A Survey on Augmented Reality

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Abstract—*Augmented Reality (AR) superimposes virtual imagery object onto the real world and gives user an enriched environment. AR is used to enhance our perception and help us see, hear, and feel our environments in a new way. AR has been a field of research for many years. With the rise of personal mobile devices which is capable of producing AR environments, the vast potential of AR has begun to be explored. This paper surveys the current state-of-the-art in AR. It includes brief definition of AR, its history of development, the enabling technologies, applications and their characteristics.*

Keywords: *learning environment, application, Augmented Reality, smart phones*

1. INTRODUCTION

AR is a technology through which the view of real world environment is augmented by computer generated elements/objects. AR is related to a mediated or mixed reality, in which a view of reality is been modified. Unlike, virtual reality (VR) replaces the real world with a simulated environment [44]. In the Reality-Virtuality Continuum (Figure 1) by Milgram et al (1994), AR lies between the virtual world and real world [45].
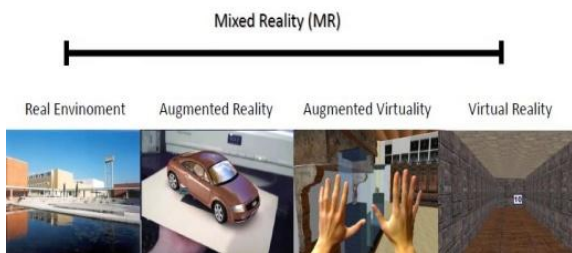

Figure 1: Simplified Representation of a Reality-Virtuality Continuum

Registration and Tracking are the critical issues in AR applications. The proper alignment of virtual objects to the real time environment is known to be registration [27]. Tracking is the main issue for outdoor AR applications [6].

The term AR is used to describe a combination of technologies that enable mixing of computer-generated content with real world. AR is based on techniques developed in VR [44] but it has a degree of interdependence with the real world. Ronald Azuma and his team provided valuable and rich surveys on the field of AR in 1997 [44] and later on, 2001 [45]. To the best of our knowledge, no updated surveys in the literature have holistically addressed AR technologies with respect to the numerous application domains, the impact of mobile technology and the relationship that holds between AR and Virtual Reality (VR). This survey provides an overview of AR with recent technologies, potential applications, challenges.

2. HISTORY OF AR

The concept of AAR was introduced in 1960's, after the invention of first HMD by Ivan Sutherland, [15]. The term AR was coined by Tom Caudell and David Mizell in 1990 [9]. KARMA was the first research paper that completely focused on AR. Rekimoto developed 2D matrix markers that allows camera tracking with 6DOF [63]. Mann developed a 1st GPS-based outdoor system that provides navigation assistance to the visually impaired [41]. Mobile AR System (MARS) was developed that registers 3D graphical information in tour guide for objects and buildings [19].

Rasker et al (1998) introduced a spatial AR, in which virtual objects are rendered directly within user's physical environment [66]. ARQuake was developed in 2000 which is the first outdoor mobile AR game [78]. AR-PDA is a small wireless AR system [20]. In 2003, a mobile AR system was developed, that guides a user through an unfamiliar building to a certain destination [33]. An indoor augmented reality guidance system was developed in 2003 [82]. Möhring et al (2004) introduced a 3D markers based tracking system using a mobile phone [46]. A hybrid tracking system for outdoor AR in urban environments was developed that enabled real-time overlays on a handheld device [63]. A parallel real-time tracking and mapping was introduced in 2007 [34]. Wagner et al (2008)

developed the first real-time 6DOF implementation of NFT on mobile phones [81]. Morrison et al. (2009) developed Map-Lens which use magic lens on a paper map to give a mobile AR map [47]. For the past few years, the field of AR has gained more attention among the researchers.

3.   ENABLING TECHNOLOGIES

The technological demands for developing AR applications are much higher than for VR, which is why the AR took longer time to mature than that of VR. The key components needed to build an AR system have remained the **same since Ivan Sutherland'**s pioneering work of the 1960s. Displays, trackers, graphics computers and software remain essential in many AR experiences.

