Virtual and Augmented Reality Animals in Smart and Playful Cities (Invited Paper)

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***Abstract*— Our future urban environments are smart. Sensors and actuators are embedded in these environments and their inhabitants. We have an Internet of Things, where the 'Things' include objects, cars, tools, buildings, street furniture, and whatever can be equipped with sensors and actuators, including human and non-human animals. Augmented humans and augmented animals have their senses extended with digital technology. Their smart wearables connected with the smart environment make humans and animals smarter. Rather than on living animals, in this survey paper we focus on non-living virtual and augmented reality non-human animals that will inhabit our smart and playable urban environments. They will co-exist with robotic animals and (digitally augmented) humans and non-human animals. We include observations on augmented humans interacting with virtual and augmented reality animals. The paper is meant to raise awareness for the possibilities of augmented reality to introduce virtual animals for social, entertainment, and educational reasons.**

Keywords—animal-computer interaction, augmented humans, augmented animals, virtual animals, augmented reality, smart cities, playable cities, entertainment technology, sensors, actuators, street furniture

I. INTRODUCTION

In smart and playable cities we have to deal with humans and augmented humans. Smart city technology makes use of augmented humans. Due to the augmented human's smart wearables and their integration in the Internet of Things playful technology embedded in our daily living environments helps to make daily activities and situations less boring, it creates a positive and stimulating mood in which people experience more enjoyment. What about the role of (non-human) animals?

Animals, in particular cats and dogs, take part in human daily life activities. People take care of their domestic animals, engage in playful and social interactions with their animals and other animal owners. Being active with your pet animal has a positive effect on your physical and mental health. These effects can be measured with wearable technology, and persuasive technology implemented on a smartphone can be used in order to stimulate playful and social interactions with animals and animal owners. These companion animals can as well be equipped with wearables such as collars or vests that allow their owners to control them and to communicate with them, or be helpful for the animal in exploring and enjoying the urban environment and meeting other animals.

In addition to companion animals such as cats and dogs, an urban environment is inhabited by working animals. Working animals such as search and rescue animals, guide animals, and drug and explosive sniffing dogs can be equipped with task-oriented digital devices as well. In a smart city these working animals can interact with sensors and actuators that are embedded in the urban environment.

Urban wildlife includes animals such as birds, hedgehogs, squirrels, stray dogs and cats, bats, butterflies, insects, that, in principle, are not controlled by humans. In some cities it is natural to see cows or monkeys appear on streets and on buildings. Sometimes to the delight of tourists. Big cities are also visited by bears, wild boars, and foxes. Digital technology makes it possible to monitor the behavior of urban wildlife and take measures to protect and control it.

Smart and playable cities can provide non-human animals (companion animals, working animals) and their human companions and handlers with tools that improve their quality of life, or, in the case of working animals, their performance. Cities have zoos or 'wildlife conservation parks' in which AR can be used for educational purposes. But usually these AR applications augment reality with some static, textual information. Exposure-based therapy for the treatment of animal phobia also makes use of virtual animals, both in (immersive) virtual reality and in augmented reality. For example, using a head-mounted device, moving spiders or cockroaches can be displayed on the table in front of you, near your hands on the table, or on your body [1].

Animals can be augmented with wearable digital technology. We can also look at robotic animals that someday will roam our streets, but this will not be done here (see [2]). We can also introduce virtual animals in urban environments. In this paper the focus is on virtual animals rather than on digitally augmented living animals or on robotic animals.

When we talk about augmented reality, it is usually about adding visual elements to reality and viewing that augmented reality on a screen such as a smartphone, or having a more immersive experience that is made possible by augmented reality glasses and head-mounted devices, or, in the future, augmented reality contact lenses. But of course, instead of digitally generated visual information, augmentation can also relate to other generated perceptual information. Sound, smell, taste and touch can be digitally manipulated and added, mediated by other than vision-oriented devices, to how

978-1-5386-1023-7/17/$31.00 ©2017 IEEE

humans and non-human animals perceive a physical environment.

