Augmented Reality Humans: Towards Multisensorial Awareness

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Abstract. In augmented reality, we have a virtual layer superimposed on reality. This virtual layer can contain multisensory content, that is, content that stimulates each of our senses: sight, hearing, taste, touch, and smell, and many interoceptive senses such as pain, heat, time, and balance. The virtual layer can contain virtual humans that have virtual senses to explore the augmented reality environment and to interact with real humans. These virtual humans can take on a role in social, marketing, retail, training, education, and entertainment augmented reality applications. In the human-like behavior of virtual humans, we expect awareness, use, and display of awareness of these senses. We present a view on the existing literature on virtual humans in augmented reality with a focus on sense-related presence issues.

Keywords: Augmented reality · Virtual humans · Optical see-through · Multisensorial · Human-computer interaction

1 Introduction

This paper is about virtual humans that appear in augmented reality (AR). These virtual humans inhabit a virtual layer that is superimposed on reality and their appearance and behavior can be experienced with various types of AR devices: smartphones, tablets, monitors, public displays, magic mirrors, video see-through, and optical see-through devices, and with projection-based AR devices. From this list of devices alone, one can conclude that Augmented Reality is vision-oriented. As mentioned in [1] "… vision as a distant sense informs us about the surroundings; it informs us about the world. Thus, vision is especially important when it comes to actively explore and navigating in this world." To explore and navigate digitally enhanced reality with our visual sense is what we initially think of when considering the use of AR. There is also more research on vision than on other senses, although, as discussed at length in the same article, the argument that this is because vision is our most important and complex sense is debatable. All our senses including the 'lower' ones in the Aristotelian hierarchy (hearing, smell, taste, and touch) function in time and space and, moreover, do not function independently of each other. Senses make it possible to perceive the world and perception integrates information across senses, across time, and space. Many more than the usual five senses

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have been distinguished and there are various viewpoints on how to classify them. They include senses that make us aware of the state of our body such as pain, temperature, balance, joint and body position (proprioception), and the state of our internal organs.

AR research is based on a definition provided by Ronald Azuma [2]. It tells us that AR (1) combines real and virtual objects in a real environment, (2) registers (aligns) real and virtual objects, (3) and runs interactively, in three dimensions, and in real-time. Usually, it is also mentioned that AR should not be limited to specific technologies and that it does not address sight only. That is, the definition doesn't play any limitations on the type of technology used, nor is it specific to visual information. AR can apply to all senses. We can have AR systems that provide computer-generated visual, auditory, tactile, olfactory, and gustatory experiences or combinations of these experiences superimposed on reality. Hence, although we often speak of virtual 'imagery' that is overlaid on a user's 'view' of the physical environment, we can address the other senses and their cross-modal properties as well, to design more useful, convincing, and attractive AR environments.

Hence, when we, according to the definition, want to register or align real and virtual objects we should take into account that the virtual objects have other than visual properties or don't have visual properties at all. We can add virtual 'objects' such as touch, sound, smell, and taste as well. They provide an augmented reality world where a user's senses receive direct or mediated input from real and artificially added objects. We receive multisensory environmental stimuli of our sensory receptors that make us aware of our (AR) environment, we respond physically, cognitively, and emotionally, and this allows AR users to take appropriate actions in their environment.

When we introduce virtual humans in an augmented reality world, we can provide them with virtual senses, including some of the non-Aristotelian senses such as pain, balance, body position, or having a full stomach. A virtual human inhabiting an augmented reality environment should behave in accordance with the knowledge they obtained from the integrated processing of the multisensorial stimuli it receives, whether they are obtained from the real world or from the virtual content that has been added to the real world. A virtual human should show appreciation for good-tasting virtual food and a virtual beer, but this appreciation should also show when we create the illusion of eating real food or beer. More generally, having different virtual senses allow them to perceive events in the real world and believably respond to them. The sound of a car collision in the real world should trigger a startle response in the virtual human. When the real sun shines in the eyes of the virtual human they have to squint their eyes. When they bump their knee they must show pain. Virtual humans that reside in AR environments should show their awareness of multisensorial stimuli that originate from the real world.

