Applications of Augmented Reality

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I. EMERGING TRENDS AND CHALLENGES

A key challenge faced by users of cyber–physical systems is that they cannot see and manipulate the cyber information needed to make decisions about physical world elements and processes directly in the physical context where they are relevant. For example, as construction practitioners walk around a site, they cannot see the 3-D building information model for the project directly overlaid on the walls in front of them to determine if they are built as planned. Instead, they may use a tablet or a laptop to retrieve the relevant parts of the plan and then mentally compare what they are looking at with the 3-D model on the screen. Mistakes often arise, however, due to the disconnect between information in the cyber and physical worlds since construction practitioners cannot directly see what is supposed to be built atop what is actually being built in the physical world.

This special issue explores both cutting-edge research applications of augmented reality, as well as advances in the underlying computer vision, indoor/outdoor localization, and human–computer interaction techniques that make these applications possible.

To help bridge the disconnect between cyber and physical world information, this special issue focuses on new applications of augmented reality (AR). AR is an approach to visualizing cyber information on top of physical imagery and manipulating cyber information through interactions with real-world objects. In AR systems, sensors (such as a mobile device's camera) are used to derive information about user interactions with the real world. This derived information can then be applied via smart devices (such as phones or tables) to help visualize information related to real-world objects (such as highlighted regions of a construction site image) or infer interactions with virtual information (such as inferring the change in shape of a virtual 3-D model created by using a knife to cut it) around the user.

AR has shown significant promise in overcoming cyber–physical system visualization and interaction challenges in multiple domains, including medicine, construction, advertising, manufacturing, and gaming. Despite the promise of AR and its successful application to many domains, however, significant research challenges remain related to sensor noise, precise localization, distraction, information fusion, complex information visualization, and computational complexity. This special issue explores both cutting-edge research applications of AR, as well as advances in the underlying computer vision, indoor/outdoor localization, and human–computer interaction techniques that make these applications possible.

Digital Object Identifier: 10.1109/JPROC.2013.2295873

II. SMOOTHING THE TRANSITION OF RESEARCH TO PRACTICE IN AUGMENTED REALITY

A significant trend in AR practice is the rapid uptake of academic research in industrial AR applications. In the past, a key barrier to the adoption of AR research was the lack of cost-efficient devices that possessed the sophisticated sensors and information processing capabilities needed to track users and their interactions with the real world. The widespread adoption of smartphones has driven rapid advances in the mobile computing industry and removed this key barrier to entry. Current-generation mobile devices, such as smartphones and tablets, have an array of sophisticated sensors, powerful processing and storage capabilities, and persistent network connections that make them ideal platforms for building AR applications.

A variety of companies have begun commercializing AR applications in industries ranging from retail shopping experiences to print advertising to automotive driving assistance. The bulk of these commercial applications are built atop commercial-off-the-shelf (COTS) mobile platforms, such as iPhone and Android. Many of the companies commercializing these applications are directly applying the results of academic research, such as Kalman filtering, to handle noise in commodity mobile sensors or deriving structure-from-motion algorithms to construct 3-D representations of physical objects using camera imagery.

In prior research, many investigators developed sophisticated head-mounted computing and other hardware equipment to create immersive AR applications. Despite the sophistication and novelty of the AR experiences that these devices enabled, however, they were impractical to manufacture cost effectively and use in practice. The proliferation of COTS mobile device platforms has also reduced the cost of developing other specialized sensor-based hardware platforms.

For example, head-mounted displays, such as the highly publicized Google Glass, are now becoming mainstream and provide a COTS infrastructure for transitioning the ideas developed in academic research on specialized—and thus expensive—AR hardware platforms. Moreover, COTS hardware, such as the Microsoft Kinect, is developing increasingly sophisticated capabilities and being used or modified by researchers. As the cost of custom sensor-based hardware continues to fall, academic research on custom AR hardware will increasingly become mainstream.

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Despite the falling cost of COTS hardware and the rapid adoption of AR applications in industry, key challenges must still be overcome to make AR an essential element of industrial software platforms. For example, Google Glass has spurred both interest in AR applications *and* concern over their implications for how we interact with the world and the distractions (and loss of privacy) they may impose on us. The papers in this special issue cover a broad range of key research topics that should be addressed for AR to continue its transition from research to practice.

The topics covered by the papers in this special issue span the following key areas of research: 1) the use of AR in safety-critical systems, such as automobiles; 2) building AR applications that fuse data from unmanned vehicles and robots to enhance user perception of their environment; 3) applications of AR in mobile computing; 4) cognitive models for understanding the impact of AR on human perception and approaches for using these models to enhance therapeutic applications; 5) research solutions for constructing real-world tools that can manipulate cyber information; 6) approaches for enhancing the perceived realism of AR experiences; and 7) application of AR for facility management in the oil industry.

Automobiles are one of the first and most interesting safety-critical application areas for AR, where visual distractions or poor AR views could lead to real-world harm. The rapid integration of new sensory systems into automobiles that allow the vehicle to automatically steer and brake has also helped create a platform that can be used to build an AR driving experience. Automotive companies, such as BMW, have begun experimenting with AR windshields that view visual information from the sensors, such as directions and road hazards, directly on top of the driver's view of the road. Developing these applications requires a deep understanding of how to overcome key challenges related to object registration, driver distraction, and driver perception. Gabbard *et al.* investigate these impediments to incorporating AR systems into automobiles and evaluate promising research approaches.

