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Marion Koelle, Patrick Lindemann, Tobias Stockinger, and Matthias Kranz (Editors)

Human-Computer Interaction with Augmented Reality

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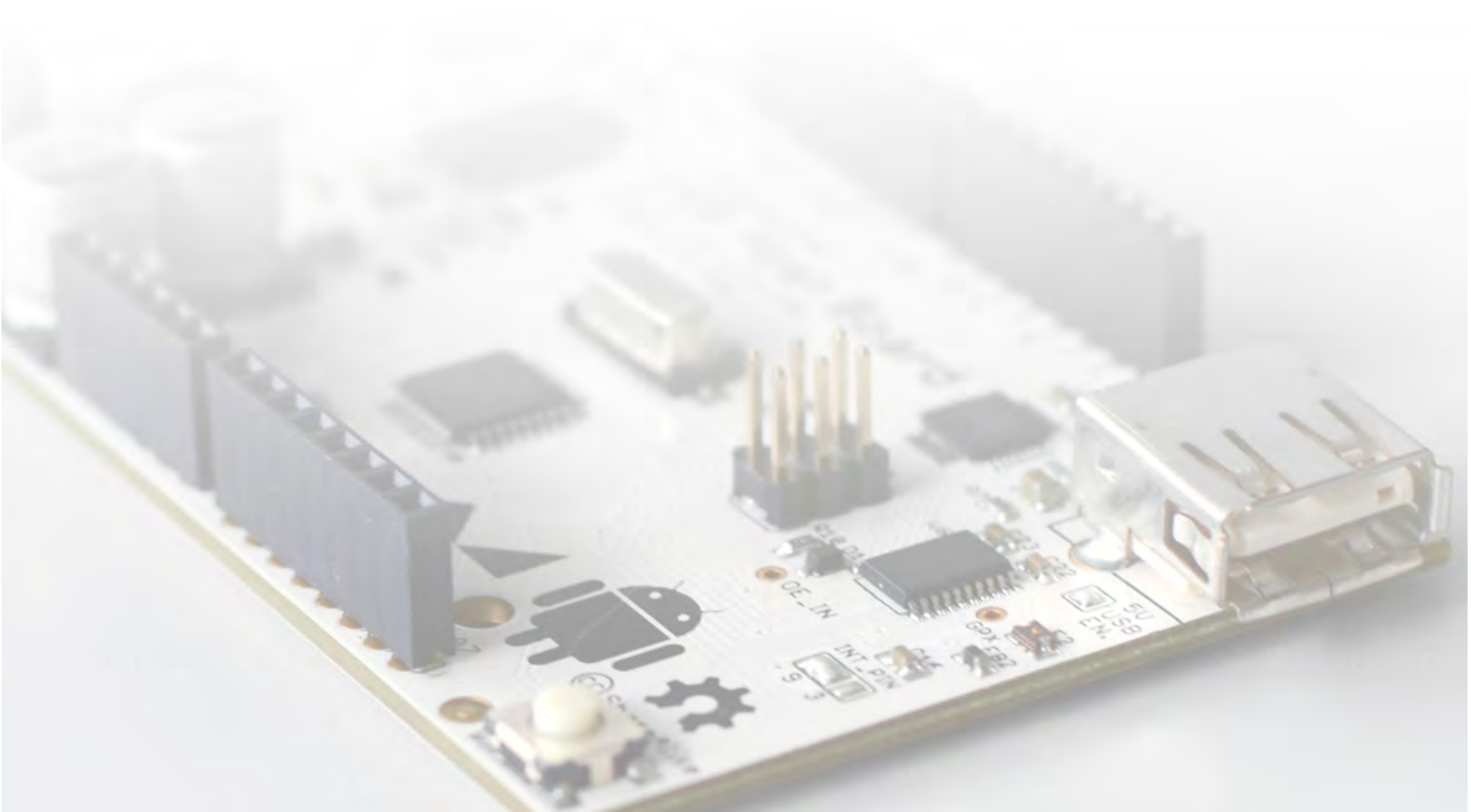

Human-Computer Interaction with Augmented Reality

Marion Koelle, Patrick Lindemann, Tobias Stockinger, and Matthias Kranz

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Contents

Preface

Augmented Reality (AR) enhances the user's view of the world with computer-generated information. While the research field of Augmented Reality recently made great progress in terms of tracking accuracy and rendering quality, human factors often play only a minor role in the development process of Augmented Reality applications. Nevertheless, there is an increasing number of developers that create AR applications. We try to satisfy their needs for design guidelines, recommendations and best practices by providing spotlights on selected applications and highlighting the relevant recommendations.

This technical report gives a brief introduction to Augmented Reality, and provides an overview of user-centered research methods that are available to Augmented Reality development as well as interaction methods and technologies.

During the summer term in 2014, the Embedded Interactive Systems Laboratory at the University of Passau encouraged students to conduct research on the general topic of "Human-Computer Interaction with Augmented Reality". Each student analyzed a number of scientific publications and summarized the findings in a paper.

Thus, each chapter within this technical report depicts a survey of specific aspects of a topic in the area of human factors in Augmented Reality.

Passau, October 2014

The Editors

Marion Koelle, Patrick Lindemann, Tobias Stockinger, and Matthias Kranz

A Brief Introduction to Augmented Reality

Prisca Bonnet
Universität Passau
bonnet02@stud.uni-passau.de

Pierre Ducher
Universität Passau
ducher01@stud.uni-passau.de

Alexander Kubiak
Universität Passau
kubiak@fim.uni-passau.de

ABSTRACT

In this report, we briefly introduce Augmented Reality (AR). Besides presenting the definitions of AR by Azuma and Milgram, this paper lists challenges introduced by human factors like discoverability or interpretability. Furthermore, technologies for AR are examined, presenting different AR devices and technical challenges.

Keywords

Augmented Reality, AR, Mixed Reality

1. INTRODUCTION

Today more than ever people have a lot of information at their disposal. Presenting these data to the user is not an easy task, one must be careful not to overwhelm him with them. Augmented Reality proposes a way to mix information with the real environment world by using different techniques. By blending data with a live view of the real world, we can better integrate them and make it feel more natural for the user. To embed information into the real environment, the most accessible and used solution is using a smartphone and its camera. However this is only one possibility. Other scenarios might require different means to display information. There are two categories: mobile and stationary AR systems. For mobile systems, the device can be worn or hand held. Stationary systems usually have a surface, like a table, to interact with them.

We will have a more formal definition of Augmented Reality in the next part, followed by the state of the art in part three. Finally, we will discuss the human factors in the conclusion.

2. DEFINITION

In 1997, Azuma defined Augmented Reality (AR) in his survey [1]: A system delivers AR if following characteristics are satisfied: The real environment is combined with a virtual one, the system is interactive in real time and registers in 3D. In contrast to other definitions this allows AR systems to use other technologies besides Head-Mounted Displays [1]. While Furht and Carmigniani define AR as enhancing the real environment by adding virtual information [4], Azuma's definition also includes applications that remove real objects from the environment.

Already three years earlier, Milgram and Kishino defined a Reality-Virtuality Continuum spanning between the real and virtual environment creating a Mixed Reality in [7] as shown in Fig. 1.

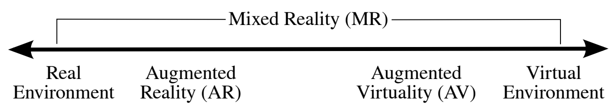

Figure 1: Milgram's Virtuality Continuum based on the definition in [7]

As shown in Fig. 1, Mixed Reality also contains the Augmented Virtuality (AV). While AR enhances the real environment by adding virtual objects, AV adds some real objects to a virtual environment [7]. Figure 2 shows an example of an AR application meeting Azuma's definition. The application combines the real world, registered in 3D with virtual addons and reacts to interactions in real time.

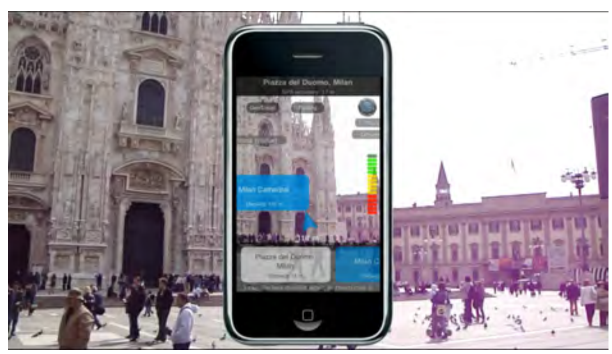

Figure 2: Example of an AR application [8]

When it comes to developing mobile AR applications, there are not only the definitions of Azuma and Milgram to be considered. Also, human factors present the following challenges [6]: The first challenge is discoverability as many users may not be aware of what services are avail-

- Prisca Bonnet, Pierre Ducher, and Alexander Kubiak are master's students at the University of Passau, Germany

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able. The application needs to assist the user by showing e.g. hints. The next challenge is the interpretability of the virtual objects by having clear meanings. Another important challenge is the usability by providing easy learnability and usage of the application. Also, the usefulness of an application is important, meaning the application offers a long term value [6]. An example of usefulness would be the use of AR for navigation instead of advertisement.

3. TECHNOLOGIES FOR AR

Augmented Reality can be applied to a variety of domains is a vast domain, using different types of devices. In this section, we will describe the different devices and methods mostly used in AR, and the technical challenges they raise.

3.1 Devices in AR

We can distinguish two main groups of devices used in Augmented Reality applications. First, there are fixed devices, that can be used in museum or public places. They can consist of screens, pedestal-mounted binoculars or projectors displaying images directly on physical objects [3]. Second, mobile devices can be carried by the user. The most widespread devices are hand-held devices such as smartphones and tablets, but head-mounted displays are getting more and more popular, with the commercialization of dataglasses such as Google's Glass.

In AR, devices can be either optical see-through or video see-through [2]. Optical see-through devices consist of a semi-transparent screen, on which information is overlaid to appear as if it was part of the real world. Dataglasses or fixed transparent screens usually are optical see-through. Video see-through devices capture the scene using one or several cameras, add virtual information on the recorded image, and display it to the user. Most hand-held devices are video see-through.

3.2 Challenges in AR

Depending on the type of device, AR applications are facing several technical challenges [4]. Most applications using mobile devices are based on computer vision techniques, in order to analyze a scene before adding corresponding virtual information. Computer vision is a vast and complex field, and the algorithms still have to be improved. Besides, the algorithms used in AR have to be very effective, in order to minimize the latency. AR applications often use one or more tracking technologies to determine the user's absolute position, or his relative position to an object. To this end, the application can use GPS data, marker-based or markerless tracking [5]. AR applications often rely on other data, such as compass, gyroscope or voice commands. The quality of a given application will depend on the precision of those sensors, which can cause accuracy and latency issues.

4. CONCLUSION

We have seen that with the rise of better and more efficient technology, Augmented Reality is now possible. It could change and improve the everyday life of everyone [4]. Nevertheless, wearing a computer equipped with sensors all day can rise some concerns. To achieve good information quality, we need to share some personal information with the device, thus causing privacy issues. Also, communication with the device may seem unnatural to most as we normally don't speak to computers. For this reason we need better interfaces increasing the need for more sensors, so that we can interact more naturally with computers. To fulfil this latter goal, devices may have an integrated camera potentially filming what is in front of the user. This is also a concern of the citizens. They are not keen to have this kind of technology being used around them, especially because of privacy issues. All of these questions will need answers before Augmented Reality becomes more popular.

