Assessing the Usability of Augmented Reality Systems

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Abstract— Rapid technological progress in all aspects of human everyday life defines our current era. A specific area that has met with significant growth in our times is that of Augmented Reality. In this paper we present the field of Augmented Reality, we make a reference to the ways that it is implemented and present the main sectors in which it is applied. Furthermore, we discuss the issue of Usability Evaluation of Augmented Reality interfaces commenting on the use of the methods currently employed for traditional systems.

Index Terms— Applications of Augmented Reality, Augmented Reality, Augmented Reality Display Devices, Usability Evaluation

I. INTRODUCTION

Augmented Reality, according to various scientist concerned with this field [1] – [4], is defined as the augmentation of the real environment as perceived by the human senses such as vision, hearing, feel and scent, enhanced with additional virtual information produced by suitable devices. In order to successfully combine both worlds, that of the real and the virtual, Augmented Reality must contain the following basic properties [1], [5]:

- combination of real and virtual objects in a real environment
- interactive and real time operation
- registration (alignment) of real and virtual objects with each other

It should be noted at this point that particular Augmented Reality applications require the removal of real objects instead of adding virtual ones. This action is called diminished reality by some scientists, but generally it is considered to be a subset of Augmented Reality [5].

Augmented Reality derives from the expansion of the Virtual Reality field where computer software creates entire visual environments. Virtual reality software can be found in different forms such as virtual worlds, which are used in several computer based games including complex flight simulators. Contrary to the virtual worlds, Augmented Reality software create a mixed world where the real and the virtual are combined for the user.

In 1994, Milgram [6] described the Reality-Virtuality Continuum based on which Augmented Reality is part of a more general category called ‘mixed reality’ (fig. 1). The real environment and the virtual environment lie in the two different ends of mixed reality. Augmented Reality is found right next to the real world end as its concept is based on the augmentation of the real world with data coming from a computer. Augmented Virtuality is a term created by Milgram; it is closer to the virtual reality and describes systems which present mainly complex images with the addition of components from the real environment in order to make them appear more realistic.

The main difference of Augmented Virtuality and Virtual Reality (Virtual Environment) and that of Augmented Reality lies in the surrounding environment. For the former two the surrounding environment is virtual whereas in the case of Augmented Reality the surrounding environment is real.

The outset of Augmented Reality, as defined today, dates back at the beginning of the ‘60s, when Ivan Sutherland [7] became a pioneer in using this design as a new communication vehicle for computers (sketchpad system) with the help of a special pen (light pen). Following that, in 1965, he published an article [8] in which he describes a room where the existence of matter is fully controlled by a computer and some years later he created the first display helmet (HMD, Head Mounted Display) [9]. This creation laid the foundations
for the creation of Augmented Reality and Virtual Reality as a whole. Such research progress was absent from the subsequent two decades, 1970 and 1980. From the mid of the 90s onwards, work on the field of Augmented Reality advanced immensely including the present days where its use is not exclusive to traditional sectors such as military and medicine but expands onto several areas of our everyday life.

II. REGISTRATION OF VIRTUAL OBJECTS IN REAL ENVIRONMENTS

Despite the fact that there are several applications of Augmented Reality, the outmost purpose is for the user to have the sensation of a solid scene at all times. Creating such sensation requires the perfect combination of real and virtual objects, namely a virtual object must be registered (aligned) with the real space where it is placed and thus with real objects present in this space. In an attempt to exemplify the notion of ‘registering’, Azuma used the example as displayed in fig. 2 [1] where he shows the picture of a room containing a real table and a real telephone. The same room also contains a virtual lamp and two virtual chairs. What is noteworthy in this particular picture is that the lamp, although virtual, covers a very small part of the table and the table covers some parts of the chairs. What is more, the virtual lamp is perfectly aligned with the table surface giving the impression that it is indeed on the table, as a result the human eye might not be able to pick up the difference between that which is real and that which is virtual.

![Fig. 2. Real desk with virtual lamp and two virtual chairs](image)

The former example underlines the importance of ‘registering’ in Augmented Reality in order to present to the user a realistic picture combining the two worlds the virtual and the real [10]. According to Azuma [11], a system or an application of Augmented Reality which fails to correctly ‘register’ virtual with real objects will not be easily accepted. Similarly Jacobs [12] states that “registering complex virtual components with the real world is of great importance for Augmented Reality. Data from the user’s input device as well as detection applications must be registered both in terms of space and time with the user’s view of the surrounding space”.

III. AUGMENTED REALITY IMPLEMENTATION DEVICES

There are a series of devices used to enable the implementation of Augmented Reality. Display devices are both of highest importance and most commonly utilized. Apart from display devices a variety of other types are used complementary such as sound devices and gloves with sensors.