3.1 DISPLAYS

Display section mainly focuses on visual displays, however aural (sound) displays, Haptic (touch) displays are mentioned below. Whereas olfactory (smell) and gustatory (taste) displays are less developed or practically non-existent AR techniques and will not be discussed

Aural display

Aural display application in AR is mostly limited to self-explanatory mono (0D), stereo (1D) or surrounds (2D) headphones and loudspeakers. True 3D aural display is currently found in more immersive simulations of virtual environments and augmented virtuality or still in experimental stages. Haptic audio refers to sound that is felt rather than heard [26] and is already applied in consumer devices such as Turtle **Beach's** Ear Force5 headphones to increase the sense of realism and impact, but also to enhance user interfaces of e.g. mobile phones [10]. Recent developments in this area are presented in workshops such as the international workshop on Haptic Audio Visual Environments6 and the international workshop on Haptic and Audio Interaction Design [39].
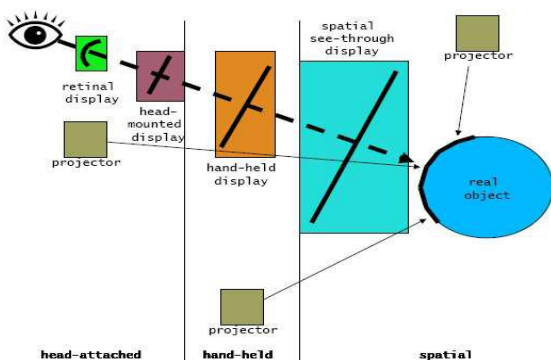

Fig. 2: Visual display techniques and positioning [49].

Visual display

There are basically three ways to visually present an AR. Closest to VR is video see-through, where the virtual environment is replaced by a video feed of reality and the AR is overlaid upon the image target. Another way that **includes Sutherland'**s approach is optical see-through but displays only the AR overlay by means of transparent mirrors and lenses. The third approach is to project the AR overlay onto real objects themselves resulting in projective displays. The three techniques may be applied at varying distance from the viewer: head-mounted, hand-held and spatial (Figure. 2).

Video see-through

Besides being the cheapest and easiest to implement, this display technique offers the following advantages. Since reality is digitized, it is easier to remove the objects from reality. This includes replacing fiducial markers or placeholders with virtual objects (Fig. 7) [32]. The digitized images allow tracking of head movement for better registration. Disadvantages of video see-through includes low resolution , a limited field-of-view, and user disorientation due to a eye-offset due to the camera's pose **at a distance from the viewer'**s eye, causing significant adjustment for the viewer [18]. This problem was solved at the MR Lab by aligning the video capture. A final drawback is the focus distance of this technique which is fixed in most display types, providing poor eye accommodation. Some head-mounted setups can however move the display (or a lens in front of it) to cover a range of .25 meters to infinity within .3 seconds [72].

Optical see-through

Optical see-through techniques with beam-splitting HOEs may be applied in head-worn displays, hand-held displays, and spatial setups, where the AR overlay is mirrored either from a planar screen or through a curved screen. Optical techniques are safer because users can still see when power fails, making this an ideal technique for military and medical purposes. However, other input devices such as cameras are required for interaction and registration. Combining the virtual objects holographically through transparent mirrors and lenses will be a drawback, as it reduces brightness and contrast of both the images and the real-world perception which makes it less suited for outdoor use. The field-of-view is limited for this technique. Finally, occlusion of real objects is difficult because their light is always combined with the virtual image. Kiyokawa et al. [23] solved this problem for head-worn displays by adding an opaque overlay using an LCD panel with pixels that opacity areas to be occluded. Virtual retinal displays or retinal scanning displays (RSDs)

solve the problems of low brightness and low field-of-view in (head-worn) optical see-through displays. Schowengerdt et al developed a full-color, binocular version with dynamic refocus to accommodate the eyes (Fig. 5) that is promised to be low-cost and light-weight.

Projective

This display does not require special eye-wear **thus accommodating user'**s eyes during focusing, and they can cover large surfaces for a wide field-of-view. Projection surfaces may range from flat, plain colored walls to complex scale models [50]. Zhou et al. list multiple Pico-projectors that are lightweight and low on power consumption for better integration. Also, projectors need to be calibrated each time the environment or the distance to the projection surface changes. Calibration may be automated using cameras. Further, this type of display is limited to indoor use only due to low brightness and contrast of the projected images. Occlusion of the objects is also quite poor, but for head-worn projectors this may be improved by covering surfaces with retro-reflective material.

3.2 DISPLAY POSITIONING

AR displays may be classified into three categories based on their position between the viewer and the real environment:

- Head-Worn
- Hand-Held
- Spatial

Figure 3: Head-worn visual displays.

