a sense over the others. If we apply this solution, we can have a better and deeper immersion level. The dominance of a sense over others allows real (i.e. physical) elements to be incorporated into a virtual environment as proxy objects [8–11], as we briefly explained in the introduction section above.

The idea is to start with the basic situation (Milgram and Colquhon's continuum) that contains only one sense (usually vision) and move progressively from this situation towards deeper immersion levels containing more senses (and dominated by the basic sense). Each time we add a new sense, we create another (enhanced) mixed reality continuum connecting the real and the virtual worlds. We could continue with this process until we reach a complex situation containing all human senses (which is probably unreachable in practice). Fig. 2 illustrates this idea, as an extension of Milgram and Colquhoun's taxonomy [12]. Fig. 2 represents a 2D conceptual space of mixed reality situations, which can be traversed horizontally and vertically. Fig. 2 shows one vertical continuum corresponding to levels of mixed reality in the real world (at the left side of the diagram) and the virtual world (at the right side of the diagram). The vertical arrows (from top to bottom) represent evolution in this continuum.

In this paper we are interested in the vertical continuum's right side (Fig. 2). At any point in this right side, the user is using context-aware devices (e.g. sensors and wearable technology) embedded in a wireless networking environment, which enables him/her to move freely in a world populated with proxy objects that exist because of the dominance

[2] https://www.cnet.com/news/google-avoids-the-term-mixed-reality-in-its-ar-and-vr-plans/ [Accessed Feb 08th, 2018].