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Evaluation of Augmented Reality in the Field

Alexander Kubiak
Universität Passau
kubiak@fim.uni-passau.de

ABSTRACT

While there already exist several surveys analyzing the evaluation of usability of Augmented Reality (AR) applications, most reviewed papers did not conduct any field studies. Therefor, this work reviews papers in the context of AR that conducted field evaluations. With usability becoming the central goal in the design process, field studies become more important to evaluate the user experience under real conditions. To integrate evaluation in the design process, new techniques will be required. This paper also lists methods describing how to make usability the central goal in developing AR applications.

Keywords

Augmented Reality, AR, Field Study, User Experience, Usability, Evaluation

1. INTRODUCTION

With modern technology, AR is becoming more popular. As it is still a considerably new domain, especially for the users, research about user experience is still in its infancy [24]. Nevertheless, to make AR applications more attractive, user experience should be a central goal and design strategy [24]. To identify usability problems early in the development, user testing is required. Studies show that usability evaluation is rising [3, 8]. However, most usability evaluations are conducted in the laboratory [7, 24].

While testing the performance and system functionality in the laboratory is good practice, evaluating the usability and user experience should be conducted in the field. Even though analyzing the usability in the laboratory is less time consuming and more cost-effective [15, 22], more usability problems are found in the field [7, 22, 27]. An important factor is the increased cognitive load in the field compared to the laboratory [7, 22, 23] which cannot be simulated.

Fortunately, field studies become more popular as big companies start investing into AR technology. Especially VW and EADS invest in big projects like ARVIKA [5, 10] and AVILUS [28] to use AR in the manufacturing process. This shows that AR is past being of interest for research exclusively. Not only the industry invests in AR. The military also starts using AR for their purposes [11, 12, 13]. Those projects do not only help advancing the technology used in AR, by using user-driven development and new methods like Wizard of Oz and field evaluation, they also set examples how to create good AR systems.

The paper is structured as follows: Chapter 2 lists related work evaluating usability of AR systems and comparing laboratory vs. field studies. Chapter 3 lists techniques how evaluation can be integrated into the design process of AR applications by applying traditional HCI principles or by using new approaches like the Wizard of Oz. In Chapter 4, papers conducting field studies will be reviewed. Finally, Chapter 5 presents a summary of the topic.

2. RELATED WORK

In this section, related work will be listed. It is divided into two parts. In Section 2.1, surveys analyzing the usability evaluation in different papers will be described. Section 2.2 reviews papers comparing usability evaluation in the laboratory vs. in the field and arguing about the importance of field studies.

2.1 Surveys

Dünser et al. [8] published a survey of user evaluation techniques used in AR. They reviewed all papers published between 1993 and 2007 evaluating AR applications. Overall, they identified 165 papers which were grouped in the following categories: perception, user task performance and collaboration. Furthermore, the papers were categorized according to the user study approaches. However, most papers mentioned did not conduct field studies.

Bai and Blackwell [3] review usability evaluations of papers published in ISMAR between 2001 and 2010. They identified 71 papers which were grouped in the categories task performance, perception and cognition, collaboration and finally user experience. The categories were adopted from [8] and extended by user experience. For each category, the authors analyzed common metrics used to measure the category's goal. Also, the authors analyzed the evaluation approaches and challenges. Similar to [8], most papers mentioned did not conduct any field studies. Still, this paper is the basis for Chapter 4 as the evaluation approaches are

- Alexander Kubiak is a master's student at the University of Passau, Germany
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also grouped in the suggested categories.

Olson and Salo present experiences of mobile AR applications in [24]. Conducting an online survey, they explored the user experience of applications available in 2011. Users gave mostly narrative feedback about their experiences, for example when using Google Goggles which was renamed Google Glass. While the paper does not present other work about evaluating user experience, it summarizes common experiences and discusses design considerations for future work. Also, the paper lists different measurements for user experience and states that user experience is becoming a central goal and design strategy.

2.2 Lab vs. Field

To analyze the use of usability testing in the field, several papers discussing evaluation in the laboratory vs. in the field were published. Kjeldskov et al. [15] present a mobile system to support planning and conducting work tasks in a hospital. The system was evaluated in both the laboratory and the field. The authors argue that a study in the laboratory is less time consuming and more cost-effective as transportation cost do not exist and observation of the participants is a lot easier. Cameras can be mounted to the ceilings allowing different angles of view. Also, the participants can focus more on the system instead of other tasks that arise in the hospital. The authors conclude that laboratory testing is cheaper, easier and finds more usability problems than field testing.

In contrast, Nielsen et al. [22] and Rogers et al. [27] both conclude that field testing is "worth the hassle", meaning that even though it is more expensive and time consuming, field studies reveal more usability problems. While [22] is a direct reply to [15] by evaluating and discussing the results of both laboratory and field studies, [27] argues in a more informal way.

Nielsen et al. [22] compare the two approaches by evaluating a mobile system which is usually used by skilled workers to register the use of equipment, materials, mileage and time. The system consists of a mobile phone and a scanner attached to the phone. As mentioned before, the authors argue that testing in the field found more usability problems than testing in the laboratory. While the laboratory evaluation revealed 48 problems, field testing detected 60. An important remark is that only field evaluation was able to identify usability problems related to cognitive load and interaction style. This goes well with Nunes and Recarte [23]: In their paper, they state that there exists an inverse relationship between cognitively demanding activities and visual processing capacities.

Similar to [22], the authors of [27] also argue that field testing reveales more usability problems. Rogers et al. [27] present a system for scientists and students to observe the growth of a freshly planted forest. While the laboratory testing, conducted by environmental scientists, could not reveal usability problems, the field study performed by students found several problems using the system. As in [22], a large factor was the increased cognitive load in the field. The authors conclude that despite the difficulty of collecting observations for analysis, for example in form of video recordings, the field study reveals a lot more usability problems than the laboratory evaluation.

The biggest difference found between laboratory and field testing was presented by Duh et al. [7]. They conducted an evaluation of the common use of a mobile phone, like calling or messaging other people. With 171 problems found, the field test revealed nearly twice as many usability problems as the laboratory test with 92 problems. When it comes to critical problems which prevent participants from completing tasks, the difference was even more severe: Field testing revealed 64 critical problems while testing in the lab only found 12. Aside from higher cognitive load as argued above, users also stated the lack of privacy and the noise level in the field as possible reasons for the different amount of revealed usability problems.

Concluding can be said that field studies usually reveal more usability problems, especially problems caused by increased cognitive demands that are very hard to be simulated in a laboratory. However, the evaluation in the field is more expensive and time consuming as recording the participants for analysis after the testing is difficult. Also, common practices used in the laboratory as thinking aloud might be difficult to apply in the field as there are many other people nearby and there is more noise. Furthermore the equipment has to be transported to the field which also increases the cost and time usage.

3. EVALUATION IN THE DESIGN PROCESS

As user experience and usability become the central goal in AR applications [24], it is important to model them as early as in the design process. While user experience in AR is still in its infancy [24], design goals for HCI exist. Dünser et al. [9] identify fundamental differences between traditional GUI systems and AR systems: GUI guidelines assume that the user uses mouse, keyboard and a screen to interact with the system. However, these typically do not exist in AR. There are numerous other possible interactions between the user and an AR application. Also, while traditional HCI guidelines for interfaces work in 2D, AR registers and often displays information in 3D [1].

Lacking guidelines for user interfaces in AR, applications are often developed using rapid prototyping to allow evaluation to be a recursive activity during the entire design cycle [2]. One approach is using the Wizard of Oz. After discussing the use of HCI techniques and principles in AR in Section 3.1 and showing a model for usability engineering applied to AR in Section 3.2, the Wizard of Oz will be introduced in Section 3.3.

3.1 HCI Techniques & Principles in AR

As mentioned above, there exist many HCI guidelines for GUI user interfaces. However, these cannot easily be applied to AR as information is registered and displayed in 3D [1] and AR incorporates other means of interaction [9]. Several papers propose using HCI techniques in AR. Dünser et al. [9] introduce the following common design principles for AR allowing the development of applications with better usability and user experience:

Affordance to make the application have an inherent connection between a user interface and its functions. This can be achieved by providing a model describing subject-object relationships.

Reducing cognitive overhead to allow the focus on the actual task instead of overwhelming the user with information resulting in poor user experience.

Low physical effort to make a task accomplishable with a minimum of interaction steps. Applications with interaction that is too complex will not be successful.

Learnability to provide easy learnability for a user. As AR provides novel interaction techniques, the usage of those techniques has to be easy to learn.

Responsiveness to guarantee good performance of the application as users only tolerate a certain amount of system lag [35].

Error tolerance to deliver stable applications. As AR systems are mostly in early development stages there exist many bugs. Applications should be able to continue working even when experiencing an error.

While above principles are just some desirable design principles to be integrated into the design process of an AR system, Swan and Gabbard [30] discuss the usage of traditional HCI methods in AR. In their opinion, methods like domain analysis, user needs, task analysis and use case development can easily be applied to AR. However, those methods only determine *what* information need to be presented to users, not *how* these information should be displayed.

3.2 Usability Engineering in AR

Gabbard et al. [11] describe how to use usability engineering for AR systems. This allows the reduction of usability problems already in the design process. They propose an iterative process consisting of the following phases as shown in Figure 1.

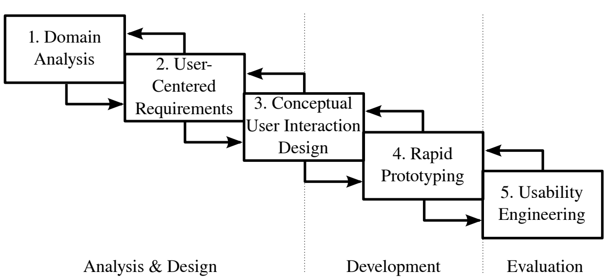

Figure 1: Usability Enginnering as proposed in [11]

As it can be seen in Figure 1, the model consists of five phases that can easily be re-iterated. The following describes the purpose of each phase:

Domain Analysis to specify the system domain by analyzing which users attempt to perform which tasks.

User-Centered Requirements to specify the user interaction with the system.

User Interaction Design to design user interactions.

Rapid Prototyping to implement user interaction designs.

Usability Evaluation to evaluate the usability.

Based on an application for the military, the authors focused on the domain analysis to show the difficulties of developing good AR applications. They state that user profiles sometimes are generated using surveys. However, with new AR applications the actual end-use population may not be easily definable or reachable [11]. They state that a user profile should include information about a user, such as the amount of computing or AR experience.

By studying military books and manuals the authors identified around 100 tasks that could be enhanced by using AR. For each task they analyzed how the AR system could support perceptual and cognitive demands. As they identified a list of features that cannot be delivered by existing AR systems, the authors want to conduct more research before continuing the development. This shows that the process of usability engineering identified problems that have to be solved first instead of creating prototypes that will not deliver satisfactory usability.

3.3 Wizard of Oz

To evaluate the user experience and usability of a system, rapid prototyping is helpful as design flaws are revealed early in the development. One promising approach is the usage of Wizard of Oz. In this approach, a wizard usually simulates either some part of the model or the complete envisioned interface [6]. Therefor, a first prototype can be evaluated very early in the design process, even when it is not clear what the underlying technology should be [6]. The wizard then works as controller by simulating unbuilt system components.

Later in the development the wizard can also be used as supervisor controlling the system, still able to override decisions made by either the system or the user. The wizard can be a moderator as well which lies between the controller and supervisor. This role is used when a component is already working but not trusted [6]. The advantage of the moderator is that it can override the component's output before it reaches the rest of the system.