Head-worn Display

Visual displays attached to the head include the video/optical see-through HMD, VRD, and head-mounted projective display (HMPD). Cakmakci and Rolland [51] gave a detailed review of head-worn display technology. A current drawback of head-worn displays is the fact that they have to connect to graphics computers like laptops that restrict mobility due to limited battery life. Fig. 3

shows examples of four (parallax-free) head-worn display **types: Canon's Co**-Optical Axis See-through Augmented Reality (COASTAR) video see-through display [36] (Fig. 3a**), Konica Minolta's holographic optical see**-through, Fo**rgettable Display" prototype (Fig.** 3b), Micro-vision's monochromatic and monocular Nomad retinal scanning display (Fig. 3c), and an organic light-emitting diode (OLED) based head-mounted projective display (Fig. 3d).

Figure 4: Hand-held video see-through

Hand-held Display

It includes hand-held video or optical see-through displays as well as hand-held projectors. Although these displays are bulkier than head-worn displays, it is currently the best work-around to introduce AR to a mass market due to low production costs and ease of use. For e.g., hand-held video see-through AR acting as magnifying glasses may be based on existing consumer products like smart phones Möhring et al. (Fig. 4a) that show 3D objects, or PDAs (Fig. 4b) with e.g. navigation information. [15] apply optical see-through in their hand-held sonic flashlight to display medical ultrasound imaging directly over the scanned organ One example of a hand-held projective display was AR flashlight developed by Raskar et al. [64]. This tracked projector adjusts the virtual imagery based on the current orientation of the projector relative to the environment.

Spatial Display

These categories of displays are placed statically within the environment and it includes screen-based spatial optical see-through displays, video see-through displays, and projective displays. These techniques lend themselves well for exhibitions and large presentations with limited interaction. Early ways of creating AR are based on conventional screens that show a camera feed

with an AR overlay. Head-up displays (HUDs) in military cockpits are a form of spatial optical see-through and are becoming a standard extension for production cars to project navigational directions in the windshield [76]. Spatial see-through displays may however appear misaligned when users move around in open spaces by Ogi et al. [77] (Fig. 6a). 3D holographs solve the alignment problem, as Goebbels et al. show with the ARSyS TriCorder8 (Fig. 6b) by the German Fraunhofer IMK (now IAIS9) research centre.
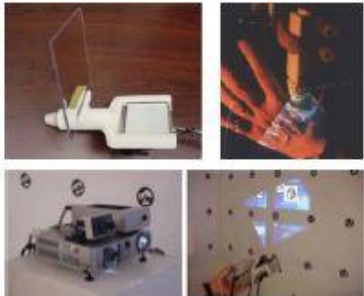

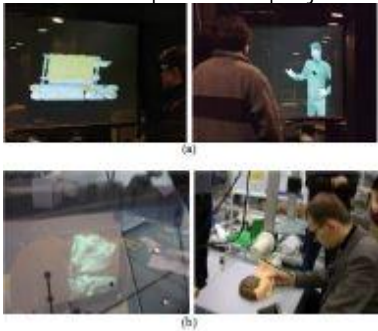Figure 5: Hand-held optical and projective displays

Figure 6: Spatial visual displays by [77]

4. GESTURE BASED INTERACTION APPROACHES

A simple definition of gesture [7] is a motion of the body that contains information, while gesture recognition is the mathematical interpretation of a human motion by a computing device which is successfully accurate when the repeatability of a certain movement is interpreted in the same way from different people [13].

4.1 Gestures classification

A challenge on gesture recognition systems is that there is no exact meaning for a gesture to be universally understood, however, a distinction between gestures can be established as continuous (online) and discrete (off-line)[7][70]:

- On-line Gestures (continuous): Are evaluated while are being performed. e.g. A zooming metaphor with the fingers movement.

- Off-line Gestures (discrete): Are evaluated after they have been completely performed, e.g. pointing gestures towards a screen, clicking, static symbols to execute commands [13] [70].

With the previous taxonomy in mind, the fundamental interactions [30] [29]: Rotation, translation and scaling are performed. For rotation, a user would pinch or grasp the object with at least two contact points and would move their hand or turn their wrist accordingly. For scaling on 3 axes, participants would grasp or use open-hands to align with the sides of object and increased or decreased the distance between them to enlarge or shrink in the same direction as the transformation. Uniform scaling is less obvious as for example some users prefer using open hands moving along a single axis in front of them while others grasp objects opposing diagonal corners and moving along diagonal lines [55], [56].