When we now look at the few virtual humans we encounter in augmented reality, it soon becomes clear that we are still a long way from the multisensorial virtual humans that we described above. In this paper, we will survey existing occurrences of virtual humans in AR. There are not that many, and especially in some interesting cases, it will turn out that they were introduced and investigated in Wizard of Oz (WoZ) experiments that aimed at researching the effect of a virtual human's environmental awareness on a user's feeling of 'presence' rather than on multisensorial capabilities of virtual humans. Here presence refers to the degree of feeling immersed in a computer-mediated environment.

In this paper, we provide an overview of the aspects that play a role in research that should enable the above behavior of virtual people. This overview includes a brief summary of the virtual humans that in previous research have been introduced in AR environments. Our focus is on optical see-through AR with head-mounted displays. In Sect. 2 we have some general observations on virtual humans, senses, and AR. Section 3 discusses examples of virtual humans and pets that have been introduced in AR environments. Believability and presence for virtual humans are discussed in Sects. 4 and 5. Section 6 focuses on multisensorial awareness of multimodal events. Conclusions can be found in the final section.

2 Virtual Humans in Augmented Reality: Observations

Virtual humans have been introduced in interactive graphical 3D and virtual reality environments. They are interactive anthropomorphic characters that are expected to behave like their living counterparts but are 'just' virtual objects. Their smartness is limited. Although we can expect them not to walk through walls or collide with furniture, research on intelligent virtual agents has not yet lead to computational models of nonverbal and interaction behavior that make them behave naturally and autonomously. Usually, they are meant for face-to-face interaction with users of these environments. For that reason, apart from graphical qualities, research on virtual humans focuses on their verbal and nonverbal capabilities and cognition and emotion in the context of interaction. The sensorial input comes mainly from their human partners and there are no interventions from their environment. If virtual persons have to perceive and respond to events in their environment, these are algorithmically controlled events and interventions. This is different in AR. Especially in outdoor environments the real world on which we superimpose a virtual layer is beyond our control.

We need to distinguish between an avatar and a virtual human. An avatar has an owner who controls the avatar's behavior or whose behavior is translated in some way to the avatar's behavior. The owner's behavior is obtained from sensors such as cameras, motion capture systems, microphones, and HMDs. The perceptive capabilities and behavior of a virtual human are controlled by algorithms that are designed to give us the impression that they behave autonomously. In this paper, we focus on virtual humans in AR, not on avatars. We can communicate with virtual humans, just as we can communicate with virtual objects using different input modalities that can be recognized by our AR devices. Gaze, head movements, body postures, hand gestures, touch, voice commands, and dialogue are established input modes. Virtual objects can move around, can be animated, do know about other virtual and real objects, and can trigger changes in the (smart) real world. Hence, the same can be done by virtual humans and we can communicate with them using said input modalities. Both real and virtual humans act in an AR environment in which the virtual humans can show virtual versions of human skills and behavior while using virtual versions of the human senses. Using their virtual sensors virtual humans can also show that they have multisensory experiences, that they are aware of virtual and real objects, their dynamics and interaction, that they are aware of sound (distinguish between familiar and unexpected sounds), that they are aware of being touched and aware of changes in scents.

Artificially created visuals, sounds, and tactile and haptic qualities of objects can be experienced with ‘see-through’, ‘hear-through’, and ‘tactual-through’ devices. Artificial touch addresses our tactile sensory organs. With tactile gloves, we can manipulate real and virtual objects that produce tactile sensations of texture or shape. Kinesthetic sensibility makes tactual perception (active touch) possible. Ultrasound introduces invisible ‘objects’ in mid-air or gives the sensation of touch near surfaces. The sound of a moving object in the real world can be manipulated in a virtual auditory layer. Users can be given a hear-through experience with binaural microphones integrated into earphones. Artificial sounds can be added to real objects. Whether it is visual, auditory, or tactile, we can add virtual content that can be perceived by each of these senses and we change the way our senses perceive real content.

