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Introduction: Augmented Reality—Usability and Collaborative Aspects

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1. INTRODUCTION

In the past few years, *augmented reality* (AR) has received increasing attention from research and industry. By its very nature, AR is a highly interdisciplinary field engaging signal processing, computer vision, computer graphics, user interfaces, human factors, wearable computing, mobile computing, information visualization, and the design of displays and sensors. AR concepts are applicable to a wide range of areas involving the automotive industry, surgery, and office environments. In addition to a series of symposia and workshops devoted to this field, several journals have offered special issues on AR. Three special issues—from 1993, 1997, and 1999—give a good overview of contemporary AR research and development.

The first special issue, edited by Wellner, Mckay, and Gold (1993), was titled "Computer-Augmented Environments: Back to the Real World." The topics ranged from mobile computing, gestures, tracking requirements, and ubiquitous computing to the mixing of paper and digital information. The second special issue, edited by Barfield et al. (1997), offered articles on wearable systems, a magnifying glass approach, registration errors, confluence issues, and judgment of distance to nearby objects. The third special issue, guest edited by Hildebrand and Gervautz (1999), offered articles on outdoor mobile systems, tracking in unprepared environments, robust tracking, optical and magnetic tracking, occlusion in collaborative environments, three-dimensional aural augmentation, and direct manipulation. Some of these topics, such as registration errors, have become less researched. Other topics, such as tracking and mobile outdoor devices, remain prevalent in AR research and development. As AR technology advances, it has become increasingly accessible to a wider public and offers promising capabilities in supporting collab-

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orative work. For instance, the field of tangible user interfaces is a practical example of how AR technology can mediate collaborative work (Arias, Eden, Fischer, Gorman, & Scharff, 2000; Fjeld et al., 2002, Fjeld, Voorhorst, Bichsel, Krueger, & Rauterberg, 2000; Ullmer & Ishii, 2000). Such observations motivated the contributors of this issue to organize a series of articles devoted to usability aspects and collaborative uses of AR systems.

The historical background for this issue was a special session on AR, which took place at the International Conference on Human-Computer Interaction 2001 in New Orleans, LA.[1] After that conference, two of the papers presented were extended into journal articles, and an additional four came from external sources. Hence, a body of six articles focusing on usability and collaborative aspects of AR is presented here.

2. MOTIVATION FROM A HUMAN-COMPUTER INTERACTION PERSPECTIVE

In the design process of an AR application, a series of questions related to human-computer interaction (HCI) call for attention. First, who are the users, and what are their needs? This follows with: How can a system be designed to work effectively and efficiently for these users? How are effectiveness and efficiency measured in AR applications? Do users prefer an AR system or an alternative tool to go about their work? Finally, with what kind of tasks and what kind of alternative tools should the usability of AR applications be tested? A set of perceptual issues calls for further attention, mostly related to the user's visual and auditory capacities (Azuma, 1997). Embodiment and embodied interaction must also be considered and was recently addressed by Dourish (2001). In his understanding, users create and communicate meaning through their interaction with a system. Last, issues related to the work context, to the task at hand, and to collaboration call for additional investigation.

The articles presented in this special issue touch on most of the HCI questions, and topics, listed here. Some articles are more visionary and focus on novel enabling technology for collaboration, whereas others offer solid empirical work, presenting experimental studies with alternative applications. In reading some of the studies presented, the reader will recognize that the topics of usability and collaboration are dealt with simultaneously.

3. SPECIFIC ARTICLES

The need for studies evaluating the effect of computerized tools on human cooperation and communication is well justified and documented in the first article, authored by Billinghurst, Belcher, Gupta, and Kiyokawa (this issue). The authors report on two experiments: The first involves collaboration with AR technology

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[1] An overview of this special session is offered at http://www.fjeld.ch/hcii2001

as compared with more traditional unmediated and screen-based collaboration; the second involves the comparison of collaboration with three different AR displays. In both experiments, the authors used process and subjective measures in addition to more traditional performance measures. Process measures capture the process of collaboration, through the number and type of gestures and the number of deictic phrases spoken. Billinghurst et al. used these measures to analyze communication behavior and found that users exhibited many of the same behaviors in a collaborative AR interface as they did in a face-to-face unmediated collaboration. However, user communication behavior changed with the type of AR display used. The experimental task used was well suited to elicit collaboration and allowed for different styles of interaction to be evaluated within a single experiment. The authors then describe implications of the results for the design of collaborative AR interfaces and present directions for future research. The variety of different, and very relevant, measures contrasts most AR research, which typically focuses on easily quantifiable aspects of task performance, such as task completion time and error rate.