Animals can be equipped with devices that present them with a perception of the urban environment in which they are moving and in which virtual objects, tastes, smells, and sounds are added. We can augment reality for animals by augmenting their senses (feel, hear, smell, taste, and see) by using digital technology. There is no reason to restrict the concept of augmented reality to adding visual elements to reality. An augmented reality experience can also be gained by overlaying reality (environments and objects) with sound, taste, odor, or virtual touch. A smart collar that allows an owner or handler to communicate with a dog at a distance is an augmented reality device for the dog [3]. In [4] research on setting up a controlled grazing environment for cows is reported. The ideas behind this 'virtual fencing' project can be used for other animals as well. A smart collar is used to identify and track the animal based on GPS information. When the animal approaches the virtual boundary the animal receives an audible alarm and if necessary an electric shock to keep the animal within the boundary.

However, this paper is not really about augmenting animals, it is more about augmenting physical environments and integrating virtual animals moving in these physical environments. Use can be made of recordings of real animals, their behavior, and their movements, or of digitally generated animated and naturally behaving virtual animals added to a physical environment. That is, to a street, a public space, a train or bus station, a parking lot, or a cemetery. Although the underlying AR technology is extremely interesting, our focus is primarily on applications that are easy to implement and that are public-friendly and entertaining, and sometimes also have a social or educational element.

II. SMART AND PLAYABLE CITIES

Animals will be part of smart cities. In observations and designs of smart cities, the focus is on efficiency and more recently on sustainability. That is, smart cities use information and communication technology to monitor their citizens' consumption, domestic, family, social, and recreational behavior. People have to provide information to their national, regional, and local governments. Many more organizations collect information, for example, insurance companies and health services. Another source of information that can help to make a city smart comes from the social media that provide details about locations, preferences, and affective connections between their users. Sensors and actuators in houses, buildings, public spaces, and public transport also provide information about where people are, what their interests are, what they do, and how they behave. Based on this information, whether it is used off-line or real-time, digital smart city technology can help to make smart decisions that make city life more efficient and sustainable.

Another use of smart technology is to make a city more playable. To do this, we can collect data available in company-owned databases and databases that are owned by (local, regional) government organizations.

Figure 1. Dog meets delivery robot

Can we use such data and decide from such data that residents are interested in car-free streets, in independent mobility, and unsupervised play for children? In playable cities [5,6] we assume that citizens and city communities have the opportunity to use sensors and actuators embedded in their environment to address not only local safety, but also issues related to health and well-being, child-friendly traffic, and, why not, games and entertainment. Can a city be designed such that it is animal-friendly?

A distinction can be made between a city's top-down support, guidance and control of citizens' digital activities and bottom-up citizens' initiatives to use or hack existing digital infrastructure or to introduce their own digital technology in order to make urban environments more animal-friendly. Animal-friendly communities can be initiated and supported by social media. It will be interesting to see how top-down and bottom-up initiatives on animal life in urban environments will meet.

III. ANIMALS IN SMART AND PLAYABLE CITIES

Although this paper is not about living animals, living animals augmented with digital technology, or robotic animals, a few words about how animal behavior and tasks can be supported by digital technology are in order. Especially search and rescue dogs and assistance dogs can have collars and vests that allow them to be monitored, to communicate with their handlers, and to receive information from smart sensors and actuators embedded in the urban environment.

We can as well look at robotic animals that perform tasks in urban environments, or that serve as companion animals. Augmented, robotic and virtual animals have to co-exist with human animals in real, augmented real, or immersive virtual environments. Dogs will meet dog-like delivery robots (Fig. 1). Birds will be chased away from squares and buildings by bird-like drones.

Animal behavior can conflict with technology or have unexpected consequences as shown in Fig. 2 (a pigeon that does not stick to the maximum speed and gets flashed).

