BurnAR: Involuntary Heat Sensations in Augmented Reality

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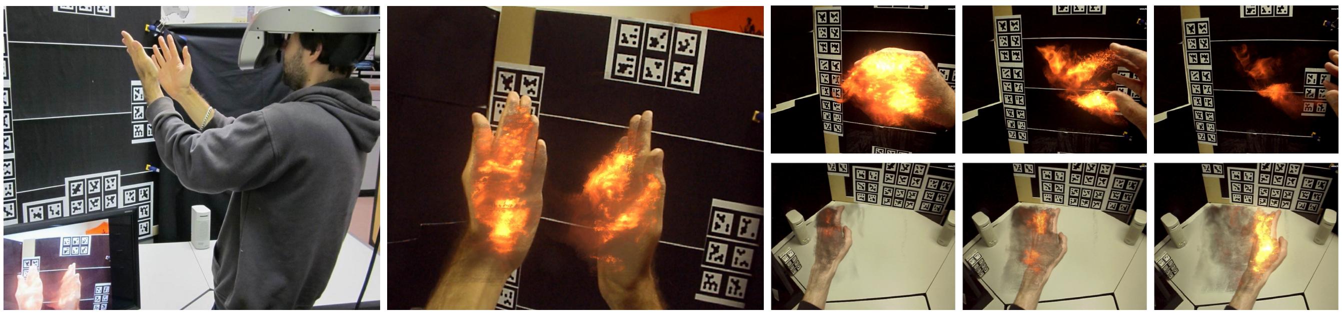

(a) (b)

Figure 1: (a) Our BurnAR demonstration enables users wearing a stereo head-worn display to experience the illusion of seeing their own hands burning, which we achieve by overlaying virtual flames and smoke on their hands. (b) Hand movement affects flames and smoke.

Abstract

Augmented Reality systems that run interactively and in real time, using high quality graphical displays and sensational cues, can create the illusion of virtual objects appearing to be real.

This paper presents the design, implementation, and evaluation of BurnAR, a novel demonstration which enables users to experience the illusion of seeing their own hands burning, which we achieve by overlaying virtual flames and smoke on their hands.

Surprisingly, some users reported an involuntary warming sensation of their hands. Based on these comments, we hypothesized that stimulation of multiple sensory modalities presented in this AR environment can induce an involuntary experience in an additional sensory pathway: observation of virtual flames resulting in a heat sensation. This cross-modal transfer, known as virtual synesthesia, is a temporary experience which affects some people who are not synesthetes and only lasts for a short time during the illusory experience.

To verify our hypothesis, we conducted an exploratory study where participants experienced the BurnAR demonstration under controlled conditions.

Index Terms: H.5.1. [Information Interfaces and Presentation]: Multimedia Information Systems—[Artificial, augmented and virtual realities] H.1.2. [Information Systems]: Models and Principles—[Human factors]

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1 Introduction

Advances in technology have allowed the development of sophisticated systems that display real and virtual objects aligned with each other in a real world scene, termed Augmented Reality (AR) [1]. AR systems that run interactively and in real time, using high quality graphical displays and sensational cues, can induce significant feelings of presence [24], the illusion of virtual objects appearing to be real.

At public demonstrations of BurnAR, more than 100 people experienced the illusion of seeing their own hands burning, which we achieved by overlaying virtual flames and smoke on their hands. Surprisingly, around one fifth of users reported experiencing an involuntary sensation of heat in their hands, with one user also experiencing the smell of smoke.

Based on these comments, we hypothesized that stimulation of multiple sensory modalities presented in this AR environment can induce an involuntary experience in an additional sensory pathway—observation of virtual flames resulting in a heat sensation. This cross-modal transfer, is defined as a form of synesthesia, known as virtual synesthesia [20], where a perceptual illusion results in a perceived stimulation to an unconnected sensory modality that receives no apparent stimulation from the virtual environment. The process of integrating the data generated by actual stimulation of multiple sensory modalities of sight, hearing, and body state, results in a perceived stimulation to the sensory modality of thermoception, the sensation of heat.

Contribution: We have shown that the stimulation of multiple sensory modalities presented in this AR environment can induce an involuntary experience in an additional sensory pathway. First, we have created a novel demonstration, which is capable of producing an illusion which can result in an involuntary sensation of heating of the participants hands. Second, we have demonstrated this effect for the first time, under controlled experimental conditions.