Cross-modal effects should be investigated and designed as well. The appearance of an object can have an impact on how we experience its weight. The appearance of food has an impact on our flavor experience. Hence, also, to augment the intrinsic elements of a particular experience (for example, smell and taste in the case of food), we can design crossmodal stimuli by augmenting, among other things, color, shape, or sound [3]. In this way, we can speak of ‘taste-through’ and ‘smell-through’ augmented reality. Especially in the non-vision-oriented AR worlds, multisensory experiences play an important role. Flavor, for example, is an experience that involves, taste, smell, and texture (mouthfeel [4]).

Different kinds of taste sensations can be produced digitally, that is, electrical and thermal [5]. For objects in the real world, in particular food, of course, we can have augmented taste and smell, and personal olfactory and gustatory displays. In his foreword to a book on augmented taste and smell, world owned chef Andoni Luis Aduriz Mugaritz [6] tells us that we need ‘glasses’ for the mouth and perhaps in the future, they become as common as spectacle glasses. So we can think of a virtual layer superimposed on the real world that contains artificial tastes and smells, there are devices to produce and perceive these augmentations, and their inclusions in a virtual layer can be designed in a way that addresses and takes advantage of possible cross-modal effects.

3 Virtual Humans in See-Through Augmented Reality: Examples

In the current research on virtual embodied beings in AR, we see them appear as virtual assistants, as virtual pets, as trainers, or as opponents in a game, but most often they are introduced to study the effect of anthropomorphic and behavioral realism on aspects of user experience such attractiveness, engagement, and presence. At first, virtual assistants seem to be the most obvious application of virtual humans in AR. The scope of AR, for example, training and education, may require substantive assistance in the performance of a task by the AR user. That assistance could normally be provided by a human trainer or teacher. But the user can also be assisted in handling the AR device and specific characteristics of AR that are application-independent. Human-like responsive tools can layer around the built-in commands that make the AR device function. Knowledge of the user and their preferences can be automatically collected for personalized use in future more human-like interactions with the augmented reality application. Such assistants, in particular speech assistants, do not necessarily require a visualization, it can be distracting. HoloLens’s Cortana is invisible.

In more conversation-like applications virtual humans using a human voice can be given a human-looking visual representation. As mentioned earlier, such a representation allows adding non-verbal communication cues that facilitate conversation and make the agent more human-like. The virtual human becomes included in the virtual layer that is imposed on the real world and then appears in AR, displayed on a head-worn display, a handheld, a static display, or in spatial AR.

Virtual humans have been introduced in virtual reality environments. Not only in experiments to study how they are experienced by VR users but also to perform certain tasks in environments for education, training, entertainment, or exposure therapy. There are not that many virtual humans introduced in experience and application-oriented AR studies. We give a few examples of virtual beings that have been introduced in AR to study whether they can perform a certain task. In later sections, we look at approaches that aim at studying the effect of behavior and awareness realism of embodied agents on user experience. AR in this subsection refers to see-through AR using an HMD.

A human-like cartoon character with capabilities that transcend those of man is Welbo [7]. It is an example of an early AR assistant that convincingly showed the various possible capabilities and uses of such an assistant integrated into an AR world. Welbo is a 3D embodied interactive character that helps to visually simulate the location of virtual furniture in a physical living room. Welbo has a model of the living room and it can move virtual furniture, taking into account the physical characteristics of the living room. Welbo is instructed using speech. The user wears an optical see-through AR headset which provides Welbo with the user's viewpoint. Spatial properties, such as its size, position, and proximity turned out to be important factors in its evaluation by users.

Two virtual humans are present in an AR implementation of Façade [8]. Façade is a conversation-centered interactive drama where a human player interacts with two virtual humans living in an apartment. The original Façade version could be played using a desktop. In the AR implementation, it has the characters superimposed on a physical realization of the apartment using a video see-through HMD. With video see-through virtual content is integrated in real-time with a first-person video recorded view of the physical environment. This AR version allowed a player to walk around and gesture to the virtual humans. The purpose of this implementation was also to study the effect of this AR embodiment on engagement and compare it to the earlier desktop version. A higher level of perceived presence was reported, but no increase in engagement was observed.