In the second article, Kooper and MacIntyre (this issue) demonstrate how the current World Wide Web (WWW) will evolve over time into a Real-World Wide Web (RWWW). A strong argument for such a scenario is the increasing integration of information available on Web servers with some kind of associated context. Hence, they call this information space the RWWW, as it merges the WWW with the physical world. Kooper and MacIntyre describe a prototype AR system that allows one to interact with a three-dimensional spatialized WWW-based information space. They present the assumptions they make about the characteristics of such a system, discuss the implications of those assumptions for AR interfaces, and describe their initial experiences creating a prototype RWWW browser. The RWWW browser does not display information nodes directly in the world; instead, the browser uses spatially located anchors to indicate the location of information nodes. This provides users with an unobtrusive indication of the information available that does not significantly interfere with their view of the world. A major interactive aspect of anchors is the use of glance and gaze selection. These two forms of selection are interesting solutions toward a usable realization of an RWWW. Although the system is designed to work without the use of additional displays, the authors have included support for hand-held devices. They show how hand-held devices can be used for convenient configuration and control of the system.

In the third article, Menozzi, Hofer, Näpflin, and Krueger (this issue) examine what happens to users of AR when of two sources of information interfere. They investigated the interference between real-world and artificial information, which affects performance in completing a visual search task. The search task was carried out under three different conditions, two of them as found in typical mobile AR systems and the third a benchmark. A video recording of a car drive served as the background. In one condition, the recording was replayed continuously. In a second condition, static images of the recording were sampled at 5-sec intervals and replayed as background. A uniform gray background served as the baseline condition. As expected, it was found that the detectability of the target was highest in the baseline condition, reduced in the presence of static images, and lowest in the condition with continuous playback. However, participants were more efficient when targets were presented in the lower, rather then the upper, part of the screen. Menozzi et al. conclude that performance in detecting artificial information depends not only on spatial characteristics but also on temporal variations of the background on which the artificial information is superimposed. Hence, the authors indicate under what circumstances artificial information in AR systems should be avoided. The results of this article are well documented and will be of interest to designers of mobile AR systems.

In the fourth article, Pedersen, Buur, and Djajadiningrat (this issue) present a design case involving two conceptual interaction designs for a frequency converter. Such converters control the speed of electric motors in many industrial applications. They are found in environments unfamiliar to design teams, making it difficult for designers to suggest usable interaction concepts. The authors therefore suggest methods to bridge the designers' imagination and users' insights into the use context. Bringing design nearer to the users, especially in the design of new interfaces, is highly interesting and important in HCI. The design team, which has a background in the Scandinavian tradition of participatory or cooperative design, observed and talked to users, sketched and produced mock-ups, acted out scenarios, and received user feedback during these field trips. By practicing design in the field, designers achieve a direct physical experience of the circumstances and a nonrepresented, nonabstracted introduction to the problems at hand. To achieve a maximum benefit of AR in the design of professional tools, Pedersen et al. argue that knowledge of the technology state of the art is necessary but not sufficient. Technical insights must hence be complemented by design approaches providing insight about the users, their work practice, and the use context. The methods suggested will most likely provide substantial help in designing successful "technology rich" applications. Through the work presented, Pedersen et al. explored an interesting problem that is not adequately addressed in the existing literature.

In the fifth article, Thomas, Quirchmayr, and Piekarski (this issue) present a model for bringing the coordination power of workflow management systems to outdoor wearable AR systems. They show how mobile equipment may be integrated with adaptive, context-aware work environments. A scenario of a medical emergency task is described to illustrate the functionality of this form of a collaborative system. Appropriate information stickers are introduced to support data collection in medical emergency scenarios through a hands-free user interface for medical workers. A key feature is the access to relevant information for users in the mobile environment as well as for those in the advanced control room. An additional advantage is the automatic recording of on-site data, which helps to build the medical record of a patient without interfering with the work of the emergency team. The user interface technology the authors propose to be investigated includes multimedia, AR information stickers, and the allocation of patient medical records to specific locations of the human body. These are novel and innovative uses of AR technology. The strength of this work lies in describing the application scenario. Thomas et al. show a strong expertise in developing outdoor AR interfaces and show how the prototyping of some elements required for the envisioned large-scale system occurred. Finally, they show how outdoor collaborative AR can be embedded into a larger workflow system.