The Wizard of Oz is often applied by using persons as "wizards", triggering events with a remote or a controller application when the participant arrives at some point or activates an event. This approach is used in [6] and [20].

Even though the wizard helps conducting more realistic evaluations, the awareness of it or incorrect behavior can corrupt an evaluation and compromise the results [19]. However, as user experience is becoming the central goal of the design process [24], early evaluations are very important. Without the usage of the wizard, the system, early in its development, might behave unexpectedly and contain many bugs. Therefor, the Wizard of Oz is a great method for developing AR applications as its usage allows very early usability evaluations.

Examples

Dow et al. [6] use this approach to develop a system for creating a mixed reality on a cemetery by using location-based audio recordings. They showed how well the Wizard of Oz approach works with the iterative design as they developed and implemented the system in three stages. While the first stage used the wizard as controller, the second stage only required a moderator whereas the last stage used the wizard just as supervisor.

The authors used the Wizard of Oz approach to perform early evaluation of the content the users could listen to as well as of the interface. During the iterations, they did not only improve the Mixed Reality system but also the interface for the Wizard of Oz controller.

Friedrich [10] introduces ARVIKA, a large project to use AR for development, production and service in the industry. The pilot project, sponsored by the German ministry of Education and Research and big companies like VW, EADS, Siemens and others, also used the Wizard of Oz to include concepts in the tests that have not been implemented yet. Therefor, test persons have been able to evaluate the system very early in the development.

Möller et al. [20] present different user interfaces for indoor navigation using a mobile phone. They implemented AR as well as Virtual Reality to evaluate the user experience. The navigation mechanism was also implemented using the Wizard of Oz approach. In contrast to above systems, the wizard was used to modify the accuracy of a user's position as well as guaranteeing comparable conditions for all participants. To do so, a Wizard of Oz app was built to control the instructions shown on the participants' devices. Also, the control application sent location information to the participant's device. Each participant was followed by a researcher operating the control application.

4. EVALUATION IN THE FIELD

Evaluating AR in the field is still not very common. Kjeldskov et al. [15] state that field evaluation is very expensive and time consuming. Even though the actual evaluation sessions took less time in the field, the overhead in planning and transporting requires many man-hours, resulting in higher costs. Also, recording is difficult in the field as cameras cannot be mounted to walls or ceilings.

Most of the papers conducting field studies mainly evaluate usability and user experience. The success of an AR application depends a lot on the user satisfaction. Therefor, user experience is not only a central goal, it is also a design strategy [24]. This was already discussed in Chapter 3. Olsson and Salo [24] state that user experience research is still in its infancy.

Bai and Blackwell [3] and Dünser et al. [8] both categorize published papers in terms of their evaluation. In both, papers that conduct usability evaluation have been grouped according to categories introduced by Swan and Gabbard in [30]. In [3], these categories are extended by user experience. The following list describes the categories adopted from [3] that are also used in this paper.

Task Performance to evaluate the user accomplishments when using the system.

Perception and Cognition to understand how perception and cognition work in AR.

Collaboration to evaluate the interaction of multiple users.

User experience to evaluate the user's subjective feelings.

As most of the papers cited in [3] and [8] did not conduct any field studies, the following sections describe the results found by Bai and Blackwell in [3] as well as results of an own research in the context of AR and field evaluation.

4.1 Task Performance

This section describes papers evaluating task performance. As seen in [3], the task performance is always measured in time. Usually the time to complete a task is measured. Another metric for the performance is accuracy, which is used in 63% of the papers according to [3]. Furthermore, the error rate is used to measure the performance, as a system works better if the user makes less errors. This metric is interchangeable with accuracy which increases if the error rate decreases.

Most of the papers listed in [3] did not conduct field evaluations. Listed below are papers cited in [3] that performed field studies as well as the results of an own research which evaluated the user task performance by conducting field studies.

Schwerdtfeger et al. [29] introduce an AR system to assist workers in a warehouse. Using head-mounted displays, the worker will be guided to the correct box and shown the amount of its content to be picked. The AR system was compared to the common paper approach. When evaluating the field study, the authors used error rate and picking time as measurements for performance. To observe the participants, they used a special observer who was placed on an observation deck above the experimentation area. The observer analyzed each step the participant did.

Besides measuring performance, the field test also evaluated the subjective strain using the NASA-TLX test and the user experience by questionnaire which will be described in Section 4.2 and Section 4.4.

Similar to [29], Henderson and Feiner [12, 13] also used completion time and error rate to evaluate their AR system for task localization in maintenance of an armored personnel carrier turret. The system was evaluated in field conditions with six participants. The evaluation purpose was not only to evaluate the AR system but also to compare it to a system only using a LCD display showing the next steps. Besides completion time and error rate, the authors also used localization time analysis to measure the performance. However, they did not describe how the observations were made.

In addition to measuring the task performance, the field study also evaluated the user experience using a formal questionnaire. This will be described in Section 4.4.

Kjeldskov and Stage [16] also used completion time to evaluate task performance. Instead of error rate, they used accuracy which can be interpreted the same way. The authors introduce new techniques to evaluate the usability of mobile systems. They conducted two experiments considering mobile messaging on phones. The goal was to compare different scenarios like walking on a treadmill or walking outside next to other pedestrians. To identify usability problems, evaluations were initially recorded on video to be analyzed by experts afterwards. As the authors found collecting high-quality video data in the field to be very difficult, they only recorded audio for the second experiment and took written notes. This resulted in a lack of detailed data.

The authors state that because of recording the participant's actions, it was difficult to experience realistic pedestrian motion as other pedestrians tended to move away [16].

Besides measuring task performance the authors also analyzed the work load which will be described in Section 4.2.

Completion time was also used by Morrison et al. [21] to evaluate the task performance. They present a mobile AR game using paper maps and overlay information on screen. They conducted several evaluations with the third one being a field study. Participants were asked to take photos for completing tasks. Besides measuring the completion time, the authors also counted the photos taken and grouped them by task-related and non-task-related. To collect the data, each team was accompanied by a researcher taking notes, photographs and videos.

Additionally, the authors also evaluated collaboration and user experience. The results will be analyzed in Section 4.3 and Section 4.4.

Concluding can be said that the metrics used to evaluate task performance in the field are very similar to the findings presented in [3]. In every paper the task completion time is measured and analyzed. The usage of error rate or accuracy is also very common. Combined with task completion time this shows the effectiveness of a system.

While field evaluations conducted indoors allow good observations similar to laboratory evaluations, researchers testing their applications in the outdoors found collecting high-quality video recordings very difficult [16]. Therefor, they often used written notes or photographs which however lack of detailed data.

4.2 Perception and Cognition

To measure perception and cognition, Bai and Blackwell [3] found that common measures are depth and occlusion perception, display technology, virtual information layout and registration error. Also, time and accuracy are used in half of the presented papers. However, in this category, all papers listed in [3] did not conduct any field studies. Therefor this section only contains papers of an own research.

Schwerdtfeger et al. [29] conducted a cognition evaluation as well. The paper that was introduced in Section 4.1. To evaluate the cognition, the authors used the NASA-TLX to analyze the task load and compare it to the approach not using AR. For this purpose, the heart rate variability was analyzed by making participants wear a pulse recorder. Their study showed that the task load is higher when using AR, but the difference is not significant. Also, they report about users having problems using the head-mounted display, especially with focussing. This shows that the perception of the system did not work as well as expected.

As the heart rate was measured with a pulse recorder, the analysis was not more difficult than it would have been in the laboratory.

Kjeldskov and Stage [16] also used the work load to evaluate cognition by performing a NASA-TLX test immediately after each evaluation. Therefor, the evaluation was not more difficult than it would have been in the laboratory. The paper was already presented in Section 4.1. As they evaluated the impact of movement on the ability to perform a task, the work load indicates that the perception of the application is reduced when the user is moving.

In contrast to [16] and [29], Henderson and Feiner [12, 13] did not use the work load to evaluate cognition. Instead, they measured the head movement. In their paper which was presented in Section 4.1, they described that participants had to wear a head band to collect the tracking data. As they compared their AR system to an LCD approach, the amount and degree of head movements is an indicator for the user's perception. They stated that the AR system had less movement in nearly all tasks.

Perception and cognition can also be evaluated informally, as conducted by Hile et al. [14]. They present an application for a mobile phone using AR to navigate pedestrians. To determine a user's position, they use geotagged photographs. The navigation was performed either using a 2D map or by showing floating arrows on images to direct the user. To evaluate the system in a field study, an informal study was performed by evaluating the participants' user experience in semi-structured interviews. Participants complained about missing depth of arrows making the instructions not clear.

Summarizing can be said that there is no common measure for evaluating perception and cognition. While the work load can be evaluated formally by using the NASA-TLX and is often applied, it is only a good indicator for cognition when comparing different systems. Evaluating the work load in the field does not seem to be more difficult compared to evaluation in the laboratory, as it is either measured using pulse recorders or evaluated using the NASA-TLX test immediately after each test.

Perception can also be evaluated using informal interviews where users express their experience which then can be traced back to perception or cognition.

4.3 Collaboration

In [3], the papers grouped in this category usually measured collaboration with awareness and ease of use. As already in Section 4.2, the papers listed in [3] did not conduct any field studies. The following two papers evaluated collaboration very informally.

Wagner [32, 33] presents an invisible train game using AR. The game consists of a real miniature wooden train track and PDAs simulating the trains. Users are able to operate junctions and control the simulation. Collaboration was evaluated informally by conducting unsupervised field tests. Researchers could observe users passing around the PDAs and explaining the game to each other. This showed the ease of use of the application as users could easily explain it to each other. Also, unstructured interviews were conducted with some users.

A similar approach for evaluating collaboration was used by Morrison et al [21]. In their paper which was presented in Section 4.1, they state that the application itself did not require collaboration. However, as the field study was conducted in teams, the authors observed team members interacting to use the application efficiently.

It can be seen that collaboration is not evaluated frequently. While Bai and Blackwell [3] just found 9 papers evaluating collaboration, an own research only resulted in two papers. Both presented an informal evaluation of collaboration by just observing the participants or interviewing them afterwards.

4.4 User Experience

The evaluation of user experience is split into formal and informal evaluation, similar to [3]. Formal evaluation mostly uses a quantitative approach by using structured questionnaires or interviews, the informal evaluation uses a qualitative approach allowing users to communicate their feelings about the application.

While the performance of field studies is usually more difficult than laboratory testing, the evaluation of user experience in the field can similar to the evaluation in the laboratory. As the evaluation is mostly performed by using questionnaires and interviews, there is no difference between laboratory and field. However, observing users in the field which is often used when conducting informal user experience evaluation, is more difficult.

4.4.1 Formal User Experience

In addition to evaluating task performance and cognition, Schwerdtfeger et al. [29] also evaluated user experience. The paper was presented in Section 4.1. By conducting questionnaires using the Likert scale and semi-structured interviews, they formally evaluated the user experience, particularly the discomfort of using the system. For example, using the AR system caused more headache or other discomfort concerning eyes compared to the paper system. As the observer was standing on a platform above the participant, recording and analyzing the user's actions was simple.

Henderson and Feinder [12, 13] evaluated the user experience as well. Similar to Schwerdtfeger et al. [29], they used questionnaires with Lickert scale. This paper also was presented in Section 4.1. To determine the ease of use, the satisfaction level and intuitiveness were evaluated using questionnaires. The authors found that the LCD system is easier to use, while the AR system is more satisfiable. For intuitiveness both systems were tied.