A virtual human in a more traditional role but implemented in an outdoor AR application is MARA [9]. MARA is a virtual embodied agent that is superimposed onto the user's optical see-through view provided by an HMD. MARA is included in a mobile AR application that allows a user to walk around campus, while she presents and explains campus buildings to the user. MARA senses the user's position and orientation, she can walk towards the user, turn to the user, and follow the user while walking around the campus and commenting on its objects.

AR HMD producer Magic Leap has developed an AR assistant called Mica [10]. This virtual embodied agent uses AR technology to know about your AR environment, your position in the environment, and then it can interact with you to get certain tasks done, for example, in your home environment. As mentioned above, the many sensors in a head-mounted AR device make it possible to gather all kinds of information about the user and his environment. That information can be made available to an AR assistant who can integrate it with existing knowledge and use it in AR tasks to be performed, perhaps without the user being aware of it.

In [11] a virtual human is given the role of the job interviewer. An important advantage over a simple desktop version is that AR makes eye contact possible. This virtual character can face the user dynamically. Moreover, due to the Magic Leap HMD sensors, the user can be given feedback on performance, such as information about head orientation, response delay, response length, eye gaze, blink rate, and voice volume. This automatically obtained real-time information can be useful to improve a user's performance during job interviews or to train the job interviewer.

People communicate and find comfort in interacting with pets. So, we also should have a look at the possibility of having social interaction with virtual pets that appear on our head-worn OST AR devices in an augmented reality view of a specific indoor or outdoor environment. We mention the introduction of a dog as a virtual pet companion [12, 13] in optical see-through AR with a HoloLens device. It offers a view of AR applications where we take a walk through the city with a virtual friend (see Fig. 1).

Fig. 1. Three virtual creatures in AR. From left to right: Welbo (2000) [7], Mara (2007) [9], and a virtual dog (2019) [12].

4 Believability and Presence

In the previous sections, we already made a few references to the notion of "presence". It is an important criterion that, when presented informally, indicates whether a user experiences a digitally enhanced or mediated environment, in which they are wholly or partly immersed, as appropriate or uncomfortable. In the case of a virtual being, we can look at task performance, but a more general approach is how its appearance (anthropomorphic realism) and behavior (behavioral realism) affects the degree of presence a user experiences. In 1970 Masahiro Mori [14] introduced the concept of "uncanny valley" to give shape to his idea that when a humanoid robot comes close in appearance and behavior to appearing human, minor imperfections will produce uncomfortable, even creepy, feelings. This phenomenon is assumed to apply to virtual humans too [15] but research on it usually focuses on the design of appearance and directly observable body language [16]. As mentioned in the latter paper, and in line with our previous observations on incongruent events and behavior, there can be applications where perceptual mismatches and unrealistic characters can be accepted as long as there is some consistency in being unrealistic. Especially in a multisensorial context, there are many ways in which imperfections and crossmodal inconsistencies can show.

Rather than with Mori's uncanny valley, in virtual human research interest in presence started with Joseph Bates's 1994 paper [17] in which he focused on an agent's performance and introduced the corresponding notion of "believable agents": "There is a notion in the Arts of "believable character." It does not mean an honest or reliable character, but one that provides the illusion of life, thus permitting the audience's suspension of disbelieve." A believable character is lifelike and makes senseful decisions. In virtual reality environments "believability" has been given various explanations. A related term is "presence". The general notion of "presence" has been described as one's sense of being in a virtual world, so involved in activities that awareness of mediation disappears. It is a perceptual and subjective notion that can be applied to interactive 3D task and game environments, immersive virtual reality environments, and augmented reality environments where in addition to virtual objects, performing virtual humans are superimposed on reality.