Display devices are picture configuration systems which use visual, engineering and electronic parts to produce images at some part of the optical path, that is somewhere between the eyes of the observer and the object which is going to be augmented. Display devices are split into three categories [13]; Hand-held Displays, Spatial Displays and Head-Attached Displays. The latter can be found in two main types:

- Optical see-through displays
- Video see-through displays

A. Hand-Held Displays

Hand-Held displays are portable flat LCD screens that have a built-in camera to produce augmentation of the environment. The real world is displayed on the screen via the camera where virtual objects are portrayed as covering the real. This means that the user is not immerged in an augmented environment but rather looks at the combination of the virtual – real via the device’s screen.

The most important Hand-Held Display devices are pocket computers [14], [15], mobile phones [16] and PDAs (Personal Digital Assistances). These particular devices combine memory, processor and an interactive screen in only one machine and are built for the use of wireless technology.

B. Spatial Displays

Spatial Displays are devices which directly project visual information onto natural objects. In the simplest cases, information is projected on an object via an ordinary projecting machine (Projector). For example, on a visible surface of a cube the picture of a black cycle is projected, giving the impression that there is a hole.

C. Head-Attached Displays

Head-Attached Display devices are placed on the user’s head and portray images in front of the user’s eyes. Engineers decided that with this device the user will always be able to see the image regardless of where he decides to turn his heads towards.

There are two types of Head-Attached Displays: optical see-through and video see-through. The first type presents the augmented reality overlay through a transparent display whereas the second uses video capture, taken from cameras attached on the head as a background for the Augmented Reality overlay [5].
IV. IMPLEMENTATION OF AUGMENTED REALITY

There is a multitude of fields where Augmented Reality is implemented. The following paragraphs will detail the most important implementations.

A. Medicine

One of the fields that benefits from the use of Augmented Reality is medicine. In medicine, there are various applications using Augmented Reality. One of which is the assistance to surgeons during an operation by overlaying real time information relevant to the state of the patient or other useful information such as an x-ray, ultrasound [17] or a computer aided microscope [18], [19].

B. Industry

Augmented Reality can also play an important role in the industrial field. Some of the activities that could benefit from Augmented Reality, according to Barfield [20], are product design, fabrication, assembly, inspection and testing, material handling and maintenance. In such cases, Augmented Reality can provide an industrial worker with useful information such as which tasks to be performed, instructions or diagrams for machining parts in real time, supervising the machining process, or information on machinery faults etc.

C. Military

Military is one of the leading sectors in the employment of Augmented Reality applications. These applications include HMDs for pilots [21] and Special Forces, systems that provide real-time building or terrain information as well as information updates in the battlefield [22] and systems such as MARS (Mobile Augmented Reality System) for training and simulation support [23].

D. Education

Augmented Reality has started appearing also in the field of education. Both inside and outside the classroom, for example in educational trips, Augmented Reality can aid learning and make the overall learning process much more interesting and pleasant.

Examples of educational Augmented Reality applications are the ‘Magic Book’ [24] and the educational game ‘Environmental Detectives’ [25]. ‘MagicBook’, is an ordinary book, complete with a story written on pages with the addition of virtual animated figures which when viewed with a HMD would act out the story in a 3D space above the pages. ‘MagicBook’ has the additional feature of completely immersing a reader in the land of the characters thus making the reader a virtual object within the virtual environment of the story. ‘Environmental Detectives’ is an educational game created in MIT. This game intends to teach students environmental sciences end ecosystems, by finding clues and solving a mystery on the MIT campus. This is accomplished with the use of PDA devices including GPS system.

E. Media and Entertainment

Augmented Reality has already been used by television channels for weather forecasts and sport news. Maps utilized by various channels are digital where the presenter stands in front of a blue or green screen and the application adequately combines the real with the digital so as to present a more life-like weather forecast, where clouds change colors and certain areas are more projected than others. Moreover, both advertisements and off-side lines are also digital information projected in real time and combined with real image from the football ground. Augmented Reality is also found in films [26] and computer games.

F. Tourism

Another sector that benefits from Augmented Reality applications is that of tourism. In this case a hand-held device such as a PDA or a Mobile Phone can navigate a traveler through a place that is being visited or provide useful information such as the history of the place, museums that can visit, nearby restaurants and hotels, in real-time.

ARCHEOGUIDE (Augmented Reality-based Cultural Heritage On-site GUIDE) [27] is an example where Augmented Reality is used to record and file archeological findings and ruins. This application offers a sound description of the history of a place, reconstruction of ruined ancient monuments, revival of scenes from ancient times, display of ancient sculptures and other ancient findings, panoramic views of a given space and navigation assistance.