Instead of a questionnaire using the Likert scale, Walter-Franks and Malaka [34] used the System Usability Scale to evaluate the user experience. Furthermore, they conducted a structured interview. They present a pedestrian navigation application using AR and photos. To navigate a pedestrian, the system uses GPS to locate the user. Then, the user is navigated using pre-recorded images augmented with arrows showing the directions. A field study was conducted to compare the AR navigation mode to a 2D map. While the questionnaire showed a better user experience using the AR system, the interviews revealed usability problems for all modes that were evaluated.

It can be seen that formal evaluation of user experience is usually performed by using structured questionnaires and interviews. Formal questionnaires mainly use the Likert scale or the System Usability Scale to evaluate the user experience. Interviews can also be formal by structuring them with questions expecting clear answers. Usually an open question is added at the end to allow the user to comment on usability issues not covered by the previous questions.

4.4.2 Informal User Experience

Hile et al. [14] evaluated user experience using semi-structured interviews. The paper was already presented in Section 4.2. By analyzing the interviews, the authors evaluated the usage patterns, learned about confusion while navigating and received suggestions for improvement. Also, they received feedback about the satisfaction of the users. They conclude that most participants would use the AR system instead of a common map if given the choice.

Completely unstructured and informal interviews were used by Wagner [32, 33] to evaluate the user experience. The papers which were presented in Section 4.3 state that no specific or predetermined sets of questions were asked [33]. Still, those interviews helped to learn about the usability and improve the system. Also, user experience could be observed unsupervised as visitors passed around the devices and explained the usage to each other.

Aside from interviews, Miyashita et al. [18] also used questionnaires, observations by the museum staff and analysis of action logs to evaluate the user experience. They present a system to enhance museum visits with AR. Augmentation had two functions: Providing background knowledge to artwork as well as guiding a visitor through the exhibition. The observations showed that the text displayed on the device is often too small and the brightness to low. Also, the device is too heavy for many users. Interviews confirmed the observations. Still, users admitted that the system motivated them to examine the artwork more closely.

Rakkolainen et al. [26] used interviews to evaluate the user experience as well. Furthermore, the participants were asked to think aloud during the evaluation which was recorded for further analysis. The authors introduce a navigation system for pedestrians using AR with a handheld device. As the paper compares different models, the usability study determined that users prefer the 3D model combined with a map rather than 3D only or map only.

Using simple feedback by users was the choice of Pasman et al. [25]. They built a system to display large 3D models on a handheld device using AR. The purpose of their system is to simulate the presence of a large 3D model, e.g. a building outside or a sofa inside. In a field study the system was tested. Aside from determining problems with the tracking system and the brightness of the display, the field test showed that the building being rendered at the actual site was appreciated by the users. However, the authors do not describe if the evaluations were conducted using interviews, questionnaires or recordings.

A similar approach was used by Thomas et al. [31]. They introduce an AR implementation of the game Quake. Using the system, the campus of the University of South Australia was turned into a level of the game. The system was evaluated with an informal user study as the participants were asked how they felt about the system. Users commended the ease of use of the system but complained about the lag which made it difficult to aim at the monsters. Many users also found bright lightning to make it difficult to see through the display. As earlier, the authors do not describe how the participants' feelings were evaluated.

Bartie and Mackaness [4] evaluated the user experience using interviews and logs of dialogues between the user and the system. They present a speech-based system to help the user explore a city. The user wears a laptop in a backpack and communicates with the system by using speech commands. Using GPS, the system locates the user and gives information about what buildings the user can see. If desired, the system also gives additional information about a building. As the system was running on a laptop carried in a backpack, data logging was easy. The evaluation of the logs revealed some problems addressing the performance. The informal user feedback collected in interviews also revealed possible improvements.

Solely interviews were used by Kray et al. [17] to evaluate the user experience. They introduce a mobile navigation system for pedestrians using mobile phones to display routing information. The interviews were used to collect the opinions of the users. Even though the attitude towards the system was positive, interviews showed that users complained about the slow usage of 3D maps. Also, the interaction between 2D and 3D maps did not work well.

Concluding can be said that informal evaluation of user experience is mostly conducted using interviews or feedback. The interviews are often unstructured using open questions. Also, observations help evaluating the user experience. In [18], the interviews mostly confirmed the observations. When conducting informal evaluation, interviews are usually recorded and analyzed afterwards to extract the usability flaws. As seen in [4], logging can also help identifying usability problems. Especially if the field test takes longer than just a few minutes, users probably will not remember all usability problems they detected.

5. CONCLUSION

Even though usability evaluation of AR applications is rising [3, 8], field studies are still not common. Most papers reviewed in [3, 8] only evaluate usability in the laboratory. However, several papers comparing laboratory vs. field evaluation show that field studies reveal more usability problems [7, 22, 27]. They conclude that even though field testing is more expensive and time consuming, it is worth the effort and cost.

As usability becomes more important, user experience should be a central design goal [24]. To allow user-driven development, different strategies exist. One is to apply traditional HCI principles to AR. However, this is difficult, as AR registers information in 3D [1] and offers different interaction possibilities [9]. While traditional HCI methods can be used to determine what information should be presented, they do not show how to present those information [30]. To allow user-driven development the model for usability engineering can be used [11]. Another technique allowing fast usability evaluation is the use of the Wizard of Oz to simulate components that do no exist yet.

When evaluating the usability of an AR application, there are four categories, as presented in [3]. Even though most field studies mainly address the user experience by using informal evaluation techniques such as feedback or interviews, some also evaluate the task performance, perception & cognition and collaboration in the field. Task performance is usually measured in time to complete an assignment. Other metrics are accuracy or error rate. Measuring perception & cognition is often performed using the NASA-TLX to evaluate the work load in comparison to non-AR systems. Another metric is informal feedback, for example users complaining about headaches when using the AR system [29]. Collaboration is rarely evaluated. If analyzed, the study is usually very informal by just observing how people interact with the system. To evaluate the user experience most papers state questionnaires, interviews that can either be structured or unstructured and feedback. Some also use video or audio recordings or action logs to gather information about the usability.

Despite higher costs and more time consumption [15, 22] compared to laboratory evaluation, it can be seen that many papers conduct field studies to evaluate the usability under realistic conditions. As the cognitive load is higher in the field [7, 23], users are more stressed than in the laboratory. Reasons can be privacy issues, noise, low visibility because of sunlight, low GPS signal and others. Those reasons cannot completely be simulated in the laboratory which makes field testing indispensable for good usability evaluation.

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Evaluation of Augmented Reality Applications in a Laboratory Context

Prisca Bonnet
Universität Passau
bonnet02@stud.uni-passau.de

ABSTRACT

The development of Augmented Reality (AR) applications has become increasingly popular recently, with the spread of portable and cheap high-fidelity mobile devices such as smartphones, tablets and dataglasses. Those devices are particularly suited for AR applications because of their mobility and their various input mechanisms e.g. voice command, touchscreen, high-quality camera.

In the field of Human-computer interaction (HCI), usability and user experience (UX) studies are often conducted via user-based evaluation. Those evaluation can be divided in two categories: laboratory and field-test studies. While evaluation in a laboratory allows to control precisely the experiment's condition, evaluation in the field is more realistic and take more parameters into account.

Recently, new techniques has been developed to conduct more realistic evaluations within a controlled laboratory environment. In this report, we will consider several laboratory evaluation setups and discuss their advantages and drawbacks. We will describe and classify those setups using different aspects : display, interaction, controller and measures. Finally, we will discuss the main issues related to those setups.

Keywords

Augmented Reality, Evaluation, Usability, UX

1. INTRODUCTION

The evaluation on any application can be done either with or without users. If conducted without users, the evaluation is based on heuristics [2]. If several studies have been conducted to create guidelines for the evaluation of virtual environments [28, 29], heuristics-based evaluation is difficult to apply to AR applications, because of the range of the domain itself [2]. When an AR application can be needing mobile or fixed devices, one or several users, be controlled by voice command or a touchscreen, and be intended for novice or experimented users, it is indeed difficult to define relevant heuristics [6, 9].

Advances in Embedded Interactive Systems '14 Passau, Germany

Therefore, a user-based evaluation is often suitable. As AR creates a new user experience, new evaluation techniques have to be developed. The mobile aspect of AR applications require to develop new methods during conception, development and evaluation. "HCI methods, models and techniques will need to be reconsidered if they are to address the concerns of interactions on the move." [12].

Evaluation can be conducted either in the field or in a laboratory environment. Testing in the field is the natural way to conduct user-based evaluation, because it puts the user in realistic conditions, but it requires specific consideration compared to controlled laboratory experiment [18, 22].

It can be difficult to collect data in the field, and it may be impossible to concentrate research on specific aspects of the interactions [22, 24]. Furthermore, several evaluation techniques, such as Think aloud or video recording,can be difficult to use in the field [12].

Evaluating a product while sitting down in a laboratory leads to different results than an evaluation in the field, or while moving. On the other hand, focusing only on the product can lead to the finding of more usability problems [15]. On the contrary, other studies [8, 22] point out that evaluation in the field allows to discover more usability problems, due to various parameters: ambient noise, movement, privacy concerns.

A survey by Kjeldskov and Graham in 2003 on evaluation of mobile systems [14] pointed out that 71 percent of the evaluations were conducted in a laboratory environment, but most of them preferred to use a trial and error mechanism rather than focusing grounding engineering to develop new techniques to meet the challenge of mobile systems. In 2004, Kjeldskov and Stage [15] reviewed 114 papers (1996 - 2002) dealing with HCI in mobile systems. Only half of the papers considered usability, and 6 proposed new evaluation techniques. More recently, several solutions have been developed, in order to create a realistic environment in a laboratory context. Different aspects of the user experience have been studied, and have led to new ways of conducting user evaluation in a laboratory.

In the following sections, we will describe and compare several setups for evaluation in controlled laboratory environment. It can rely on a display to immerse the user in a given situation, or on specific interactions techniques. Those will be described in the next two sections. The different controllers that can be used to simulate a real environment are described in section 4. Section 5 lists the different measures used during evaluation process. In section 6, we discuss the issues related to evaluation in a laboratory environment.

2. DISPLAYS

This section covers the different displays used to immerse the user in a given situation for the evaluation. We discuss advantages and drawbacks of the described methods. We distinguish two types of setups: those where a prerecorded scene is displayed, and those which use computer-rendered environments.

2.1 Prerecorded video

Singh et al. [27] propose to use immersive video as a tool for prototyping and evaluating AR applications. It displays a recorded video in a wide field-of-view display. In their prototype, they used three screens to create a viewing angle of about 140 degrees. Their setup is shown in Figure 1.

Ostkamp and Kray [23] created an environment where any android application could be evaluated. They used an immersive video environment with a viewing angle of 114 degrees. The video footage was recorded with three cameras mounted on a tripod and an audio recorder.

This kind of approach allows to use real video footage instead of a computer-rendered environment. Therefore, the simulation is more realistic. Furthermore, it is relatively cheap and fast. Thus, this approach does not allow the user to move in the environment, and limits the control over the displayed video.

2.2 Computer-rendered environment

The main advantage of this approach is the possibility for the user to move freely in the computer-generated space. This means that the user can walk, turn and even duck, and see the corresponding image on the screen. With this approach, it is possible to control the content of the virtual environment. Therefore, it is suitable to study the influence of some parameters on the user's reactions.

To evaluate an advertising application in a supermarket, Hühn et al. [10] used a computer assisted virtual environment (CAVE). The virtual environment was projected on 4 screens disposed as a close space around the user. A virtual supermarket model was created, and adjusted to the different experiments. With this approach, the developers were able to modify the virtual supermarket to fit the needs of the experiment, and the user could move freely in the virtual space.