Many subtleties in the definitions of presence and some more specialized notions such as co-presence and social presence are discussed in [18]. Co-presence has been defined as our awareness of being together with a virtual human (or an avatar representing a human) in a shared space. Social presence is about feeling socially connected to a virtual human or avatar in a shared space. For a virtual human in augmented reality, the notion of corporeal presence has been introduced [19, 20]. It focuses on the visual appearance and the alignment of virtual objects in the augmented reality world. More in particular, on the visual appearance of a virtual human and its animated behavior in an augmented reality environment, taking into account the virtual human's ability to blend in its appearance and observable behavior with its physical environment. Knowing about real and virtual objects while moving around, taking care of possible occlusions, avoiding collisions, compliance with physical laws, anticipating and reacting to possible changes in the environment, all these things help to increase the physical, corporeal presence. Hence, corporal presence is about a virtual human's situatedness within its virtual representation and its interactive capacity, that is, its ability to sense and act within its AR environment. A notion of social embodiment can be extracted from Paul Dourish's ideas on embodied interaction [21]. It refers to a virtual embodied agent's relationship with its social environment, that is, it should act as being in a social world. We can use these concepts in AR, but we must also take into account the presence in the augmented reality world of other (non-virtual) beings than the user of an augmented reality device. The AR world must remain socially coherent whatever real or virtual humans enter the world.

In AR, we are not fully immersed in a virtual world. Our sense of presence is determined by how naturally the virtual objects and their behavior are attuned to the world we are supposed to experience. For this reason, presence questionnaires have been developed for AR that deviate from the standard (virtual reality) presence questionnaires

[22]. Although this can change in the future, our sense of presence is also affected by having to wear a bulky HMD. Moreover, with optical see-through the augmented visual region is limited. In natural vision, we have around 180-degree horizontal Field-of-View (FoV) and around 150-degree vertical FoV. The Hololens 2 has a region for augmentation of only 43 by 29°. Also, the virtual content is semi-transparent, there can be color distortions, and the resolution is far from ideal. All these limitations affect the perception of virtual content. Another issue is that with a limited FoV virtual content may look cropped and appear in a separate window. There is not always a smooth transition from the central area with its virtual content to the peripheral vision. Change of view direction can cause parts of a virtual human's body to disappear, which is unlikely to positively affect the sense of presence. In [23] such limitations are referred to as the 'device-gap'. Another issue needs to be added. In a social setting, we can have other human interactants, whether or not using HMDs [24]. Social cues, such as facial expressions, that are normally visible in human-human interaction are now partly hidden behind the HMDs. This hinders a natural interaction, interactants remain aware of the technology, which however is not by definition a problem, it depends on the application. In [25] we review the attempts to recover nonverbal communication cues from occluded face regions.

5 Presence and Virtual Humans

One of the most obvious situations that will reduce the degree of presence is when a virtual human collides with or seems to walk through virtual and real objects. In [26] it is argued that despite advances in AR HMDs spatial understanding technology collision situations remain and are inevitable. For example, in mobile applications dynamic real objects that are not related to AR content might have unexpected behavior that interferes with the virtual human's actions. For that reason, they investigate visual effects for conflict situations where plausible behavior is difficult to generate and where a less precise special visual effect such as a fade-in/out or a flare-up can be tolerated. Visual effects make conflicts between virtual and real objects less noticeable and therefore have a positive effect on maintaining social/co-presence.

We interact with our environment and the people within it from a personal space around our body. Should this peripersonal space also be maintained by us or a virtual human when they move around and interact in the AR world? We should take into account that in some AR applications a first-person perspective may include a virtual representation of part of the user's body in the environment. It introduces technical problems of synchronous movements, to be addressed with, for example, motion capture methods, and (the effect of) stimulations in the real and the augmented world, and related psychological problems of body ownership and "self-presence" [27].

