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International Symposium on Ubiquitous Virtual Reality 2009

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Mobile phones are now ubiquitous—recent advances in mobile phone platforms have given them many new user-friendly capabilities, such as taking pictures with a built-in camera, finding locations through GPS, playing audio/video files, rendering hardware-accelerated 3D graphics, and browsing the Internet. These features with augmented reality (AR) technologies also make mobile phones an ideal user interface in smart physical environments because the phones recognize the environment, augment physical objects with related content from Internet servers, and update content by reflecting user feedback. As an extension of this scenario, mobile phones will provide a better user experience by enriching existing contents with virtual reality (VR) technologies on ubiquitous computing infrastructures.

Here, we report on the current state and future direction of ubiquitous (VR), based on the presentations and discussions we had during the International Symposium on Ubiquitous Virtual Reality (ISUVR) 2009, held in Gwangju, Korea, from 8–11 July. The program emphasized enabling technologies and applications for realizing ubiquitous VR through mobile devices and also reported on several approaches aimed at improving ubiquitous VR applications with pervasive and ubiquitous computing technologies.

MOBILE PHONES FOR UBIQUITOUS VR

Although modern mobile phones are becoming increasingly powerful and versatile, they have many limitations for use in ubiquitous VR, such as low computational power and limited resources. Thus, it's necessary to develop novel approaches that differ from traditional algorithms meant to run on desktop PCs. From this point of view, Daniel Wagner (Graz University of Technology, Austria) and Kari Pulli (Nokia Research Center) spoke about how to use modern mobile phones for ubiquitous VR applications.

The program emphasized enabling technologies and applications for realizing ubiquitous VR through mobile devices.

Wagner introduced tracking technologies that run on mobile devices and discussed how such applications could be improved. Most tracking algorithms developed for mobile phones rely on a client-server model to mitigate performance issues, but a recent trend has been to use direct tracking on phones by optimizing existing tracking methods. Although current mobile phone hardware has enough performance for real-time tracking, proper algorithm design and optimization are crucial to minimize CPU load. Code optimization for mobile phones is also important because floating-point computations are slow on mobile phones' CPUs. The remaining CPU power lets mobile phones do other jobs, such as display content on the screen and communicate with servers.

Pulli discussed how to use mobile phones for navigation and computational photography. He presented a scene recognition application designed for mobile phones that uses compressed feature vectors. Mimicking the HDR (high dynamic range) effect on mobile phones is an interesting application because their built-in cameras are improving in both performance and quality. Pulli also discussed using graphics hardware to accelerate image processing on mobile platforms. OpenGL ES 2.0 enables rich applications on mobile devices and will provide more capabilities to graphics programming through advanced graphics functions. OpenCL (Open Computing Language), an open standard for parallel programming, will make image processing on CPUs and GPUs both easier and faster.

INTERACTION ON MOBILE DEVICES

Focusing on the interaction between users and ubiquitous VR applications is important for enhancing users' experiences with those applications. How-

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ever, mobile user interfaces are challenging because of small screen sizes and limited input methods.

Bruce H. Thomas (University of South Australia) presented an approach that exploits other displays around users. In his scenario, mobile devices are connected with public displays and take the role of controller to interact with the content shown on the display. The mobile phone can also act as a "clipboard" to temporarily store information between displays. Thomas introduced the software framework required to realize such scenarios and discussed how interacting with ubiquitous VR applications in physical spaces is an important research area because AR applications merge the real and virtual environments.

Antonio Krüger (University of Muenster in Germany) talked about using public displays that configure themselves by observing their situational context and adapting the displayed content to user preferences. His team investigated the relationship between interest and attention, as well as the phenomenon of "display blindness," a phenomenon that displays for which users expect uninteresting content are often ignored. Krüger also presented a multitouch user interface for 3D visualization and user interaction in the context of a projection-based AR game with a handheld projector. Through evaluations on his systems, he was able to show that physical interaction can indeed lead to improved control of virtual objects in AR and VR applications.