Pinch Gesture

The pinch gesture is one of the most common gestures for interaction with digital interfaces. It is defined as the movement of expansion and contraction of a finger spread [28]. It has been used for different purposes depending on target applications, e.g. the zooming metaphor by contracting and expanding, scaling or picking. Moreover, with the use of multi-touch devices [28], its metaphors have become ubiquitous to interact with virtual content. While interacting with real objects, it is used to grab small pieces or malleable objects like fabrics. It resembles a grabbing or picking action and offers natural signal to select or move an object in an interactive system [86] and due to the nature of the thumb and index fingers likewise the large amount of experience. From the people, the pinch grabbing is precise and has high performance [4]. Once we have the information of the hand from sensing device, it is relatively easy to detect a pinch as there is little ambiguity whether the thumb and fingers are touching themselves or not [86]. For our purpose, and based on the commonly used gestures described on the taxonomy of [55], [56], the pinch is a pivotal gesture to implement interactions within our Augmented Reality space.

4.2 Comparison of Different Gesture Based interaction

From previous studies performed, different approaches have been proposed in order to provide an understanding of natural hand-gestures to interact with virtual objects in an AR space. Table. 1, there exists description and comparison of main concepts on AR interaction, Leap Motion Approach and AR-Gesture-based interaction.

Table 1: Comparison of Gesture Based interaction

Area	Description	Contribution
AR interaction	Tangible tabletops, gesture metaphors, hand occlusions and feedback, showed to be relevant concepts to consider for an AR interaction design.	General concepts in AR
Leap Motion approach	Few papers written so far (April 2014), mostly analyzing its capabilities for precise tracking, feasibility for sign language gesture recognition.	Device capabilities, one Leap implementation
AR Gesture-based interaction	An overview showing gesture-based approaches only, most of them based on image processing and computer vision techniques using depth cameras, Kinect,	There are no documented implementations besides using Leap Motion approach that can relate to it, the controller deals with the image processing computer vision to expose only the positional data we need.

5. EXISTING SOFTWARE DEVELOPMENT KITS FOR MOBILE AUGMENTED REALITY

A few companies have created Software Development Kits (SDK) that focuses on Mobile AR. These SDKs provide both individuals and companies the possibility of developing Mobile AR solutions. Some of these kits are free to use, while others charge licensing fees for commercial use.

Qualcomm*: Qualcomm* has developed a Mobile AR SDK called Vuforia that supports iOS, Android and Unity 3D. Vuforia uses computer vision technology to recognize 2D and 3D image targets. An image target or "Trackable" is an image that the Vuforia SDK can detect and track. These image can be in the format of JPG or PNG and is uploaded and processed in the online Target Management System, and later the system will recognizes these images by comparing their natural features against a known target resource database. Unlike a traditional marker/QR-code these images don't need special black and white regions or codes to be recognized because Vuforia uses algorithms to detect and track the features that are naturally found in the image itself. By composing several image targets in a fixed spatial relationship, Vuforia provides functionality for multi target tracking. If one image target is detected the system also knows the position and orientation to the other image targets and as long as one of these targets is visible the multi target can be tracked.

Another type of image targets is a special kind of predefined markers called Frame Markers. Vuforia provides 512 predefined Frame Markers where each marker has an unique code of binary pattern around the border of the marker image. Decoding a Frame Marker takes relatively little processing power and this allows for all 512 frame marker to run in one application and around five of them can be detected and tracked simultaneously. [58]

Metaio: Metaio has developed a mobile SDK for AR that also supports iOS, Android and Unity 3D. Metaios SDK supports computer vision functionality for recognizing marker-less 2D and 3D object tracking. Their SDK also supports a robust ID marker tracking in 2D as well as QR code and barcode scanning features. To help create a natural AR experience Metaio has also developed a patented method for gravity aware AR that allows the digital augmentations to be aware of the gravitation depending on how they are placed in the physical world. [42]

Layar: Layar is one of the leading companies in geo-location based AR. They have developed a browser application on iOS called Layar Reality Browser. Using this browser, users can download or create different layers of digital content that is placed on top of the real world depending on location. This could for example display twitter updates in a certain area. Other layers let users play games within their environment, or browse for clothes in a 360-degree virtual shop, or even view artwork that has been digitally placed into the real world like a virtual art gallery. Layar has also developed its "Layar