The main drawback of this environment was the lack of products in the shelves, and of other visitors in the virtual supermarket. Figure 2 shows the adaptability but lack of realism of their approach.

To study navigational place findings, Schellenbach et al. [26] used a virtual environment (VE) in which the user moves. They created a virtual museum, and the display was a big screen in front of the treadmill. Two projectors allowed 3D projection. They tracked the head position of the user to correct the perspective accordingly.

Computer-rendered environments are also used in van Veen et al. experiment, using the laboratory at the Max Planck Institute in Tuebingen [31].

3. INTERACTIONS

When using an AR application, the user often interacts with the system. The interaction can be limited to a mobile device used to run the AR application, or consist of several ways to move in a simulated environment.

3.1 Mobile devices

The AR application runs often on a mobile device, e.g. a smartphone or a head-mounted display (HMD). This device can be virtual, and the interaction will rely on a keyboard and/or a mouse. It can also be physical and interact if needed with the virtual environment.

3.1.1 Virtual mobile devices

When the environment is simulated with a VE, the mobile device can also be part of the simulation. Several prototyping or evaluation tools follow this approach [3, 7, 11].

For example, Ubiwise [3] is a simulation tool designed to investigate applications which use mobile phones as interac-

Figure 1: The immersive video environment of Singh et al [27].

Figure 2: The computer-rendered supermarket of Hühn et al. [10]

tion devices. Those devices are represented in the 3D simulation, an therefore have to be interacted with via mouse and keyboard. The interaction process is neither intuitive nor immersive, and cannot represent a realistic use of the devices [10].

Those approaches provide a cheap an easy way to conduct evaluation, even in the prototyping phase [3]. But the main drawback is the disruption with the real usage of the mobile device [11]. The user has to use a mouse and keyboard instead of directly interacting with the device.

Therefore, hybrid simulations, using a virtual environment and a physical mobile device, can be a good way to have a more realistic and intuitive simulation.

3.1.2 Physical mobile devices

Using a physical mobile device for evaluation, even in early stages of development, can be a rapid way to discover many usability issues [8, 10].

Leichtenstern et al. [16] used a virtual world and physical mobile phone as an evaluation platform for user studies. They implemented several interactions the user can make on the virtual world, e.g. control a TV or a heater, through several interaction techniques: scanning, pointing and touching. They conducted two user studies, one in real condition and the other one within the hybrid environment, and obtained similar results for both experiments. Since they used a standard screen to display the virtual environment to the user, some test subjects had difficulties immersing in the simulation. Using a CAVE could improve the immersion.

Hühn et al. [10], Ostkamp and Kray [23] and several others [26, 8, 15, 1] used a physical mobile device to conduct their evaluation. Since they wanted to study the user experience with a given application where the mobile device was in the center of the interaction, using a physical mobile device was the best way to have a realistic simulation.

3.2 Movement

Most of the time, AR applications are used while "on the move". Taking the user's movement into consideration in a laboratory evaluation can be helpful both for the user's immersion and to consider that part of the user's experience.

3.2.1 Treadmills

In their study, Schellenbach et al. [26] used a treadmill to simulate the user's movement in their VE. They argue that self motion is an important component of navigational place finding, as pointed out in [19]. In fact, it has been proved that cognitive and motor functions compete for shared mental resources [17, 32].

Shellenbach et al. [26] argue that laboratory evaluation allows to have a clean data collection with replicable conditions. The different parameters on the user experience can be distinguished and studied. The treadmill they used can adapt to the user preferred speed. Since the treadmill only moves in one direction, only one screen is sufficient for the user to immerse in the simulation.

3.2.2 Buttons

In the treadmill experiment by Schellenbach et al. [26], the user could only move in the direction of the treadmill. To enable turning moves in the VE, they used wireless handeld buttons to perform smooth virtual turns in the virtual museum. It was not a very intuitive approach, but it was an easy way to overcome the issue of turning moves.

Vadas et al. [30] wanted to study the action of reading on a mobile device while on the move. They wanted to compare three mobile devices, but without taking their input mechanisms into account. To that end, they asked their test subjects to use a basic input device with buttons, regardless of which mobile device they were testing. The subjects had to read a text and answer multiple choice questions. The text was displayed either on a mobile device, on an e-book reader or on a head-mounted display. The keypad used for input allowed to choose an answer and validate the answer. Figure 3 shows their setup. With this method, only the display mechanism of the three devices had an influence on the the user's experience.

3.2.3 Sensors

In their CAVE, Hühn et al. [10] used a head-tracking system to know the position of the user and adjust the displayed image accordingly. The user could duck or jump during the experiment, and see the perspective adjusted. To control his movement in the virtual supermarket, the user acted as

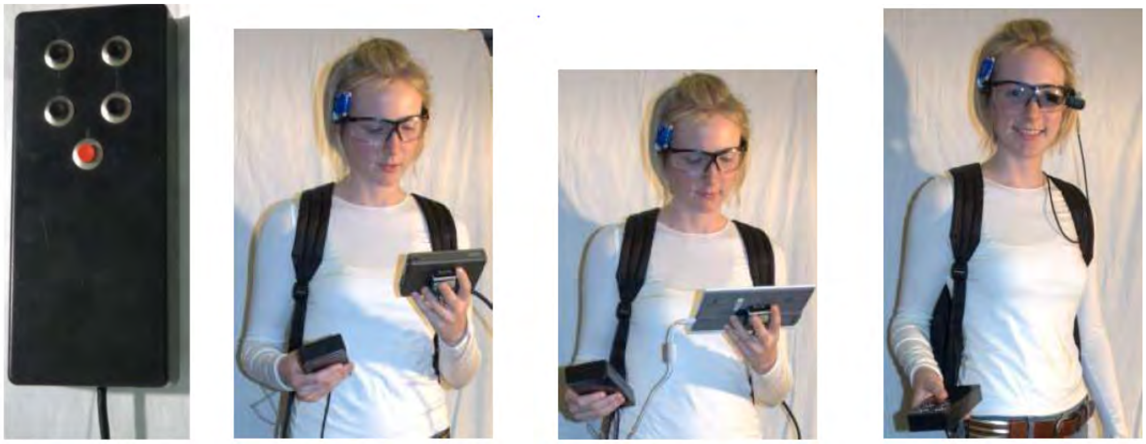

Figure 3: The experiment of Vadas et al [30]. Left: Input device. Right: Three reading devices compared in their study.

a "human joystick". When standing in the center of the CAVE, the virtual camera does not move. When the user move away from the center, the virtual camera moves in the same direction as the user. Since the CAVE provides a 360 degrees display, the user can turn freely in the virtual supermarket. This was a good solution to allow the user to move freely in the virtual environment. However, the users could experience dizziness due to disorientation in the CAVE.

4. CONTROLLER

When evaluating an AR application in a laboratory context, there is often a need to control the virtual environment, or to simulate real world conditions. In this section, we describe several ways to achieve this goal in a limited amount of time.

4.1 Wizard of Oz

The Wizard of Oz paradigm is described in [5]. Using a Wizard of Oz system allows to conduct user studies without the need of a high-fidelity prototype. The Wizard of Oz paradigm was e.g. used in [20] to simulate high-precision indoor tracking.

Hühn et al. [10] simulated the act of selecting a product in their virtual environment by asking the user to make a grabbing gesture, while the developer played an auditory feedback. This is a easy and rapid way to simulate this interaction, without spending to much time on development. In this case, the act of grabbing a product was not in the center of this experiment. Therefore, the lack of realism of this interaction did not represent an important issue.

Schellenbach et al. [26] used a Wizard of Oz mechanism as well. The user, who only could move in one direction on the treadmill, had the possibility to use voice commands to control turns in the virtual environment. Voice recognition has not been implemented in this experiment, but the researcher acted as a wizard by manually running the turning movement when the test subject emitted the voice command. This was more intuitive for the user than wireless buttons, and using a Wizard of Oz mechanism was a way to reduce implementation time without modifying the user's experience.

4.2 Prototypes

In his research on interactive public displays, Nakanishi [21] used two different methods to evaluation an application in early stages.

The first method used full virtual prototyping, where the environment, display and users are represented in a virtual world. He used Landolt rings to clarify whether an element was clearly visible to the users, which allows to adapt the text or images to an appropriate size. The visual field of each virtual user was represented by a green cone-shaped light. This method allows to discover many usability problem without needing to deploy the system, which can be very expensive, especially for public displays.

The second method used by Nakanishi involve miniature model of the system, using miniature characters, cameras and displays. This is a good solution to deploy a miniature version of a public display, but it can be difficult to take many parameters into account, e.g. brightness level. The methods used by Nakanishi are illustrated in Figure 4.

4.3 Sensor overwriting

In their immersive video environment, Ostkamp and Kray [23] used android push notifications to manipulate the GPS information without needing the source code of the application. However, this method only works with GPS information, and cannot be used for other sensors e.g. compass.

5. MEASURES

Usability can be measured via objective and subjective measures [4]. Most of the time, usability problems are identified via subjective measures such as questionnaire or Think aloud.

Objective measures are used to consider performance or learning curve. In this section, we describe several types of measure commonly used during evaluation in a laboratory context.

5.1 Usability questionnaire

Usability questionnaire is a simple way to discover usability issues [2]. Therefore, it is commonly used to collect subjective data on an application.

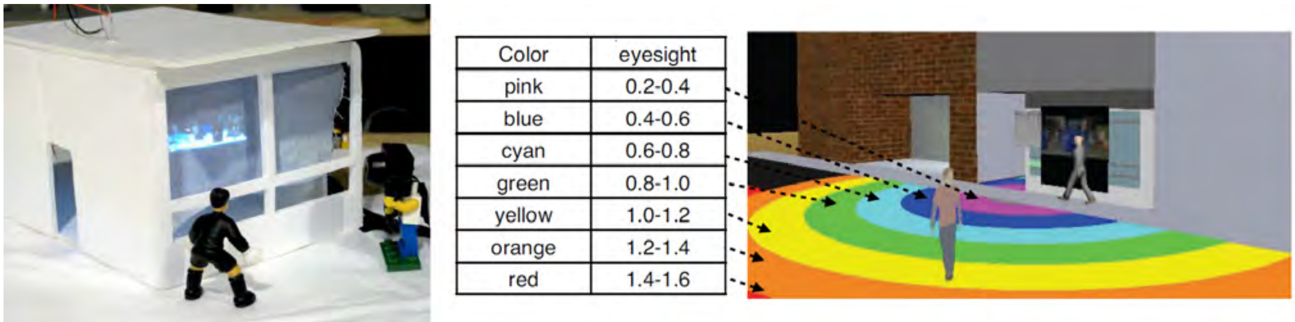

Figure 4: The experiment of Nakanishi [21]. Left: Miniaturing. Right: Full virtual prototyping.

In their paper, Duh et al [8] compared laboratory and field tests to evaluate a mobile application. They used a usability questionnaire to gather information of the user's subjective response to the experiment. They used both Likert scale and open-ended questions.

Hühn et al. [10] studied the perceived intrusiveness of an application in different conditions. After the experiment, they asked the participants to fill out a questionnaire to measure the user's reaction to the add. Using the same questionnaire in different conditions, they were able to verify their hypotheses.

In their experiment, Vadas et al. [30] used the NASA Task Load Index (TLX) to measure subjective workload ratings. They used this questionnaire to compare the perceived workload while reading on three different display technologies: palmtop computer, e-book reader and HMD. With the results, they were able to determine which device was perceived the most frustrating or demanding the most effort.

