Virtual and Augmented Reality

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Virtual and augmented reality technologies have entered a new near-commodity era, accompanied by massive commercial investments, but still are subject to numerous open research questions. This special issue of *IEEE Computer Graphics and Applications* aims at broad views to capture the state of the art, important achievements, and impact of several areas in these dynamic disciplines. It contains three original articles that consider important aspects of VR/AR technologies and outline future research opportunities.

These are special times for virtual reality (VR) and augmented reality (AR). These technologies have just entered the life and the imagination of general audiences in a spectacular way. Only two years ago, hardly anybody—apart from some specialists and geeks—had experienced head-mounted displays, and such headsets were still considered futuristic and expensive gadgets, limited to research or purpose-built application use. But today, anybody can purchase a complete VR setup at various consumer electronics price points at a neighborhood or online electronics retailer. These devices come complete with sophisticated and effective display and tracking technologies, and showcase impressive 3D contents and experiences, realistic and artistic. AR is following suit, with great promise and technologically advanced prototypes from major industrial players that are heavily invested in the technology.

This new era of VR and AR brings with it new issues to consider, not only scientifically but also on the side of societal impact, with potential ethical questions arising from the higher realism of VR content compared to conventional games that could lead to behavioral changes in real life, or health issues stemming from long-term use of VR/AR displays. It brings new business and mass-market opportunities, with different focus areas (entertainment, education, training, etc.). It also engages a new and young generation of passionate audiences discovering this field, eager to learn more about the best practices, the guidelines, and its current and future challenges.

Therefore, we believe that this is a good moment to take a step back for a bigger picture and examine aspects of this discipline front and back, gathering knowledge from the past but also projecting into the near and far future of VR/AR technologies.

We particularly aimed to include broad views in this special issue to capture the state of the art, important achievements, and current impact of these dynamic disciplines. At the same time, we

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encouraged the submitting authors to highlight the most important future directions for new work in the areas of their expertise. We hope that the reader may profit from these outlooks.

IN THIS ISSUE

This special issue contains three original articles that provide fresh broad views on very different topics, each one considering important aspects of VR and AR technologies. They cover: a crucial sensory modality for AR and VR (audio); the psychology and technological challenges of using limited tracking spaces for wide-area locomotion; and, in a more application-oriented outlook, immersive simulations with educational or training goals packaged as game-like entertainment.

In "Sonic Interactions in Virtual Reality: State of the Art, Current Challenges and Future Directions," Stefania Serafin, Michele Geronazzo, Cumhur Erkut, Niels Christian Nilsson, and Rolf Nordahl provide an overview of the state of the art of sound synthesis, propagation, and rendering in immersive virtual environments. They describe the different elements needed to create an immersive sonic experience and explain how to present auditory feedback in VR and AR. They illustrate various applications, and finally discuss remaining challenges and future directions.

In "15 Years of Research on Redirected Walking in Immersive Virtual Environments," Niels Christian Nilsson, Tabitha Peck, Gerd Bruder, Eric Hodgson, Stefania Serafin, Evan Suma Rosenberg, Mary Whitton, and Frank Steinicke present a survey of the literature on the topic of redirected walking. They start with an overview of the diverse methods devised to provide people with the illusion of freely walking within a larger virtual space than they are actually physically traversing. They review the different types of redirection controllers implemented to realize these methods and provide a discussion of perceptual and cognitive effects of redirection. The article concludes with an overview of remaining challenges and an outline of promising directions for future work.

In the third paper, Aline Menin, Rafael Torchelsen and Luciana Nedel propose "An Analysis of VR Technology Used in Immersive Simulations with a Serious Games Perspective." They review immersive simulation research that uses gamification techniques for educational or training purposes. Their article also presents a classification of the reviewed simulation and usability evaluation papers along several axes and discusses the benefits and limitations of using immersive VR in simulations with serious purposes. Training, treatment, and learning were major objectives of immersive simulations they reviewed and they identified several benefits of immersion.

FUTURE RESEARCH OPPORTUNITIES

There are numerous other research topics with high impact on AR and VR, which are not covered in this special issue. Sensory modalities other than audio or visual will be of increased interest as technology capabilities expand. Immersive haptics in particular is currently heavily pursued by VR research and development, with numerous investments and startup efforts on this topic, aiming to bring touch and force-feedback sensations to users interacting with virtual scenes.

Many perception issues still need to be fully understood and resolved, such as the notorious distance compression commonly observed in VR, which drastically affects VR applications such as industrial design or architectural walkthroughs. The phenomenon of cybersickness is another well-known barrier preventing a more widespread and safe adoption of immersive VR technologies. A complete understanding of all the perceptual dimensions of VR and AR experiences is still far off, with the literature reporting phenomenological observations but not yet establishing reliable models that could help address these problems methodologically or technologically.

The ever-improving core technology of VR/AR systems progressively takes into account perceptual design criteria, but many great challenges remain to be solved in addition to perception-based rendering and interaction. Wide-area tracking and modeling will enable 3D interaction in much larger workspaces. Photorealistic rendering and (re-)lighting in AR could further blur the

boundaries between real and virtual objects, paving the way to a potential confluence, or at least synergy, of VR and AR.

3D reconstruction, simulation, and interaction with virtual avatars must be drastically improved to produce fulfilling shared immersive social experiences and successful virtual embodiments. In spite of all recent progress regarding deep learning, true artificial intelligence supporting AR and VR experiences is still in its infancy.

Last but not least, assuming that all these difficult technological challenges can be met, considerable ethical and societal challenges arise through widespread adoption of VR/AR systems. A dedicated research effort should assess the long-term impact of these technologies, and could define a VR/AR "code of ethics," elucidating what constitutes a good or a bad immersive application.

CONCLUSION

We hope that this special issue and that these three overview papers will bring some insight and inspiration to the readers, and that they will also stimulate other opinions and complementary views on the past and future of virtual and augmented realities.

We realize that the road ahead is still very long and that the VR and AR research communities still have a lot of work to do, but this also makes it a fascinating, fantastic playground, and there is no doubt that, in the years to come, we will witness tremendous technological breakthroughs and amazing applications of VR and AR technologies.

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