How to deal with this personal space in augmented reality? In virtual reality research, it has been shown that many factors influence distance and proximity behavior. For example, the presence of others, familiarity, gender, and appearance. In AR there are not yet many examples of research that focus on personal space and proximity. In the OST AR world described in [28], we have two physical chairs next to each other. One chair is empty, the other has a virtual human or object on it. What will be the seating behavior of an experiment participant who is wearing a Microsoft HoloLens AR headset and is asked to walk to the chairs and sit down? Will the distance kept from the virtual object be different from that of the virtual person? If the participant wants to sit in the empty chair, will they turn their back to the virtual person or will they face the virtual person while rotating? Some animations could be added to the virtual person (change head orientation, idle movements) to increase its (behavioral) realism. From the experiments, it was concluded that in this particular setting the distance that was maintained between participant and chair with the virtual human was larger than between participant and chair with the virtual object. Higher presence ratings were induced by the more realistic virtual human.

Some preliminary proximity experiments with a virtual pet in an OST AR study are also described in [12, 13]. Just like a virtual human, a virtual AR pet must display context-appropriate behavior given its pet's intelligence and senses. How to model dog walking with a human handler using an AR headset and a virtual dog? How to take care that collisions with someone walking right past the dog and its handler are prevented? And of course, the passer-by can also be provided with a headset and share the augmented reality. In this research in progress, different proximity behaviors were triggered in a WoZ setting to study the effect on the dog, its handler, and a passer-by.

However, most current experiments with virtual humans in AR concern their suitability to perform a certain task, or the effect of their anthropomorphic realism on attractiveness, trust, usability, and presence. Usually, as we see in the examples below, this is done with the assumption that the virtual human is in AR to assist the user. Hence, user preferences and the influence of embodiment on perceived trust, attractiveness, confidence in the ability to perform a task, and perceived presence have been explored in several recent papers. For example, in [29], using an OST HMD, an embodied version of Amazon's Alexa was compared with the standard voice-only version. A trend of a positive influence of embodiment on perceived trust was recognized. Also in [30] an AR agent with a human body and gestures using an OST HMD was compared with a voice-only agent in an interactive AR scenario, and improved perceived social presence with and confidence in the embodied agent could be concluded. Results on gaze behavior and size of the agent when interacting with different virtual agents in OST augmented reality are presented in [31]. Gaze and speech interaction with four different agents and the users' preferences were compared. The agents (voice-only, non-humanoid, full-sized embodied, miniature embodied) were not integrated into the task environment. The users preferred the miniature embodied agent because of its size and reduced uncanniness. As mentioned by the authors, the limited FoV of their HoloLens (34° diagonal) may have an impact on a user's sense of (co-)presence and affect an agent's perceived capabilities. For a similar reason, although not for a virtual human but an avatar representing a VR user, in [32] a miniature avatar was introduced to reposition the VR user and its communication cues in the user's FoV. From experiments with a HoloLens device and more and less realistic virtual humans, it was concluded in [33] that more realistic agents in AR were rated higher from the point of view of usability and attractiveness.

It should be noted that a virtual assistance agent is not necessarily continuously present in the AR environment. Especially with limited augmented viewing, the embodiment can be distracting rather than helpful. Its appearance can be triggered by a special event or task to be performed. The way an embodied AR agent makes its entrance into the AR environment is another issue. We will have different expectations depending on the role an agent has. We do not expect full human social, collegial, or amicable contact skills from every kind of assistant. Some assistants can behave magically, others must remain strictly realistic in their behavior. To conclude with another more general observation on all these experiments, AR experiments with virtual humans are limited, there is to learn from many experiments that have been done with embodied conversational agents and with virtual humans appearing in virtual reality, rather than in augmented reality. On the other hand, the mixing of virtual and real content in AR gives rise to own problems that cannot be fully covered with research that is purely focused on interaction performance of embodied agents or on virtual agents that are almost entirely focused on virtual content and need no knowledge of an unpredictably changing world in which they are embedded.