Our findings are of interest to cognitive science and experimental psychology, as they provide further insight into perceptive and cognitive processes. The Augmented and Virtual Reality communities can additionally benefit from our findings by using them to inform future interaction designs and implementations, as our novel prototype can serve as a case study of cross-modal sensory illusions.

2 Related Work

In this section, we summarize previous work that has documented the occurrence of involuntary cross-modal sensory illusions. In the BurnAR demonstration the actual senses being stimulated are vision, audition, and proprioception—these multimodal inputs are capable of creating a high level of presence, which provides the platform for the illusion of the fire on the hands becoming believable and therefore stimulating the additional sensory pathway of thermoception, the sensation of heat.

Humans experience their world as a whole, constantly merging and synthesizing inputs from different sensory modalities dynamically, resulting in a world of coherent perceptual entities. Studies of human perception indicate that stimuli in one modality can alter the experience in another, with these cross-modal transfers leading to illusions in virtual environments.

Cross-modal audiovisual interactions have been investigated by Shams et al. [23], where the visual percept is altered due to cross-modal perceptual interactions, resulting in a visual illusion which is induced by sound. Similarly, the illusion of haptic sensations from visual cues has been observed in several psychophysical experiments Biocca et al. [3] , Lecuyer et al. [12].

Biocca's study [3], found that some participants reported haptic illusions in the absence of stimulation, while connecting cross-modal transfers of visual and auditory cues, defining this form of cross-modal interaction as a form of synesthesia, Cytowic [5].

An AR system called Hand-displacEMent-based Pseudo-haptics (HEMP) [18], actually induces an active force field illusion, from purely visual cues, using a video see-through head-worn display to displace the visual representation of the user's hand dynamically. The sensation of a force applied to the user's hand is induced by visually displacing the hand in the virtual environment. The dominance of vision over proprioception [25], adds to this artificial conflict between visual and proprioceptive sensory information about the user's real hand. This setup is similar to BurnAR, in the co-location of the video with the real representation of the user's hand, avoiding occlusion violations.

Earlier research [7] documented experimental work on a perceptual illusion, where a visual stimulus on the hands of test participants produced an involuntary heat sensation. In a variation of the classic "Rubber Hand" experiment [4], the false rubber hand was stroked with the light from a laser pointer, which produced involuntary heat sensations in the unseen, real hand. They also report that when the subject's real hand was stroked with laser light similar levels of involuntary heat sensations were recorded. They discuss their results in terms of multi sensory integration theory [6], where the perception of one modality can influence the experience of a second modality. The experiment used a questionnaire to make subjective assessment of the responses to the laser light stimuli. One question asked the participant to rate whether the laser light had been felt, having separate checkboxes to indicate whether the sensation was "warm" or "tingly". This style of question may lead to over reporting by the participants, as it is a suggestive prompt. This very problem has been analyzed in other work by Slater [24]. While not being an AR system, this can be compared with our experiment where the visual stimulus on the hands is the simulated fire, which sometimes leads to the participant experiencing a similar outcome of involuntary heat sensations in their own hands.

In another experiment [26], a Virtual Reality system was used to investigate what level of realistic responses participants would have to a virtual fire in an immersive virtual environment. Some participants reported feeling heat, and even smelling smoke. In this experiment, even though the visual stimulus of the simulated fire was not on the body of the participant, the level of plausibility of the illusion and depth of immersion was significant enough for some participants to experience involuntary heat sensation.

The related works of Shams et al., Biocca et al., Lecuyer et al., Pusch et al., and Durgin et al., [23, 3, 12, 18, 7], all report findings of cross-modal integration of sensory cues producing an illusion in separate modality in the absence of any direct stimulation of that sensory modality. Similar results from other research into cross-modal sensory illusions involving the visual, olfactory, and gustatory senses are reported by Nambu et al., Narumi et al., and Koizumi et al., [14, 15, 11].

These findings confirm our experiences of the illusion generated by the BurnAR system resulting in the involuntary heating of the participant's hands.

3 Design and Implementation

Our demonstration simulates fire and smoke effects, being responsive to the user's motions, and always visually interesting. The choice of a fire effect over other possible effects is deliberate. Fire is self-illuminating, removing any requirement to match lighting of the generated visuals with the real-world environment—a significant challenge—and it is straightforward to compose. Fire is abstract and noisy in appearance and changes quickly, which allows some margin for error when matching with our computer vision component. Fire is recognizable and well-understood, but seeing one's own hands on fire is something most people do not encounter, thus providing an experience which is easy to grasp, but is both compelling and unique.