Kjeldskov et al. [15] also used the TLX to compare six evaluation setups: walking in a pedestrian street, sitting at a table, walking on a treadmill at constant or varying speed, and walking on a constantly changing course at constant or varying speed.

5.2 Think aloud

The Think aloud technique is a simple way to identify usability problems. The participant is asked to speak as much as possible during the experiment. It allows to understand the user's subjective response to an application, and to identify usability problems in a more spontaneous way than with a questionnaire.

To identify usability problems, Duh et al [8] used the Think aloud technique and recorded the user's reaction and comments. They noticed that this technique is easier to use in a laboratory environment than in the field, mostly because of social behavior issues in real conditions.

Because of the ambient noise and the presence of strangers, Think aloud may be difficult to use in a field setting [8, 25]. But in a laboratory evaluation, it is a trivial way to observe the user's reaction to an application.

5.3 Video recording

Video recording allows to study the user's reaction to an application (e.g. body language, frustration), but is also a way to conduct retrospective Think aloud. The main advantage of retrospective Think aloud is that the participant can focus on the application during the experiment, and take the time to analyze his reaction afterward.

Kjeldskov et al. [15] compared six evaluation setup in the experiment. They recorded all evaluations and used three experienced usability experts to identify usability problems by viewing the video.

Duh et al [8] also used video recording to analyse the user's response to the given task.

While video recording can be complicated in a field evaluation [8, 15], it is easy to use in a controlled laboratory environment.

5.4 Sensors

To study the user's behavior toward an application, different sensors can be used. It can consist of head or eye tracking, or sensors to capture the user's posture or movement.

Schellenbach et al. [26] proposed a setup where the user's movement on a treadmill can be studied. The VICON motion capture system allows for body motion capturing. Such a setup can only be realized in a laboratory environment.

5.5 Performance

To compare different applications or setups, objective measures can be taken, to allow a quantitative comparison.

Vadas et al. [30] asked their test subjects to walk a path while reading short texts and answering multiple-choice questions. As they intended to compare three display technologies, they measured the walking and reading performances. They considered the reading time, the percentage of correct answers and walking time to quantify the differences between the devices.

Kjeldskov et al. [15] also measured the test subject's performance on five different evaluation setups in order to compare with the performance in real conditions (here, walking on a pedestrian street).

6. ISSUES

We described several setups allowing to conduct realistic evaluation in a controlled laboratory environment. However, a laboratory evaluation will not give the same results as a field evaluation [8, 15, 22].

In this section, we will describe the main issues related to evaluation in a laboratory environment.

6.1 Virtual Environment

When evaluating AR applications using a virtual environment, different issues may occur.

First, the physical environment can be limiting during the experiment [4]. For example in the setup of Schellenbach et al. [26], the user can only move in one direction. The physical limits when interacting with a virtual environment may prevent the user from accomplishing some actions, e.g. reaching a given point in the VE.

Second, the interactions between the participant and the VE are limited. Interactions with an object or another person will be limited or artificially simulated, as in [3, 10, 11]. This prevents the user from completely immerse in the simulation and may cover up usability problems.

Third, computer-rendered may lack realism, and therefore introduce bias in the user's reaction to an application. Advances in computer graphics may allow to render more realistic virtual environments in the coming years, and therefore help overcome this issue.

6.2 Device reliability

When using devices in a laboratory environment or simulating interaction with a Wizard of oz technique, the device's reliability may not be taken into account. For example, the accuracy of GPS location is not always ideal in real conditions, especially for indoors applications. This lack of accuracy won't occur when using a Wizard of Oz technique.

The ambient noise of real conditions may not be taken into account when using an application with voice recognition features in a laboratory experiment. Therefore, a perfect application in laboratory conditions may be difficult to use in the field.

The brightness level or speaker volume of a smartphone can appear ideal in laboratory conditions, but not in certain field conditions.

In those cases, several usability issues may be neglected [8].

6.3 Movement

The user's movement is an important part of the UX [17]. Allowing the participant to move in the virtual environment is a way to improve the evaluation's realism [10, 26], but the evaluation's results will still differ from the results in real conditions [8, 15].

New VE technologies such as the Virtualizer by Cyberith, shown in Figure 5, may help overcome some issues. The Virtualizer is an omnidirectional treadmill allowing the user to move in any direction within a very limited space. The user can walk, run or even duck and jump in a natural way, and his movements are directly transmitted to the computer. Combined with a CAVE or a HMD, this technology can allow to overcome movement-related issues, without needing extra space.

6.4 Social behavior

The main drawback of laboratory evaluation is the lack of realism or the non-existence of social behavior. It has been proven that social behavior has an impact on the UX [8, 22], but it is difficult to conceive a laboratory experiment including other users in a realistic way. Users can be added in a VE [21] or played by real persons [8], but it will not be completely realistic.

However, social behavior may be affected in a field evaluation as well, due to the devices used to record the experiment [8, 15].

Another issue linked to social behavior is the fact that the user knows he is being observed. Therefore, his behavior will be affected by this knowledge. It is possible to realize observations without having the user aware of it [13], but the observation will be limited. Furthermore, this kind of experiment can only be conducted in the field and may rise privacy concern.

Another approach is to let the user ignore the main goal of the experiment. Hühn et al. [10] conducted their experiment in that way: they gave the user a task to accomplish in the virtual environment, while it was their reaction to the

Figure 5: The Virtualizer by Cyberith. Source : http://www.cyberith.com/en/virtualizer and http://www.cyberith.com/en/press

display of an advertisement on their mobile device which was observed. However, this approach is limited and cannot be applied on every problems.

7. CONCLUSION

In this paper, we described several setups to conduct realistic user-based evaluations in a controlled laboratory environment. We described the various displays, interactions, controllers and measures available to conduct those evaluations.

We discussed the advantages and drawbacks of one solution against another: prerecorded video against computer-rendered environment, physical mobile device against virtual mobile device, Wizard of Oz against Prototype.

We identified several evaluation techniques and measures, such as video recording, Think aloud and movement capture, which are easier to use in a controlled laboratory environment. We also discussed to what extent laboratory evaluation allows to control an experiment's conditions.

We described several setups which offer interesting upsides: a CAVE with real control of the environment and possibility for the user to move freely in the VE [10], an immersive video environment using real video footage and compatible with context-aware applications [23], and a setup with a treadmill, a 3D display and the possibility to model the participant's movement [26].

However, even with a very realistic environment, they are several issues remaining. First, real conditions, e.g. lightning, ambient noise or sensor accuracy, are difficult to simulate perfectly in a laboratory environment. Second, the user's movement won't be perfectly natural, due to the physical setup. Third, the user's behavior will be affected by the evaluation. The social interactions won't be realistic, and the knowledge of being observed will affect the user's behavior. Those issues are difficult to solve, even if recent technological advances may help to overcome some of those problems in the coming years.

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Interaction with augmented reality

Pierre Ducher
Universität Passau
ducher01@stud.uni-passau.de

ABSTRACT

In this paper, I will present the current techniques to interact with Augmented Reality. Indeed, the interaction part in AR is mandatory as per definition AR makes the added information interactive. First, the introduction will tell you about what is different in interacting AR as opposed as usual computers. We will then go through the different ways of interacting with Augmented Reality, as many of them are usually not so well known. This goes from Tactile UIs, to aura UIs along with Haptic and Tangible UIs or also gaze tracking. The combination between those is also possible, creating Hybrid UIs. Two main problems, among others, are introduced by the usual ways of interacting with AR. The Dimension Gap when interacting with a 3D content through a 2D interface or the screen concealment problem. We will see why and how to solve those problems with new or different kinds of interaction.

Keywords

Augmented Reality (AR), Interaction, Human Interface Device (HID)

1. INTRODUCTION

People today are used to the WIMP (Windows Icons Menus Pointing) paradigm to interact with a computer. This is the conventional desktop UI metaphor that we find in almost all operating systems. But with augmented reality, we can not use this paradigm as it wouldn't make sense to have windows floating in the reality. Even though this paradigm is not relevant any more, we still need to manipulate objects, thus the need for a way to select, drag, resize, remove, add etc. objects. Indeed, Augmented Reality is per definition interactive, so we need a way or multiple ways to interact with it. User Interfaces and inputs are used to change the system state and thus interact with it. In [14], the researchers are categorizing interfaces into 7 different groups. They have Tangible UI and 3D pointing, Haptic UI and gesture recognition, Visual UI and gesture recognition, Gaze tracking, Aural UI and speech recognition, Text input and finally Hybrid UI. I will add Tactile UIs to this list, but they can be seen as a subcategory of Haptic UIs, this will be explained later in part 2.3.

- Pierre Ducher is a master's student at the University of Passau, Germany

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2. OVERVIEW OF THE DIFFERENT INTERFACE TYPES

To have a better idea of the different possibilities to interact with augmented reality, here is an overview of the different HID. Table 1 presents different techniques to interact with virtual reality depending on their mobility and the way of interacting with them. The references are referring to the cited solutions in the same order they appear on their respective lines. Nowadays, any computer with a web-camera or phone with an image sensor can be an AR device. Especially smart-phones, which have cameras along with a touchscreen and other sensors such as a gyroscope, compass, GPS or accelerometer. That's why most of the AR systems make use of a touch-screen. This area is evolving and we can see today projects such as ATAP Project Tango from Google [7] trying to integrate a depth sensor into mobile devices. For Project Tango, the main goal is not direct interaction from the user (i.e. using it to "see" his hands) but to create a map of the environment. Mapping the user's environment in 3D allows for a better integration of virtual object.

2.1 Tangible UI and 3D pointing

The first step toward a more natural user interaction is to have something both tangible and registered in 3D to manipulate for the user. This way the user is not lost with abstract concepts and can relate to already existing concepts. The Studierstube project by Szalavári et al. [24] implemented this principle by having a pen and panel being tracked by their system. The user sees the layer of augmented reality with his see-through glasses. The pen is used to do any 3D manipulation, with 6 degrees of freedom, and the panel is here to display information, menus or options that would other be a problem to integrate with reality. The system "projects" information on the panel, as if it was a 2D display. This system makes collaboration relatively easy. Users can manipulate a 3D model with their respective pen and will share the view of this 3D model. Their goal is to have naturally integrated displays, represented by the panel, and enabling the users to independently control the 3D model from their viewpoint. Their experiment showed that this kind of system is ideal to work collaboratively on synthetic data, such as 3D curves.

More recently, we have seen this kind of user interface

	Fixed	Handheld	Wearable	references
Tangible	Studierstube, PlayStation 3			[24]
Tactile		Smartphones (Hürst et al.)		[12]
Visual 2D	PlayStation 2 and 3	Smartphones (Hürst et al.)		[12]
Visual 3D	HoloDesk, Studierstube MirageTable	Tango	Digits	[11], [24], [19], [3], [7], [13]
Gaze	FreeGaze		Occulus Mod, Google Glass	[20] [5]
Hybrid	Sublimate	KITE, 3DTouch & Homer-S	Google Glass	[15] [22] [18]

Table 1: User Interfaces Categories

Figure 1: SensAble/Geomagic PHANTOM Omni Haptic Device[1], providing force feedback to the user.

with video games and the Nintendo Wii, where the user has a "remote" integrating an accelerometer and infra red camera. This system enable the gaming console to track the gesture of the user precisely while the user still has a concrete object in his hand. Feedback can be given to the user with either vibrations or sound, also integrated in the controller.