Figure 2. A pigeon exceeding the speed limit

IV. Virtual and Augmented Reality Animals

In this main section of this paper we give various examples of virtual animals in urban environments. Virtual animals can be projected onto the real world, including their movements, going from one place to another. Virtual animals can also be superimposed onto a user's view of the real world. If that real world is determined by the camera of a smartphone, then the animals can be projected onto the image of the world that is captured by the camera. Hence, Pikachu and Mimikyu are animal-like Pokémon GO characters that become part of the user's view of the world. More realistic virtual animals and their behavior can be displayed on billboards that have cameras that capture what is happening in their view and in real-time add animated life-like animals to the recorded real-world environment and events. More realistic virtual animal behavior can be experienced, supported, and controlled when the user wears a headset that allows immersion in the augmented physical world. In these augmented physical worlds the behavior of virtual animals can be programmed in such a way that it looks that they have knowledge of their environment, including how to interact with humans or other animals that inhabit their urban augmented reality environment. The appearance of the virtual animals can be enhanced by computer-generated perceptual information: visual, auditory, haptic, somatosensory, and olfactory. Hence, the augmentation that is generated can address more than 'just' the visual effects that are superimposed onto a user's perception of reality.

A. *Projecting Animals and Animal Behavior onto Large Public Screens*

In addition to smartphone applications, more about that in a future section, there are nice examples where virtual animals are superimposed onto real-time video recordings of visitors to a museum, travelers in a railway station, or audience members during a public event. Real-time displaying the results of this superimposition on a big screen in a museum, a railway station or during a public event, makes the audience aware of the animals in their virtual vicinity and it often happens that they try to interact with them (Fig. 3), unsuccessfully because the animals have not been equipped with interaction technology, in fact, with no intelligence at all. Just their appearance and some pre-scribed animations are visible for the audience (Fig. 4). The animals, or rather the control of their projections can be made location-aware. Audience members can be asked to position themselves at a location marked on the floor so that the projected animals seem to be aware of audience members.

Figure 3. Passer-by trying to touch a virtual animal that, together with his image is displayed on a screen in a public environment (London (UK), Waterloo railway station).

Figure 4. Augmented reality display at The Science Museum, London, 2013.

B. *Projecting Animals and Animal Behavior onto Physical Real-World Objects*

It is not that difficult to project a running mouse on a baseboard and let it disappear in a virtual or real mouse hole. But it can become part of a game or there can be a story behind it that makes it interesting [7].

In 'Shadowing', a project of Chomko & Rosier memory is given to Bristol's city lights. The streetlights record and playback shadows of those who passed underneath. Hence, passers-by can be confronted with a shadow that is following them and is different from their own shadow (Fig. 5). Hence, the real-world shadow of a passer-by can be augmented with an earlier recorded shadow of a dog or another animal.

More sophisticated technology is used in the Urbanimals project by LAX - Laboratory for Architectural Experiments in Poland [8]. In this project, various existing city locations in Bristol (UK) are modeled in 3D and the possible interactions that different virtual animals (dolphin, kangaroo, rabbit, beetle) can have with these environments are prescribed in this 3D model.

Figure 5. Shadowing

Each virtual animal and its activity can then be projected on floor or wall surfaces in its physical environment. There will be no collisions with walls or other objects in the environment and if there are stairs to climb the animal displays the appropriate limb movements. Hence, the animal acts as if it is familiar with the physical environment. The activity of animals is triggered by people passing or stopping. Each location had a Microsoft Kinect to track passers-by and their movements once they started to play with the animals. The animals could play according to some pre-defined scenarios and they tried to lure passers-by in their scenarios. See Fig. 6 where the virtual rabbit initiates a race with a passerby.

Figure 6. Race against a virtual rabbit. Courtesy of LAX laboratory for architectural experiments.

Clearly, the projection of the rabbit and its ‘racetrack’ is based on knowledge of this particular physical environment and the presence of the passerby. We can also say that the virtual rabbit has this particular knowledge and acts accordingly. Similarly, the nonverbal behavior of a dolphin projected on a tunnel wall invites passersby to engage in a jumping competition. If you are close enough it performs double backflips Can you jump as high as this virtual dolphin? The performance of the interested passerby is tracked and compared with that of the dolphin (Fig. 7).

Clearly, the projection of the rabbit and its ‘racetrack’ is based on knowledge of this particular physical environment and the presence of the passerby.