With the system that we have developed for the BurnAR demonstration, the user has a stereoscopic view of the real world. Being able to see the real-time kinaesthetic motion of their hands and lower arms provides a highly believable system that supports a number of sensi-motor contingencies. The user is presented with a video display of the real world and their own hands interacting with the virtual flames and smoke, complemented with sound effects of burning.

The BurnAR demonstration comprises several components based on a closed layer architecture, where data flow is only allowed between adjacent layers. The bottom MR Platform [27] layer drives the stereo head-worn display, streaming a pair of video images, and camera poses to the computer vision layer. In the computer vision layer, the video images and hands, segmented by color are processed to reconstruct a dense estimation of the hand surface. The resulting 3D point cloud, 3D scene flow, and a pair of video images are streamed to the computer graphics layer.

The graphics layer is implemented using the Demolition Engine from Fairlight, running on DirectX 9 in Windows and using HLSL shaders. It is responsible for generating a fire effect around the user's hands from the given computer vision input. The fire effect uses the 3D point cloud to initialize the particle system, which is overlaid onto the camera images. The distance d to the hand is used to control the volume of the fire sound, using the inverse square law for sound intensity: $1/(d^2)$.

The experimental platform was implemented on a 3.0 GHz Intel Core i7 quad-core desktop computer with 4 GB RAM, an nVIDIA GeForce GTX 570 graphics card, stereo sound card with external speakers, and a Canon VH-2007 video see-through head-worn display (VSTHWD).

4 Evaluation

As reported in previous work on evaluating AR systems [9], the enthusiastic responses from casual demonstrations may not be replicable in formal experiments. This necessitates that the evaluation of the responses reported from the informal BurnAR public demonstrations need to be investigated in a tightly controlled environment, minimizing the effects of autosuggestion and prior knowledge. The difficulty of confirming a subjective response has been widely discussed in the literature [24, 21], highlighting challenges for designing questionnaires. Based on these observations, we have carefully designed our experiment and questionnaire, strictly avoiding suggestive contents; for example, by not using words with connotations of heat.

4.1 Participants

Twenty voluntary participants (2 females and 18 males), were recruited from the staff and student population of the University of South Australia. Nineteen participants were aged in the range of 16–25 years, and one participant was in the range 26–35 years. All participants had no known vision impairments—their acuity[28] and stereoscopic vision[13] was evaluated using simple tests. The experiment had the approval of the University of South Australia's Human Research Ethics Committee and was carried out according to their guidelines. All participants were unaware of the purpose of the experiment, and had no previous AR experience.

4.2 Procedure

Participants were required to attend two separate sessions, which were at least one day apart. The reason for the two sessions is to initially introduce the experience of AR as viewed through the VSTHWD, so that when they experienced the BurnAR demonstration, they had already experienced the novelty of AR, removing the "Wow" effect of experiencing AR for the first time. Thus, all of the participants were on a similar basis of AR experience when they attended the main test session. To minimize distractions that would cause breaks in presence, both sessions were carried out in a quiet area.

Session A: The participant familiarized themselves with using the VSTHWD in an AR environment by experiencing our demonstration from TEDxAdelaide 2010 [22]. The experimenter was extremely careful not to infer or discuss the purpose of the experiment, other than to say that it is the participant's task to report their personal assessment of the demonstration.

Session B: The participant first read an information sheet explaining the experiment. This had been carefully worded so as not to suggest to the participant that they may experience a heat sensation from the illusion of their hands burning.

The participant put on the VSTHWD and experienced the full BurnAR demonstration, initially without the fire (15–20 seconds) and then with the virtual fire and smoke appearing on their hands accompanied by simulated sounds of a burning fire. The demonstration continued uninterrupted for 5 minutes, giving the participant the opportunity to become fully immersed in the illusion. The experimenter was very careful not to suggest anything related to feeling heat during the whole experiment. The participant's hand actions were recorded by a video camera, including any verbal comments. The camera positioned so that the display screen is also captured within the video camera's field of view. Participants were asked to speak their thoughts out loudly. At the end of the experiment, the participant completed a subjective questionnaire to rate their level of immersion in the demonstration.

4.3 Analysis and Discussion

We analyzed the questionnaire and recorded if the participants described feeling heat from the fire and/or could smell smoke/burning. For each participant, we viewed the video and recorded if they described feeling heat from the fire and smelling smoke/burning and how often and when. The overall impression given by viewing the videos was that most participants immediately experienced a high level of presence in the system, there was no question that they were observing fire on their own hands in the real-world environment that was physically in front of them. Observing the participants behavior, particularly their hand movements while experimenting with the fire, indicated that they reached a high level of immersion in the illusion after about three minutes of using the system.