In the sixth article, Wiedenmaier, Oehme, Schmidt, and Luczak (this issue) show how AR for assembly processes can be a new kind of computer support for a traditional industrial domain. They concisely link AR to a real-world task: assembly. The new application of AR technology is called *ARsembly*. Wiedenmaier et al. describe a typical scenario for assembly and maintenance personnel and how AR might support both. For this purpose, tasks with different degrees of difficulty were selected from an authentic assembly process from the automotive industry. Two other kinds of assembly support media (a paper manual and a tutorial by an expert) were examined to compare them with ARsembly. The results showed that the assembly times varied according to the different support conditions. AR support proved to be more suitable for difficult tasks than the paper manual, whereas for easier tasks AR support did not appear to be significantly more advantageous. As assumed, tasks done under the guidance of an expert were completed most rapidly. Some of the information obtained in this investigation also indicates important considerations for improving future ARsembly applications. Wiedenmaier et al. make a valuable contribution in presenting empirical results comparing different types of support for assembly processes. They also show some evidence that a particular AR system in some situations can have advantages over traditional paper assembly manuals. They have invested significant resources to build their systems and to run controlled studies, thereby furthering scientific knowledge of AR and HCI. Their work shows where AR is both suitable and unsuitable. For AR to achieve wide spread application, it is important to take AR "out of the laboratory" into the "real world." The work presented successfully achieves this transfer.

3.1 Common Themes and Threads

The articles in this issue weave a framework of typical AR design issues and considerations. They show how to design usable AR applications and how to support collaborative work by putting AR technology to work. Several themes recur and thus deserve particular attention. To follow the description of these themes, the reader is directed to Table 1.

All of the articles study the design and use of AR applications. Some investigate different forms of collaboration (Billinghurst et al., this issue; Pedersen et al., this issue; and Thomas et al., this issue). Two articles present work with a direct relevance for industrial settings (Pedersen et al., this issue; Wiedenmaier et al., this issue): one for the electrotechnical (Pedersen et al., this issue) and one for the automotive industry (Wiedenmaier et al., this issue). Several articles examine mobile computing (Kooper & MacIntyre, this issue; Menozzi et al., this issue; and Thomas et al., this issue), and different uses of Web applications are highlighted in three articles (Kooper & MacIntyre, this issue; Thomas et al., this issue; and Wiedenmaier et al., this issue). Applications for the medical field are examined in one article (Thomas et al., this issue), and several articles (Menozzi et al., this issue; Thomas et al., this

Table 1: Articles in This Special Issue

Article	*Authors*	*Article Title*
1	Billinghurst, Belcher, Gupta, and Kiyokawa	Communication Behaviors in Colocated Collaborative AR Interfaces
2	Kooper and Macintyre	Browsing the Real-World Wide Web: Maintaining Awareness of Virtual Information in an AR Information Space
3	Menozzi, Hofer, Näpflin, and Krueger	Visual Performance in Augmented Reality Systems for Mobile Use
4	Pedersen, Buur, and Djajadiningrat	Field Design Sessions: Augmenting Whose Reality?
5	Thomas, Quirchmayr, and Piekarski	Through-Walls Communication for Medical Emergency Services
6	Wiedenmaier, Oehme, Schmidt, and Luczak	Augmented Reality (AR) for Assembly Processes Design and Experimental Evaluation

issue; Wiedenmaier et al., this issue) present issues related to transportation. One article (Pedersen et al., this issue) focuses on user-centered design. The effect of display technology is investigated in two articles (Billinghurst et al., this issue; and Kooper & MacIntyre, this issue). Finally, the use of handheld devices is presented in two articles (Kooper & MacIntyre, this issue; Thomas et al., this issue).

4. CONCLUSION

The use of AR technology shows wide-ranging possibilities. If care and attention are paid to the usability of such technologies—in real world settings—then the evolution should be on a promising track. The implications of AR for collaborative work call for further investigation. How the use of AR systems in different work contexts will affect the way people go about their everyday occupations also merits further attentions.

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