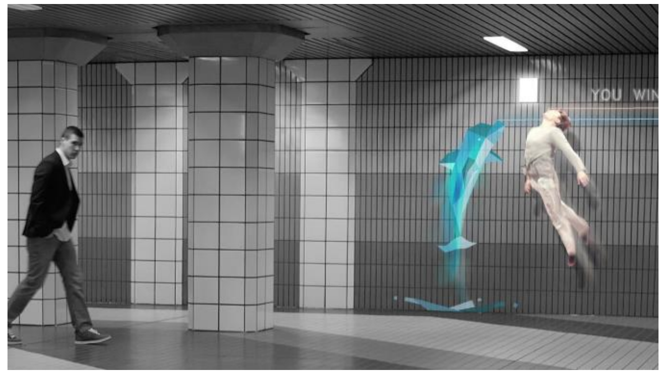

Figure 7. Can you jump higher than this dolphin? You win! Courtesy of LAX laboratory for architectural experiments.

C. *Projecting Animals and Animal Behavior into the Physical Real World*

In many countries living animals are not more allowed to perform in a circus. Can we use virtual animals instead? There is holographic augmented reality. We give two examples.

The German circus Roncalli uses digitally generated holograms of horses and elephants instead of living animals in the circus ring. So you can still see galloping horses (Fig. 8) and a life-size elephant doing headstands, but there is no need to drill the animals. The circus ring is the most important physical location in a circus. The ring and the animals’ animations have been modeled in 3D in order to have an accurate holographic projection during a performance in the real circus ring. The circus uses eleven laser front projectors for the 3D holographic 360° projections on a holographic translucent netting around the arena. It is expected that in the future use of holograms the circuses’ acrobats can interact with the virtual animals.

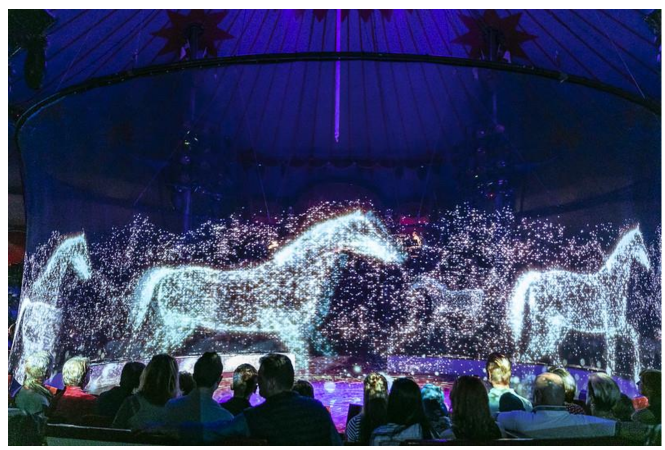

Figure 8. Galloping holographic horses in a circus ring. Copyright www.roncalli.de.

Holograms of animals can also appear on the streets. Fig. 9 shows a life-sized elephant that appeared on London’s streets in October 2018 to draw attention to illegal wildlife trade and endangered species conservation, an initiative of the World Wildlife Fund (WWF).

Figure 9. Life-sized elephant at St Paul, London, October 2018. WENN Rights Ltd / Alamy Stock Photo

D. Projecting Animals and Animal Behavior onto Smartphones Screens

Games such as Pokémon GO have animals or animaloids displayed on our smartphones. They move around, superimposed on the user's view onto the real world, but not really knowing about the physical environment.

Other commercial smartphone applications exist. Google AR allows owners of augmented reality-enabled smartphones to place animated 3D virtual animals (AR stickers) in the location of their choice. These stickers can be added on moving horizontal surfaces as well [9]. The location can be your living room, your house or any public space in your city. The animal and its movements, whether it is a tiger or a shark, will appear overlaid on what the camera of your smartphone is seeing. A chicken yard can have an animated virtual chicken added to the real chickens that can be seen walking around in the recorded environment (Fig. 10).