2.2 Haptic UI and gesture recognition

To have a better feedback and a more realistic feeling when interacting with augmented reality, Haptic user interfaces have been introduced. The difference with these category of interfaces is that the force is not only from the user to the device, but also from the device to the user. This interfaces are usually arm robots, for instance the Phantom by SensAble, see figure 1, which is a popular device for research purpose.

Hayward et al. [9] list and review Haptic interfaces and devices. One of them is a joystick by Rosenberg et al. [23], used in their study to rate the user preferences on haptic virtual surfaces. To do so they had a joystick with two degrees of liberty manipulated by the user. They simulated different kind of feedback, either having a damper or a spring wall model. This kind of studies shows that no aspect should be neglected when working to build a more natural user interface. Indeed, every detail can make the user experience better.

Gloves have also been used with an added haptic feedback, for instance the buzzing gloves of Buchmann et al. [4]. But Haptic UI in general is usually bulky and difficult to use for augmented reality, especially for mobile systems.

[1]http://www.bobspaller.com/phantomomni.html

2.3 Tactile UI

Touch-screens with vibration could be considered the poor man's Haptic UI. This kind of input is only 2D, and the haptic feedback is determined by whether or not the device is integrating a vibrator. But this has the advantage of having the input right in front of the display, making it easier to interact with virtual elements than with a traditional haptic device, such as a Phantom. Touch-screens are part of the broader category of Tactile UIs.

This area could itself be split in several categories, it has already been done in a survey [2], but we are not going to spend that much time talking about them in the present paper. We will only have an overview of what is existing. Human finger tips contain many sensitive nerves, this is only logical tu use this to give feedback information to the user. Most of the tactile interfaces use an array small actuators to "touch" back the user's finger. Only the mechanical principle changes between the different devices, with motors, electrostatic or piezoelectric technology, pneumatic, electrical etc. to give sensation to the user's fingertip. Of course tactile interfaces can be used for blind people to read in Braille. This is a nice way to have augmented reality for blind people along with Aural UI. Arrays with taller actuators are also used to produce a plane which can be deformed. This is the case with MATRIX (A Multipurpose Array of Tactile Rods for Interactive eXpression) [21] (see figure 2) and more recently with Sublimate [15] (see figure 3). The latter combines an array of actuator with a see 3D see-through display, thanks to a half-silvered mirror and shutter glasses. They also use a "wand", a Tangible UI, thus making this system a Hybrid UI. The actuators are both used to give the user a feedback and to be manipulated by the user. In figure 3, the user can move the actuators to change the shape of the surface. They also have a collaborative work use-case with a "Multi-user geospatial data exploration", where they use tablets in addition to the rest in order to extend the active workspace, interact and add layers of data.

Tactile UIs are not limited to fingertips, and some devices to substitute vision have been developed [17], they are placed on the tongue are allowing disabled people to see again.

2.4 Visual UI and gesture recognition

When leaving the Haptic feedback aside, less cumbersome user interface can be achieved. Visual UI for instance, tracks the hands of the user. It can be done with a camera, when doing so, the user's hand are free and don't have to manipulate any device. The camera can be placed at different

Figure 2: MATRIX [21], Multipurpose Array of Tactile Rods for Interactive eXpression, an array of tactile actuators

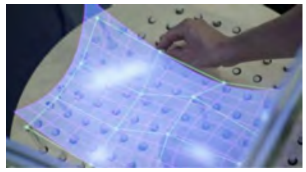

Figure 3: Sublimate [15], 3D interactive plane with actuators

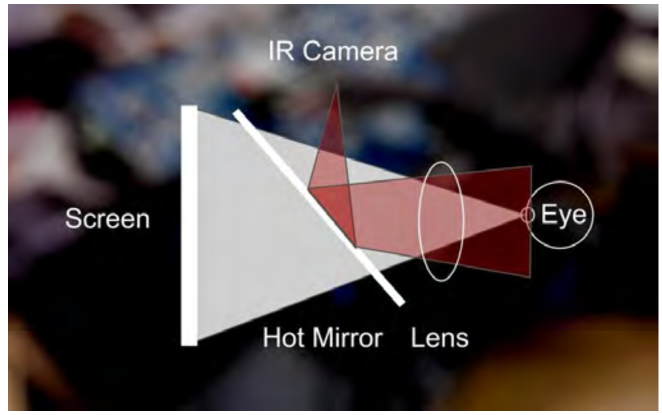

Figure 4: Homebrew Oculus Rift Eye Tracker [5]

places. Externally, filming the user, around the neck of the user, oriented toward his hands or around his wrist, has been demonstrated with UbiHand [1].

This category can be split in two, the 2D and 3D devices. Smartphones really often use their camera for gesture recognition but are limited to 2D whereas a device such as UbiHand [1] or Digits [13] can model in 3D the hand of the user. The latter aims to be used with mobile devices whereas it is not especially the case for UbiHand. However, both aim at being low cost. Digits wants to be reproducible using only off-the-shelf components. The advantages against 3D depth cameras is that depth cameras are not yet precise enough to track our finger, but we use our fingers every day to do complicated things. For this reason using fingers to do gestures, and not only the arm or hand, is viable. Digits is really precise and permits to do fine work on virtual objects.

Systems such as HoloDesk [11] or MirageTable [3] both have demonstrated that the recognition accuracy is much better in 3D than in 2D. The latter makes use of a depth camera, 3D glasses and a beamer to view the scene in 3D whereas HoloDesk also makes use of a depth camera but projects the image aligned with reality on a see through mirror. Although aligning the virtual layer with reality can be an immersive experience for the user, having this layer in 2D can introduces problems, for instance the Dimension Gap of which we will talk later. For this reason, usage of a 3D display, for instance in MirageTable [3], can result in a better accuracy when manipulating virtual objects. This solution has the advantage of being gloveless and blurs the line between the real and virtual world, but the user doesn't have any feedback when his hand is touching a virtual object, in a similar fashion to Haptic UIs. To lessen this inconvenience, Benko et al. have what they call a "mirror view", where real object are duplicated in front of the user, replicating the experience of a real mirror. This way, the user doesn't have a projected virtual object on his hand when trying to manipulate it.

2.5 Gaze tracking

Gaze tracking can be one of the most powerful user interface but also one of the most difficult to implement. Our gaze often reflects what we are thinking about in the real world. When we look at something we certainly have an intention with this object. For this reason, by following the gaze of the user, we can obtain information about what he wants to achieve. Gaze tracking is done by having tiny cameras filming the user's pupils. The difficulty is to calibrate it correctly and to filter out involuntary eye movements. Google has a very simple gaze tracking technology in his Google Glass where the screen activates only when the user is looking at it. But this can be much more powerful, as it has been demonstrated with FreeGaze by Ohno et al. [20], where a non-intrusive, fast calibrating (only two points) gaze tracking system is used for an everyday use. Their study shows that the system is viable and accurate.

James Darpinian[2] recently built his own Oculus Rift Eye Tracker [5]. The Occulus Rift is a 3D head mounted display usually used for Virtual Reality, but which can also be used for Augmented Reality. The problem when using a device such as this is that the user face is not visible, making usual eye tracking with a system such as FreeGaze impossible. James Darpinian resolves this problem by cutting a hole on top of the left eye socket in the Occulus Rift and by placing there a PlayStation 3 Eye Camera. He place a hot mirror, a mirror reflecting only infra-red light, in the Occulus to reflect the picture of the eye to the camera. The principle is illustrated in figure 4. This way of integrating an eye tracker with a head worn display could also work with see through display usually used in augmented reality. By using OpenCV, the pupil can be extracted in about 6ms per frame for a precision of 1/4 of a pixel. The user can stare at something displayed by the Occulus Rift with a precision of 2 pixels. Although the Occulus Rift is fixed to the user's head, James Darpinian still encounters problems with calibration, as when moving his head rapidly or when changing facial expression, the Occulus slightly changes position and the calibration is not good anymore.

2.6 Aural UI and speech recognition

Another natural way of interacting, especially between human, is by talking. Therefore, Aural user interfaces are today more and more used, especially with connected object which can process the voice recognition in the cloud. For instance, Google and Apple use speech recognition on their

[2] http://jdarpinian.blogspot.de/2014/06/homebrew-oculus-rift-eye-tracker.html

mobile operating systems, the voice of the user is recorded, sent to servers on the internet and the result comes back to the smart-phone. On a hardware standpoint, only a cheap microphone is needed.

Papers often make examples with an industrial application. For instance with a maintenance engineer using AR to work more efficiently. That's also the case for Goose et al. [8] who is suggesting to use a Aural UI for maintenance technicians. This application is a good example for the usage of speech recognition. Indeed, factory workers or maintenance technicians often have their hands occupied as they have to work with them. Interacting with their hands is not a solution. Their example is using a head-worn eye screen and camera along with a headset with microphone. They have specialized algorithms to recognize the equipment being maintained, for instance pipes, and the worker can manipulate the software via the Aural UI. The technician can for instance ask the system to enlarge a specific part of the picture or to recognize it and display it rotating in 3D. All those actions can help the technician, without having him to even use his hands.

Difficulties arise when working in a noisy environment, which can happen often when doing maintenance in a factory. Fortunately, noise cancellation techniques do exist, using a second microphone to capture only the noise and removing it from the first microphone audio. The main difficulty may be when using speech recognition with augmented reality. Indeed, when a human talks about an object, ambiguity can arise.

2.7 Hybrid UI

Most important of all, Hybrid UI is not a category in itself but a combination of categories. Indeed, what can be better against ambiguity when verbally describing an object than to point a finger at it? This is the principle of multi-modal interactions.

This type of UI has been very well illustrated with KITE [22] which has three different types of input. Their device is made of a Windows tablet with a touch-screen, a Razer Hydra magnetic tracker and Primesense Carmine short range depth camera, see figure 5. This camera is the same technology embedded in the Kinect or Google's project Tango. This setup is not really viable for a Handled one as it is heavy. User complained about its weight in the study. However, the goal was to demonstrate that such a Hybrid device could be possible to do with consumer devices. If it were to be integrated, it could be better done and weight less. They found out that the magnetic tracker is very accurate with a less than 1 mm error and less than 1 degree for orientation when being within 1.5 m from the transmitter. This transmitter is a huge drawback of the solution, as it transforms a potentially hand-held device to a fixed device. The benefits of the magnetic tracker is not only the accuracy but also a very reasonable processing requirement. This is especially true when comparing it to a visual tracking solution, such as the Primesense depth camera. They only achieved a processing speed of less than 10 fps while working with 640x480 pixels, and this is with an Intel Core i5 and 4GB of memory. Tablets usually have a lot less processing power, being equipped with low power ARM CPUs. Although the system is not perfect, the user experience was much better than when using only one input. This permitted to have a car racing game taking in the real world. This is the kind

Figure 5: KITE Platform [22], hand-held AR device made with off-the-shelf hardware

of capabilities I expect from the project Tango, which has a gyroscope, accelerometer, magnetometer and depth sensor. Although the Razer Magnetic Sensor is much more accurate than a gyroscope and magnetometer combined, this makes it very similar to KITE.

3. PROBLEMS WHILE INTERACTING WITH AR

All those interfaces aim at providing a better control over AR applications. Unfortunately, three sorts of problems, among others, can appear when using such a system.