The recent widespread use of unmanned aerial vehicles (UAVs) in defense, emergency response, and other mission-critical application domains has led to the potential of AR applications that increase user perception of the real world by fusing that perception with information captured from auxiliary robots that work on other unmanned vehicles. Zollmann *et al.* describe their work using UAVs to create 3-D models of construction sites and mobile interfaces to fuse this information into an AR experience that can be used to compare and contrast the "as-planned" models (e.g., the architectural models or drawings of the building plan) versus the "as-built" reality (e.g., what is actually being constructed) of a building.

One of the most rapidly evolving areas of AR applications is in the mobile computing space. Smartphones are widely used and rapidly growing in popularity around the world. One of the most pervasive AR applications in the mobile computing space are AR browsers that allow users to access and view information related to the objects around them. Tobias *et al.*'s work describes current research on AR browsers and their work on image-based methods for building AR experiences with browsers.

A key question that must be answered as pervasive adoption of AR applications occurs is how these applications affect the brain and sensory perception. For example, a deeper understanding of how AR affects the brain will enable new applications of AR technology to therapeutic medical treatments. Regenbrecht *et al.* present a conceptual framework for designing such therapeutic applications of AR.

Many interactions with virtual objects are less intuitive than the same interactions with their physical world counterparts. For example, sculpting a 3-D object out of clay may be much more natural in the real world than in a 3-D modeling program. An interesting facet of AR applications is the creation of user interfaces that allow intuitive interactions with the real world to manipulate cyber objects, such as a 3-D model. Arisandi *et al.* present techniques for building real-world tools, such as tweezers and a hammer that can manipulate virtual objects. Their work investigates the challenges and research solutions for constructing these types of AR applications that mix real-world tooling with cyber information interactions.

An important consideration when building AR applications is finding methods for enhancing the perceived realism of the augmented experience. For example, AR applications that allow users to view themselves wearing different outfits for sale online is an emerging application of augment reality. A key research challenge in this domain is maximizing the realism of the user's perception of the clothes they are virtually trying on. Jang *et al.* investigate mirror-based AR systems that blend imagery of the user and the real-world environment with virtual objects to increase the perceived realism of the experience. Their work also addresses problems related to calibrating or aligning the virtual and real worlds so that the virtual objects appear in the correct locations and move properly in response to real-world changes.

Today, the practice of facility management in the oil industry still relies on 2-D drawings, paper-based project specifications, and operation manuals. Project participants, therefore, spend a considerable amount of time querying, analyzing, and communicating project information from these data representations. Such attempts—particularly for inexperienced personnel—can cause misinterpretations and misunderstandings. Hou *et al.* present an integrated framework and a prototype based on AR and augmented virtuality to support facility management activities for a petroleum refinery. The effectiveness of AR in supporting communication and information management is also discussed.

IV. CONCLUDING REMARKS

As AR matures and becomes more widely adopted within industry, new avenues of research will open to solve emerging issues. Although prior research has investigated key technical challenges of AR, the real-world application of this technology will continue to uncover new needs. Already, privacy and security are becoming major concerns as Google Glass has gained increasing traction. This special issue provides a window into leading researchers who are helping to solve these types of critical research challenges as they emerge. We look forward to hearing your feedback on mobile AR research and experience. ■

ABOUT THE GUEST EDITORS

Jules White received the B.A. degree in computer science from Brown University, Providence, RI, USA, in 2001 and the M.S. and Ph.D. degrees in computer science from Vanderbilt University, Nashville, TN, USA, in 2006 and 2008, respectively.

He is an Assistant Professor of Computer Science in the Department of Electrical Engineering and Computer Science, Vanderbilt University. He was previously a faculty member in Electrical and Computer Engineering at Virginia Tech, Blacksburg, VA, USA. He has published over 85 papers. His research focuses on securing, optimizing, and leveraging data from mobile cyber–physical systems. His mobile cyber– physical system research spans four key focus areas: 1) mobile security and data collection; 2) high-precision mobile augmented reality; 3) mobile device and supporting cloud infrastructure power and configuration optimization; and 4) applications of mobile cyber–physical systems in multidisciplinary domains, including energy-optimized cloud computing, smart grid systems, healthcare/manufacturing security, next-generation construction technologies, and citizen science. His research is conducted through the Mobile Application computinG, optimizatoN, and secUrity Methods (MAGNUM) Group at Vanderbilt University, which he directs.

Dr. White won the Outstanding New Assistant Professor Award at Virginia Tech. His research has won three Best Paper Awards and two Best Student Paper Awards. His research has been licensed and transitioned to industry, where it won an Innovation Award at CES 2013, attended by over 150 000 people, was a finalist for the Technical Achievement at Award at the South by Southwest (SXSW) Interactive, and was a top 3 for mobile in the Accelerator Awards at SXSW 2013.

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