Figure 10. Augmenting a chicken yard with a virtual animated chicken

Leaving your house and entering your garden, augmented reality makes it possible to have virtual butterflies flying around in your garden and breeding and life cycles can be implemented, controlled and observed by a smartphone application [10]. A zoo or exhibition can have trigger points that make augmented reality animals (rhinos, gorillas, giraffes) appear on the visitors' smartphones and seemingly walk around them.

These applications of augmented reality become interesting when the artificial animals (or the systems that control these animals) have knowledge about the physical environment in which they are animated. If so, they can walk around objects, find doors, prevent colliding with moving objects, and show that they are aware of humans or other animals in their environment. There is artificial intelligence research that makes it possible to have virtual animals that, maybe in a limited way, are aware of physical, social, and many other contextual constraints that should affect their behavior. Whether it is on our smartphone or in a more immersive and head-mounted-device-controlled augmented reality environment, there is the need to model animal behavior in such a way that at least it looks that the animal knows about the environment in which it is displayed and has to perform.

E. Projecting Animals and Animal Behavior onto Billboards

There are lots of screens in our urban environments. Take a look at Times Square in New York. Augmented reality makes it possible for companies to see how a possible billboard advertisement will look when it is displayed in a particular environment. But we can have more intelligent billboards. That is, billboards that can see, hear, or smell and have been programmed to display approving or disapproving messages by a virtual agent on the screen.

Augmented reality technology has been used to prank Londoners with an augmented reality display at their bus stops. The bus shelter's wall had a fake window. The real view from that window was captured by a camera installed at the bus stop and in real-time projected on the fake window's screen. This made it possible to have virtual activity overlaid on the view presented on the fake window. People waiting for the bus looked at the window, seeing pedestrians and cars passing by, and seeing buses arrive. But suddenly they could be confronted with a prowling tiger as well (Fig. 11).

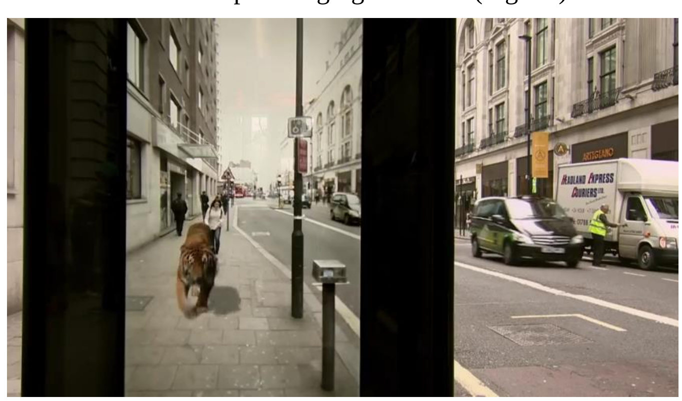

Figure 11. A prowling virtual tiger entering our physical world.

The tiger's movements were made to fit perfectly in the physical environment that was captured by the camera installed at the bus stop and projected on the screen. Also in this AR application, the designers need to model the animal's movements in a model of the urban environment that is captured by the bus stop camera in order to get this perfect fit (Fig. 12). For example, the prowling tiger should have its feet on the surface of the sidewalk, it should not collide with street furniture, and its size and behavior should change once it gets closer.

Figure 12. Recognizing street and street furniture.

Human interactions with virtual animals were not part of this project. Nevertheless, passers-by, once they understood the installation, successfully entered the physical space captured by the camera and had their friends take pictures of them of the scene displayed on the screen where it looked whether they were being chased by the tiger (Fig. 13).

Figure 13. Being chased by a virtual tiger on a London street.