V. USABILITY EVALUATION OF AUGMENTED REALITY INTERFACES

The preceding section was concerned with detailing several diverse examples where Augmented Reality can be utilized, which in turn comes to prove that such technology is both addressing an ever increasing audience and also that it has moved from research onto production.

The increasing use of Augmented Reality has called for the creation of more usable products of high quality. Therefore, researchers concerned with Augmented Reality are now occupied with an additional field that of Usability Evaluation of Augmented Reality interfaces. It must be stressed here that until very recently the Usability Evaluation of such interfaces had not been systematically examined. This was due to the fact that most Augmented Reality systems concentrated on how to register the presented information with the real environment, which is vital, and not as much with the interaction of potential users with the system.

As a result, we are yet to encounter significant progress on the smart approach of interface processes and automatization of information management/display processes regardless of the recent progress found on the method of architecture description of an Augmented Reality application [28], [29]. There have been individual studies on the usability of specific Augmented Reality applications in recent years. Most of these studies have been based on existing methods of
Usability Evaluation which can be divided into the following categories; Inquiry, Inspection and Testing methods.

**Inquiry methods**
Out of the abovementioned categories, Inquiry methods and more specifically Questionnaires and Interviews are most suitable to be employed in the Usability Evaluation of Augmented Reality systems’ interfaces. Their suitability lies in the fact that they can be employed without any changes in methodology that is used for traditional interfaces, since they are of general scope. These methods gather subjective data that relates to the opinions and preferences of users on factors such as Operability, Effectiveness, Understandability and Aesthetics. They are also useful for comparison and cross-checking of results gathered from the employment of other methods. It must however be noted that Inquiry methods are not solely sufficient in order to obtain secure conclusions.

**Inspection methods**
Inspection methods are also appropriate for conducting Usability Evaluation of Augmented Reality interfaces. In order to use these methods, it is essential for them to undergo some changes or to be extended in order to cover the peculiarities and the new utilization techniques of Augmented Reality systems.

**Testing methods**
User Testing has been the main method in Usability Evaluation and this will probably be also the case for the assessment of Augmented Reality systems. However, in order to apply User Testing to Augmented Reality we need to alter the usual procedures. Furthermore, the setup of testing should be adjusted so as to fit the needs of new interfaces and new equipment both hardware and software should be added in order to overcome a number of methodological problems.

A major difference between Augmented Reality and traditional interfaces is their physical environment. Augmented Reality has a more complicated environment in which users mainly move freely as well as moving parts of their body so as to interact with the system, rather than sit in front of a workstation. This fact alters the usual evaluation procedure that takes place in a usability laboratory, since the preparation for the experiment needs to be better planned in order to avoid disturbances such as office equipment (chairs, cables etc.).

Furthermore, recording users’ interactions becomes more complicated and difficult to obtain because the employment of stereoscopic imaging in Augmented Reality systems makes the collection of data on video a difficult procedure, since there is a need of multiple cameras employment. In this case, stereoscopic data should be accessed with the use of specialized hardware or software equipment.

Another issue is that Augmented Reality systems in many cases involve multiple users thus the usability laboratory requires a larger experimentation space than current laboratories which, in most cases, are located in limited spaces.

Moreover, in some cases the application of methods used in the evaluation of traditional interfaces will conflict with techniques used for the interaction with the Augmented Reality interface. Examples of such cases are the Thinking Aloud method, in which users express verbally their thoughts, feelings and opinions while interacting with the system, and the Co-discovery method where participants work collaboratively talking about what they are doing. In these cases if the Augmented Reality system employs voice recognition techniques in order to activate several features or the system provides information orally, then there would be a conflict, thus making the evaluation very difficult.

**VI. Conclusion**
In this paper we presented the concept of Augmented Reality and referred to the main fields in which it can be applied. From the applications presented it becomes obvious that Augmented Reality has started becoming part of our everyday lives and concerns an ever growing user audience. Such increase on the size of the user audience has called for a need in designing usable interfaces of high quality, which in turn makes Usability Evaluation testing an essential process.

In traditional Software systems Usability Evaluation has become a vital process in order to improve their interfaces. For these systems Usability Evaluation is being conducted with well established methods (Inspection, Testing and Inquiry). Such methods can be and have been applied, to a certain degree, to Augmented Reality interfaces as they use elements of traditional or of Virtual Reality applications. It must, nevertheless, be taken into account that there are differences between the way a user interacts with an Augmented Reality application when compared with the interaction of the same with a traditional desktop or Virtual Reality software.

Thus, in order to utilize the established Usability Evaluation methods in the assessment of Augmented Reality interfaces they must be altered both in terms of methodology and equipment. Also, new additional methods and equipment suitable for Augmented Reality testing must be proposed.

**REFERENCES**