3.1 Dimension Gap

One of them is what I call the Dimension Gap, AR is usually three dimensional and require six degrees of freedom while most of the HID are two dimensional. A touch-screen, camera or mouse only have X and Y coordinates, while the interaction might need a Z coordinate, for the depth. This problem has been demonstrated in [12]. In this paper, users are asked to grab a virtual object integrated to the scene captured by the camera, as illustrated in figure 6. They have markers on their fingers so that the mobile device can track them. It appeared to be more difficult to grab the object this way than by touching it on the touch-screen, because of the lack of depth with the camera. Trying to interact with a 3D space through a 2D camera is the same as trying to put the cap back on your pen with only one eye open. This is frustrating for the user as he has try again multiple times before succeeding.

3.2 Object selection and screen concealment

Another concern when using AR applications with a touch-screen, especially with mobile devices, is that the user usually has to put his hand or finger on the screen thus covering the object of interest or other important elements. This also has been demonstrated in [12]. When the object the user wants to manipulate is hidden, it makes it more difficult to move it to a desired position, scale it or rotate it for instance. One loses precision as one has to guess where the object is.

3.3 Lack of Haptic Feedback

This problem has been clearly identified by Hürst et al. [12]. When the user tries to grab a virtual object through a camera view on the device, either 3D or 2D, in reality there is

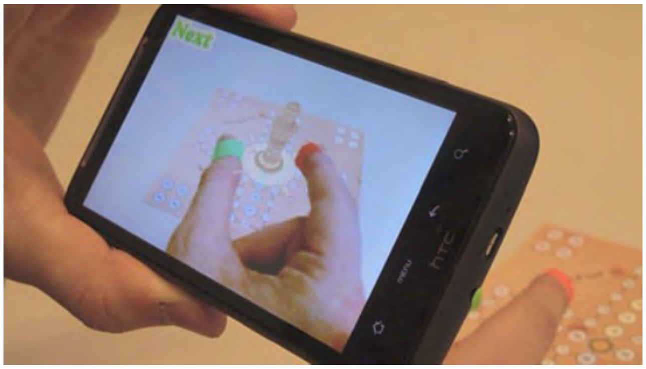

Figure 6: A green marker (thumb) and a red one (index finger) are used to track fingers and manipulate virtual objects on the board game. Source: [12]

only air. This makes the confirmation of grabbing an object we usually have in real life non existent here.

4. SOLVING THE PROBLEMS

4.1 3D Interface interaction

First of all, the lack of dimension problem can be tackled with a 3D sensor, instead of using a simple 2D camera, some use a depth sensor, demonstrated by Hilliges et al. with HoloDesk [11]. This camera will generate a cloud of points, spread in the three dimensions. Using this we can know exactly where the hand of the user is or map the environment more precisely. For instance, when the user wants to grab a virtual object, like in [12], a depth camera will enable the device to draw the virtual object in front of or behind the hand of the user. Also, the user will not need to wear markers on his fingers. With the depth, we can detect more reliably the shape of the fingers, thus detecting easily when they are moving. In addition, when displaying a virtual object, the device can integrate it more realistically in the environment with the help of depth information. With conventional cameras, AR software usually require to have a square marker on the surface we want to "project" the virtual objects, to be able to calculate the perspective. This requirement doesn't exist with depth sensors as the sensor gives information about the plane the device is looking at. Like demonstrated in [16], this makes blending virtual object with real objects much more easy.

The usage of a back camera can be a solution to the screen concealment problem, however the depth remains important even when we don't need it to grab an object. Indeed, it has been shown by a user study in [10] that the user experience is better when displaying the user's finger on top of the virtual button, for which we didn't specially need depth information. According to the study, it makes the button pushing experience feel more realistic. We can easily see here the use of depth information from a sensor to draw correctly the finger on top or under a button, thus saving computing power for other tasks.

The usage of a depth sensor may be nice, but this is not the only solution for a 3D interface interaction. Experimentations have been made with gloves [6] and more recently with a gloveless wearable sensor [13]. The advantage of this solution is a much more accurate tracking of the users finger as well as the possibility to have his hand wherever he wants and not in front of a sensor. But the drawback is that the AR application needs to draw a 3D hand on screen to represent the user's hand, as we don't have a camera.

For head worn displays and working in a somewhat fixed fashion, Schmalstieg et al. [24] propose an interface with a pen and a panel. The pen allows the user to do any movement and operation a 3D mouse supports. They project, with the head worn display, information both on the panel and everywhere else, blending it with other objects. The goal of the panel is to have a surface when manipulating text or other data we usually use with the WIMP paradigm. This combination of pen and panel makes it ideal for collaborative work. The user can interact in 3D and use a paradigm he already knows (the pen and paper). However its limitation shows up when the user wants to manipulate an object with its own hands, which are no tracked. The system will not not the user's intention. To overcome this limitation, we would need an hybrid interface.

4.2 Alternatives

4.2.1 Backside touch-panel and dual screen

An answer to the screen concealment problem can also be a backside touch-panel. By moving the touch surface to the back of the device, the fingers no longer the screen and the user can see everything that is on screen. This king of usage has been demonstrated by Sony with the PlayStation Vita and the mini game "Rolling Pastures" in "Little Deviants"[3]. In this game, the player can bump the ground in the game by placing his finger on the rear touchpad and by moving it. This way, the player can still see the whole screen while playing. Nintendo previously implemented another solution on the Nintendo DS[4] by both having two screen, one touchscreen and one regular screen, and by using a stylus instead of a finger. The stylus being much thinner than a finger, the user can see more of the screen and can also select an object more precisely. Those two examples may not be used for AR, but we can easily imagine it.

4.2.2 Haptic UI and Tactile UI

Another type of touchscreen with haptic feedback could be used to partially solve the problem of screen concealment. Like some devices described in [2], it could have a different texture when the user has his finger on something interesting, for instance, the object he tries to move. This way, even when the screen is occulted, the user can still *feel* what is under his fingertip. But the limitation is that the user can not read what is under his fingertip and that any part of the screen that is not visible but also not touch will remain equally occulted as before.

Of course, this goes without saying that both Tactile UIs and Haptic UIs solve the lack of haptic feedback problem. This is self-explanatory for Haptic UIs and as for Tactile UIs, the texture of the tactile surface can be changed when an object is selected, confirming the selection to the user.

4.2.3 Aural UI

[3]https://www.youtube.com/watch?v=JtaK6mjnTpY - CES 2012 - Sony Playstation Vita Rear Touchpad

[4]Nintendo DS - en.wikipedia.org/wiki/Nintendo_ds

Another alternative to solve the screen concealment and a few other problems is to have a Aural UI and speech recognition. By giving orders, the users doesn't need to use his hands at all, which comes very handy in some situation, for instance in the maintenance field where a technician needs his hands [8]. However, the compute power needed to understand speech is much bigger than what is required even for a depth sensor. Also, human languages are often ambiguous, making it more difficult for a computer to understand us. Finally, it may be socially unacceptable to be apparently speaking alone in a public space and private informations could end in the wrong ears.

4.2.4 Fixed System

Of course, on fixed AR systems, the problem of screen concealment is less noticeable as screens are bigger than for mobile systems. But another problem for fixed systems is the need to be near the display to interact with it, as those display are not moveable. A solution is also to have a depth sensor, such as the Kinect [5], so that the user can interact at any distance from the display. Also, a lot of fixed system use a half-silvered, for instance Sublimate [15] or HoloDesk [11]. The consequence is that they usually have the user manipulate under the half-silvered mirror, resulting in having the augmented reality layer on top of the user's hand. This can be disturbing if the system is not blending the virtual objects correctly (i.e. if the part of the object under the user's hand is displayed). However, this solves the screen concealment problem.

4.2.5 Visual Help

An additional and artificial visual help can improve the user experience in most of the problem. For instance, for the lack of haptic feedback problem, Hürst et al. [12] have implemented a system indicating the interpenetration of two objects and a visual confirmation of the selection. In their study, with a visual confirmation, the selection of an object reportedly takes less time than without.

To help resolve the screen concealment problem, some systems use a deported view of what is under the user's finger. This is also used in non AR applications on smart-phones when precision is required.

4.2.6 3DTouch and Homer-S

Without adding any hardware to an existing smart-phone or tablet, Mossel et al. [18] propose a novel way to interact with 6 degrees of freedom with AR. This is done while using the device one handedly, which can appear impossible at first. Solution to manipulate the third dimension with a 2D touch-screen usually make use of multi touch gestures, but those are difficult to do one using the device with only one hand. Here, what is proposed is to take into account the current position of the device, changing the meaning of the same gesture when the device is not in the same position. For instance, when the user slides his finger on the screen, it will translate the object along the x or y axis. But if the device is lying on its back, then it will move along the z axis, like if the user was watching the virtual object from the top through a window provided by the device. This has some advantages but it also has drawbacks. For instance, while with the usual AR interfaces the user can manipulate

[5] http://en.wikipedia.org/wiki/Kinect

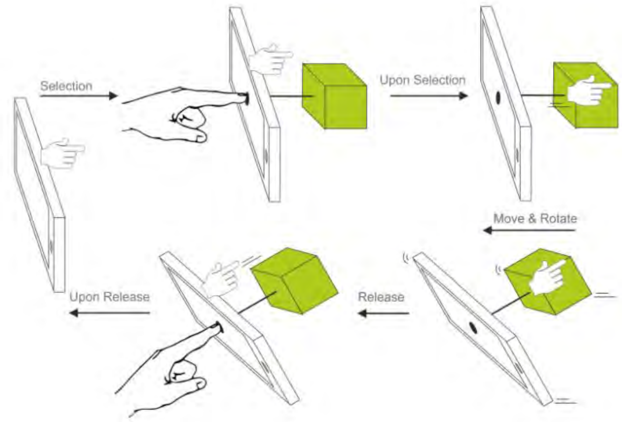

Figure 7: The Homer-S technique for rotating an object [18]

objects without moving, here the user needs to move around the virtual objects he his manipulating. Indeed, if he wants to move the object closer to him, he has to place his device on top, under or on next to the virtual object. He can then proceed to translate it. This technique is only viable for small objects and small AR environment, or if the user is willing to move around a lot.

To rotate objects, they have a technique called Homer-S which seems more viable. It is a complicated to describe gesture which combines touching the screen and moving the device. The gesture is illustrated in figure 7. In their study, user were more efficient when using Homer-S, it took them less time to complete the same tasks compared to 3DTouch, but almost only for a specific task, which was to let a barrel down an inclined platform. In average, there is no significant difference in performance among a broad type of tasks.

5. CONCLUSIONS

As we have seen, although this area is being researched for a longer time we might think, AR is not a mature domain yet. We have each year new technologies enabling us to provide better integration between virtual object and the real environments. New sensors and their miniaturisation can help improve the user experience a lot. The most important thing seems to be providing an experience as close as possible from the reality, to have a natural way to interact with the system. For that, we have seen many categories of input, we can control a computer using our hands, but also our voice or eyes. New inputs unlock new usages and make easier the usage of augmented reality. This has been illustrated with the Dimension Gape and Screen Concealment problems. Using a depth sensor can for instance solve both of this problems. The user's hand interact freely behind his device which can recognize easily his gesture in 3D. Also, the screen is completely visible to the user as the gesture are made behind the screen. Another point about having a more natural feeling is the Haptic feedback. When interacting with objects in real life, we can touch them. Using haptic devices or tactile surfaces we can recreate this feeling helping the user experience.

Other solutions can cover partially those problems, such as having a rear touch-panel and using it instead of the front touch-screen. Visual help, Touch 3D and Homer-S are also a low cost alternative to expensive hardware needs. Indeed those solutions don't need additional hardware and can work with the same smart-phone or tablet the user already has. Unfortunately, we have also seen that those solutions are not perfect, as for instance the user's hand doing 3D gestures can be tired very quickly and not having a feedback can feel not natural.

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