F. *Immersive Human-Animal Experiences*

We can look at the projection of a real or virtual mouse projected on a baseboard, moving around and disappearing in a real or virtual mousehole. Our smartphone can show us the existence and the activity of an animated cartoon-like animal, superimposed on the camera-captured real world as it is displayed on the user's smartphone's display. We can be projected on large screens in such a way that it seems that we are surrounded by photo-realistic and naturally moving animals. Street furniture, for example, billboards at bus stops, can be designed in such a way that people waiting for a bus are in a very unexpected way confronted with predators. Interaction is possible with the virtual and not-photo-realistic animals that can become of street life, as shown in the Urbanimals project. These animals want to interact and compete with passers-by. Hence, this is not about natural animal behavior in urban environments and it is not about human-animal interaction in urban environments. Dolphins do not use pedestrian tunnels in cities and kangaroos do not climb stairs in a metro station. Nor do such animals want to enter a competition with a passer-by (Fig. 6). Nevertheless, passers-by can learn about animal behavior, they can enjoy playing with a virtual animal, and this physical activity can help to improve their health.

More immersive human-animal experiences can be brought to us if we use glasses or headsets that provide us with an optical view in which the real and the virtual world are integrated. Can we walk an augmented reality dog? What does this dog need to know about the environment in which he or she will be deployed? Does it have to be fully modeled or can we allow partly modeled environments, changes in the environment, unexpected objects, and global scenarios that are complemented with the augmented reality dog's artificial knowledge about physical environments and behavior in general? An augmented reality animal can be thought of as an intelligent virtual agent (IVA). In the past, most of the IVA research was devoted to embodied conversational agents with an emphasis on verbal and nonverbal interaction, and for some applications, on moving around in a virtual 3D environment. We now see, as stated in [11] a convergence of augmented reality and intelligent virtual agents research, where the virtual agents need to know about the physical world in which they are mapped.

In [12] Microsoft HoloLens optical see-through head-mounted devices are used in experiments where someone wearing such a device is walking an augmented reality dog in the presence of another person in the physical space (Fig. 14). Different dog behaviors were triggered by an experimenter following the Wizard of Oz paradigm and its effects on dog handler and the other person, whether or not equipped with a HoloLens, were investigated. These effects mainly relate to the locomotion and proxemics behavior of the dog handler (walking speed, use of space, body orientation, distance to others) in the presence of another person. In a multi-user augmented reality environment we have different augmented reality users that see a virtual animal in their shared space and should be able to interact with it while taking into account proximity and privacy issues and social norms [13].

V. CONCLUSIONS

We surveyed the many ways virtual animals can become part of our future smart environments. We can have realistically behaving animals displayed on screens that are integrated naturally in the urban environment. We can have head-mounted devices, smart glasses, and contact lenses that provide an augmented view on an urban environment, including the appearance and movements of virtual animals. We can have virtual animals that appear on our smartphone screen, also overlaid on a display of a real-time video-recorded urban environment, when we play a game or navigate, and explore city parts.

In this survey paper, we looked at examples of video-based augmented reality such as the virtual mirrors at railway stations and museums, on smartphones, and the prowling tiger example. We also saw projected augmented reality in the Shadowing and Urbanimals examples. Holographic augmented reality was touched upon and in a laboratory setting an augmented reality dog was introduced as an example optical see-through augmented reality.

Figure 14. Walking an augmented reality dog. Illustration courtesy Nahal Norouzi.

These examples of augmented reality do not address advanced augmented reality research issues. In some examples we have fixed camera or projector positions, just one particular physical environment to deal with, and not necessarily taking into account real-time changes that can appear in that particular environment. Hence, problems related to camera localization, environment modeling, and occlusions are avoided. And, nevertheless, playful applications of augmented reality technology can be obtained.

Many challenges need to be addressed in order to have virtual animals appear in more natural ways in our smart (urban) environments. This is especially true when we introduce virtual animals that walk in our streets and that need to be aware of the environment, the street furniture, passers-by, and robotic and digitally augmented animals that will roam the streets as well. Augmented reality is becoming a multi-disciplinary research field that in addition to computer vision and multimodal display technology has to be integrated with research on intelligent virtual agents, behavior modeling, and interaction technology.

Virtual animals, whether their behavior is projected or otherwise integrated into an augmented reality setting, will become part of our smart and playable urban environments. As mentioned in the introduction and from the examples mentioned in this paper, the animals can be introduced for social, entertainment, and educational reasons. Although it is not something to look forward to, species that are threatened with extinction or cannot live in our cities any more can continue to exist virtually.

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