6 Multisensorial Awareness of Multimodal Events

Usually, we assume virtual humans who help us with our tasks in an AR environment. In future applications, we can also expect to have virtual humans who have their own or other tasks and are not directly under the command of every AR user. A virtual human in AR, can have their own view of task or life and respond to real-world events that are not under the control of the AR user or that are not intended to provide explicit feedback. Moreover, the initiative for interaction may come from a virtual human in response to an event in the real world. Such a virtual human's awareness of what is happening in the world that goes beyond direct and controlled interaction can have an impact on the experience of presence of an AR user. In this section, we give a few examples of experiments that illustrate these points of view.

Our first example illustrates how multimodality can be explored to increase the capabilities of virtual humans and multisensory experiences. In [34] a virtual human that appears to be physically challenged shows awareness of real objects and asks for help from a real human wearing a HoloLens to avoid implausible collisions with real objects. Although not mentioned in this paper, a possible extension is to give such a virtual human simulated control of physical objects with actuation mechanisms that trigger movements of objects in the real world without the intervention of a human AR user. In another collision avoidance task [35], a HoloLens user experiences visually synchronized vibrations felt through the floor and caused by the virtual human's walking. In this case, higher perceived physicality and social presence are reported.

When a virtual human exhibits awareness of an event in the real world, even if it does not actively participate in the stimuli event, does this increase the sense of social presence of a human participant? Suppose it starts to rain or the wind starts to blow in the real world. Do we expect the virtual human's hair to flutter, their virtual clothes to get wet, or see them opening an umbrella? Does the virtual human notices that the light has been turned on or that someone is passing by on the other side of the street? If we walk a virtual dog, should it respond to a real dog barking and start exploring the environment using its dog's senses? In [36] many more of these examples of relationships between the virtual and the real are presented and discussed, such as a virtual bird imitating songs of real birds in the augmented reality world or a virtual pet that gets scared away by unexpected sounds. The human user can notice this awareness behavior and any subsequent adjustments of the virtual character's behavior or embodiment where applicable. Most of such examples require a multimodal approach to augmented reality and involve crossmodal effects. In [37] a literature overview of research that addresses both AR and multimodality can be found. In the case of virtual humans, we should look at multisensorial stimuli and crossmodal effects on their behavior.

Experiments that aim at investigating the influence of awareness behavior on social presence have been designed. In [38] we can find the "wobbly table" experiment. The human participant is seated at a real table that is visually extended into a virtual world displayed on a large screen. A virtual human is seated at the virtual end of the table. If one of them leans on the table, whether virtual or real, the table will tilt slightly, synchronously in the real and in the virtual world, toward the other end. The virtual agent shows awareness of the table movement at its end. From this Wizard of Oz (WoZ) experiment, it could be concluded that this awareness caused an increase in the human user's sense of presence and social presence.

In the "wobbly table" experiment, the human subject actively participates in the stimuli events. In a follow-up augmented reality study [39] the stimulus does not come from the human participant or the virtual human, but a physical fan and a wind sensor hidden below the table. The fan's airflow is perceptible to the human subject who is wearing a HoloLens and it triggers animations in the virtual world, such as the fluttering of virtual paper and curtains. The virtual human, again in a WoZ setting, exhibits awareness of the virtual objects being affected, and also in this case the experiments showed an increase in the human participant's sense of being together in the same place. Incidentally, if the virtual human had started to shiver, we could have said that in addition to its sight sense, the stimuli addressed its virtual sense of touch and thermoception.

7 Conclusions

Our study aimed at introducing research issues that become important when we introduce virtual humans in AR environments. These virtual humans can take on a role as assistants in training, education, entertainment, marketing, and retail AR applications. Some early examples of virtual creatures introduced in AR have been discussed. How can we profit from such creatures if we give them human-like properties? What human-like properties do we expect? We tried to give some preliminary answers by distinguishing tasks and most of all, the way their virtual senses can be addressed in AR. Moreover, we had some observations using existing literature on the impact that showing its awareness of events beyond its control in the real world has on the various notions of presence. In AR virtual humans are virtual objects with human-like behavior and intelligence that are, as any other virtual object in AR, superimposed on the real world. One main observation is that these virtual objects need to react human-like to stimuli that originate in the real world.

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