Our exploratory study suggests the existence of a relationship between the illusion of presence and cross-modal illusions: specifically, that visual cues combined with auditory cues can generate significant cross-modal heat sensation illusions in the absence of any external heat source.

The outcomes of the experiment provided support for our hypothesis, with six out of 20 participants reporting an involuntary heat sensation in their hands.

Pusch and Lecuyer [17], used two theories of human perception, cognition, and action, as models to explain the underlying perceptual and cognitive processes involved in their study of the illusion of pseudohaptics. The Interacting Cognitive Subsystems cognition model by Barnard et al. [2], integrates both propositional meaning and direct sensory contributions into a holistic sense of feeling through nine interacting cognitive subsystems, and the Bayesian multimodal cue integration action framework by Ernst et al. [8], incorporates a Bayesian interference approach at the perceptual level and a gain/loss function approach at both the decision making and action planning level. Similarly, these theories can also be used to explain the underlying perceptual and cognitive processes involved in the illusion we studied, which results in involuntary heat sensations in the hands.

The brain uses inputs from the visual, auditory, and somatosensory systems to compute by intermodal integration (sometimes referred to as intersensory integration), a spatial mental model of the virtual environment which is the most likely percept, contributing to a sense of presence in the virtual environment. The majority of adults (most likely all), even from highly urbanized environments, associate the vision of flames from fire with the sensation of heat, as prior knowledge of the percept.

In his work categorizing synesthesia, Rogowska [20] defines this cross-modal transfer as virtual synesthesia and that this phenomenon only affects *some* people. Studies by Wallach et al., [29] and Hecht and Reiner [10], have revealed that personality traits and cognitive style, as well as the technological fidelity of the system, can define an individuals sense of presence. Wallach's study examined the correlation between five personality traits (empathy, imagination, immersive tendencies, dissociation tendencies and locus of control) and presence. Using personality and presence questionnaires, they found that empathy and locus of control are important in predicting the sense of presence. These results replicate Nicovich et al. [16] findings.

Hecht and Reiner used the "Rod and Frame Test" [19], to measure field dependency: the degree to which a person's perception is affected by the context of the surrounding perceptual field. They found that field-independent individuals reported a higher sense of presence than field-dependent individuals.

In the context of Slater's definition of presence [24], place illusion, originally defined for VR systems, is not an illusion in AR. Thus, what remains to be satisfied for presence is the plausibility illusion for achieving presence. We have specifically designed our system to create a plausible illusion. Two core components of our design are the VSTHWD and the fire simulation. The BurnAR system was implemented using the high quality Canon VH2007 VSTHWD; participants are presented with an accurate stereoscopic view of the near-field real-world workspace within the range of their hand reach (10-70cm). Objects closer to the eyes than 10cm would suffer from the vergence/accommodation conflict for both real and virtual objects. Being able to see their hands and arms moving kinesthetically in harmony with their proprioception provides an excellent basis for achieving a plausible illusion. We have deliberately chosen to display fire, as it is ideally suited for being depicted realistically (see Section 3).

5 Conclusions and Future Work

In this paper, we have described the design, implementation, and evaluation of BurnAR, a demonstration, which enables users to experience the illusion of seeing their own hands burning, which we achieve by overlaying virtual flames and smoke on their hands. We have shown under controlled experimental conditions that it is possible to use well-designed AR systems, such as BurnAR, to induce an involuntary sensational experience in some individuals, without direct sensory stimulation.

The BurnAR system provides the AR and VR communities with a tool that can be implemented to continue further research in providing insight into human perceptive and cognitive processes, and a means of achieving a high degree of presence through an AR experience.

In our experimental design, we were very careful not to influence participants, in any way, towards giving a positive response for feeling their hands warming. Pusch and Lecuyer [17] discuss "user-priming", the establishing of prior knowledge which may affect the outcome of an experimental task.

In a future larger scale study, we propose to split the participants into primed and not-primed groups to assess this effect. Additionally, all participants would be tested with various personality and cognitive tests, in order to investigate how personality types and cognitive processing differences influence an individual's experience of presence. This may explain why only some participants will experience virtual synesthesia for illusions such as BurnAR, due to their differing abilities to achieve a sufficient level of presence.

Besides the immediate applicability of our results to the design and implementation of AR systems, we see further applications in the area of neuroscience and psychology.

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