EXPLOITING PERVASIVE RESOURCES

Because modern mobile devices have Internet capability, they provide a chance to exploit networked resources for realizing ubiquitous VR on mobile platforms. Xun Luo (Qualcomm) introduced the concept of "cloud–mobile convergence for virtual reality," in which mobile devices could be further augmented in terms of content and processing power with the help of cloud-based resources. He proposed that cloud-based multimedia content could enrich users' experiences, and pervasive processing power could help CPU-hungry jobs on mobile phones, such as rendering large 3D scenes or processing huge amounts of data. Muhammad Rusdi Syamsuddin (Korea Institute of Science and Technology) presented a framework that aimed to create a seamless connection between the real and the virtual worlds. In his system, the virtual world reflected events in the real world by exploiting information from sensors distributed in real space to change the state of virtual objects.

DISCUSSIONS

The attendees of ISUVR 2009 also identified several obstacles that make implementing ubiquitous VR applications on mobile phones difficult, such as limited battery life, low CPU performance, low-quality video from built-in cameras, and poor 3D rendering performance. Many attendees agreed that low computational power is the most significant barrier. A related problem is that most modern mobile phones don't have a floating-point unit, a part of a computer system that carries out typical operations, such as addition, subtraction, multiplication, division, and square root, on floating-point numbers. Allowing programmers to use GPUs and even digital signal processors (DSPs) is a potential solution for the lack of high-performance CPUs. OpenCL is one such approach that could help harness all the power of mobile phone hardware for ubiquitous VR applications. However, heavy usage of GPUs and DSPs can cause problems with battery life. Battery technologies advance much slower than other hardware technologies, but they're crucial for ubiquitous VR applications to take off.

The attendees also discussed the definition of ubiquitous VR and its characteristics compared to related concepts, such as pervasive computing,

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CONFERENCES

AR, and VR. Ubiquitous VR tries to provide a seamless connection between the real and virtual worlds, in contrast to Mark Weiser's view in his article "The Computer for the 21st Century," (*Scientific American*, Sept. 1991, pp. 94–104) in which he mentioned the notion of VR is opposite to the vision of ubiquitous computing. In ubiquitous VR, the virtual world becomes ubiquitous and there's no separation from the real world—rather, they're related through their interaction.

In ubiquitous VR applications, tracking in six degrees of freedom and synthesizing virtual content in 3D space are crucial, but they're not necessary to enhance the user experience. With content such as a text message, displaying that content on a mobile device's screen will be better for users to understand information than synthesizing it in 3D space. Studies on this topic will become more important as mobile applications continue to emerge. Another important issue about developing ubiquitous VR applications is that most current content formats, such as VRML and COLLADA (COLLAborative Design Activity), aren't designed for running on mobile devices. As such, there's a need to establish a standard for content description specifically for mobile phone platforms.

Participants at ISUVR 2009 also discussed how to extend mobile phone-based applications to wider areas. Speakers highlighted several challenges during the discussion, including robust pose tracking, recognition of scenes captured by cameras, and information filtering to provide contextually useful information. Tracking and recognizing scenes in wide areas can be addressed by fusing multimodal information, such as images from built-in cameras, user locations from GPS, and directions from digital compasses. All these sensors are already available on some smart phones, and several other phone models have adopted them. Mobile phones are highly personal devices, thus filtering out useless information based on a user's context, such as preferences, will help enhance users' experience with ubiquitous VR applications by understanding their needs.

We're pleased to see a growing community of ubiquitous VR, which is at the intersection of pervasive computing and VR. The discussions during the symposium demonstrate that ubiquitous VR will spread out in line with the advances in mobile phone platforms. Although enabling technologies are essential to realizing ubiquitous VR, the content provided through mobile devices also takes an important role for better user experience, which is the ultimate goal of ubiquitous VR. We can expect continued discussions on how virtual content interacts between the real and virtual worlds at ISUVR 2010 (http://isuvr.org) with the theme of "Toward a Digital Ecosystem."

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