Vision" technology, which uses computer vision to perform image detection and tracking similar to Vuforia and Metaio. Layar wants the users to use visual triggers in their surroundings such as magazines, posters or newspapers. It **has also developed the "Layar Player", a SDK for** developers that wants to develop their own applications instead of just creating layers inside the Layar Reality Browser application. [37]

6.   MOBILE AR: APPLICATIONS AND CHALLENGES

This section presents the advances and new additions to the applications areas where mobile AR systems are used. The main mobile AR applications studies that this survey covers are:

- Virtual Character-based applications for AR
- Cultural Heritage
- Edutainment and Games
- Navigation and Path-Finding
- Collaborative assembly and design

6.1 Virtual Characters in AR

Virtual Characters have been synthesized with real actors in non-real-time mixed reality worlds [5]. **However these 'compositing' examples involve non**-real-time (offline) pre-rendered simulations of virtual characters and mostly are rendered and post-processed frame by frame in an ad-hoc manner by specialized digital artists or compositors as they are termed in the industrial domain of special effects (SFX). The active SFX sector with applications in film, television and entertainment industry has exemplified such compositing effects in a constantly growing list of projects. In this survey we study the recent surge of employing virtual characters in mobile AR systems.

6.2 Cultural heritage

Mobile AR systems are increasingly being tested in rich content environments, as they can enable **visualization of 'unseen' valuable and complex 3D content** as well as provide added edutainment-value in today cultural heritage sites. The shift that the cultural heritage sector is currently facing in its traditional economic paradigm combined with the increasing digitization efforts allow for AR interfaces to be used as ideal and novel showcases of both tangible (objects, static edifices) and intangible (ceremonies, customs, myths) cultural artifacts. In particular, mobile AR guides were employed in the site of ancient Olympia, Greece in order to visualize the non-existing ancient temple edifices (Vlahakis et al [76]), and in Pompeii, Italy to visualize ancient Roman characters

reenacting stories based on the site frescoes (Papagiannakis et al).

6.3 Navigation & Path Finding

Mobile AR systems have also been widely employed for mobile navigation assistance. Such systems typically involve a hardware device and based on an AR platform similar to those, they allow for multimodal navigation AR aid while traversing physical buildings or outdoor locations. Different approaches are followed based primarily on whether indoors or outdoors AR navigation is needed. Hollerer [8], Elmqvist et al [17], Olwal et al [52] and Newman et al [48] work indoors while Bell et al [3], Reitmayr et al and Azuma et al are employed outdoors.

6.4 Edutainment & Games

Magerkurth et al presents an overview of pervasive gaming containing a section on AR Games. AR multi-user games appeared based on generic AR frameworks (Wagner et al). Traditional 2D games also find their application in mobile AR, based on the well-**known 'Pac- Man' gaming genre (Cheok et al, Rashid** et al and Klein et al). Smart phones have also been used as kineasthetic AR interfaces in an AR tennis game Henrysson et al. Based on the **"Shoot'em up" computer gaming genre,** several AR games have been realized using mobile AR systems, such as those described in Hughes et al and Piekarksi et al . The main unsolved research issues include multiple, interactive virtual characters in AR, common-vision collaborative games as well as convincing illumination registration and real-time rendering.

6.5 Collaborative assembly and construction

One of the main features of mobile collaborative AR is that the augmentation of the real-world is adapted according to multiple-user location and knowledge. Renevier et al [67] exhibited such a mobile AR system for both archaeological field work as well as asynchronous collaborative game. Furthermore, the industrial CAD design field has also recently benefited from mobile AR systems (Stork et al [72]) allowing multiple users to reviews complex 3D CAD architectural or automotive industry models. Finally in the field of on-site collaborative AR and construction, Piekarksi et al [54] employed their generic AR software framework for novel 3D construction on real sites.

7. CONCLUSION

Thus the survey describes about the technologies, applications and characteristics of AR and it also concludes that the Physical Interaction in AR environments can be done on Hand-held devices. In the handheld AR application it results in a fully working and practical framework for AR applications on Smart **phones. The Leap Motion's** technology is very promising and it has a potential for wide range of applications for gesture interaction, virtual and AR environments and more robust and serious applications. Combined with an AR scenario, is potentially useful for virtual modeling and prototyping, collaborative environments or gaming.

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