Augmented Reality: Applications, Challenges and Future Trends

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Abstract

Augmented reality, in which virtual content is seamlessly integrated with displays of real-world scenes, is a growing area of interactive design. With the rise of personal mobile devices capable of producing interesting augmented reality environments, the vast potential of AR has begun to be explored. This paper surveys the current state-of-the-art in augmented reality. It describes work performed in different application domains and explains the exiting issues encountered when building augmented reality applications considering the ergonomic and technical limitations of mobile devices. Future directions and areas requiring further research are introduced and discussed.

1. INTRODUCTION

The term Augmented Reality (AR) is used to describe a combination of technologies that enable real-time mixing of computer-generated content with live video display. AR is based on techniques developed in VR [1] and interacts not only with a virtual world but has a degree of interdependence with the real world. As stated in hugues11, “augmenting” reality is meaningless in itself. However, this term makes sense as soon as we refocus on the human being and on his perception of the world. Reality can not be increased but its perceptions can be. We will however keep the term of Augmented Reality even if we understand it as an ”increased perception of reality”.

Ronald Azuma and his team provided valuable and rich surveys on the field of augmented reality in 1997 [1] and later in 2001 [2]. However, the last decade has been particularly rich in advances in this growing research field which opened perspectives for several opportunities to use AR in various application domains. 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). For anyone who wants to get acquainted with the field of AR, this survey provides an overview of recent technologies, potential applications, limitations and future trends of AR systems.

The rest of the paper is organized as follows: Section 2. introduces technologies that enable an augmented reality experience, clarifies the boundaries that exist between AR and Virtual Reality (VR), and focus on the contributions of mobile technology in AR. Section 3. classifies the identified applications of AR into 12 distinct categories including well-established domains like medical, military, manufacturing, entertainment, visualization, and robotics. It also describes original domains such as education, marketing, geospatial, navigation and path planning, tourism, urban planning and civil engineering. In Section 4., we identify and discuss the common technological challenges and limitations regarding technology and human factors. Finally, Section 5. concludes with a number of directions that we believe AR research might take.

2. AUGMENTED REALITY

2.1. Definition

Augmented reality technology has its roots in the field of computer science interface research [3]. Many of the basic concepts of AR have been used in movies and science fiction at least as far back as movies like The terminator (1984) and RoboCop (1987). These movies feature cyborg characters whose views of the physical world are augmented by a steady stream of annotation and graphical overlays in their vision systems.

The term ”augmented reality” was first coined by researcher Tom Caudell, at Boeing in 1990, who was asked to improve the expensive diagrams and marking devices used to guide workers on the factory floor[4]. He proposed replacing the large plywood boards, which contained individually designed wiring instructions for each plane, with a head-mounted apparatus that displays a plane’s specific schematics through high-tech eyeware and project them onto multipurpose, reusable boards.

Many authors agree to define AR in a way that requires the use of Head-Mounted Displays (HMDs) [5]. However, in order to avoid limiting AR to specific technologies, we propose to define AR as systems that have the following characteristics: 1) combines real and virtual; 2) interactive in real time; and 3) registered in 3-D. This definition aims to allow other technologies, such as mobile technology, besides

HMDs while preserving the essential components of AR [6]. 2-D virtual overlays on top of live video can be done at interactive rates, but the overlays are not combined with the real world in 3-D [7]. However, this definition does allow monitor-based interfaces, monocular systems, see-through HMDs or mobile devices.

2.2. Components

According to Bimber and Raskar [8], augmented reality systems are built upon on three major buildings blocks: tracking and registration, display technology and real time rendering. First, augmented reality is a technology that should be interactive in real time and registered in three dimensions. When trying to achieve a plausible augmented image, accurate tracking and registration is important, this because when aiming to get a believable image across to the user, the real camera should be mapped to the virtual one in such a way that that the perspectives of both environments precisely match [8]. Especially for a moving user, the system needs to constantly determine the position within the environment of the user surrounding the virtual object, this because the computer generated object should appear to be fixed [8]. If such a form of complete tracking with a global coordinate system is required, one can distinguish between outside in and inside out tracking [9, **?**]. The first refers to systems where sensors are placed in the environment that track emitters on mobile objects: for example using sensors based on Global Positioning System (GPS) to track where a mobile device is situated, or triangulating the position of a mobile device between phone masts. The second type makes use of internal sensors fixed to mobile objects; a camera for vision based tracking, digital compass to track which way the phone is facing, an accelerometer to track acceleration. However these systems both have their drawback, as GPS for example is not as accurate inside buildings as outside and vision based tracking depends heavily on lighting conditions and visibility [10].

Bimber and Rasker [8] further see both display technology and real time rendering as basic building blocks and challenges in the future. The first being connected to limited optical (e.g. limited field of view), technical (e.g. resolution) and human factor (e.g., size and weight) limitations. The second, real time rendering, is connected to the ability of augmented reality devices to place a layer of graphical elements on top of the real environment in a fast and realistic way. An ultimate goal according to Bimber and Raskar [8] would be for the integrate computer generated object in such a way that the user is unable to distinguish between real and virtual.

2.3. Augmented Reality and Virtual Reality

The term virtual reality is commonly used by the popular media to describe imaginary worlds that only exist in computers and our minds. However, let us more precisely define the term. According to [11], virtual is defined to be being in essence or effect but not in fact. Reality is defined to be something that constitutes a real or actual thing as distinguished from something that is merely apparent; something that exists independently of ideas conceiving it. Fortunately [12] has more recently defined the full term virtual reality to be an artificial environment which is experienced through sensory stimuli (as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment. [13] further defines a virtual reality to be a computer-generated environment that can be interacted with as if that environment was real. A good virtual reality system will allow users to physically walk around objects and touch those objects as if they were real. Ivan Sutherland, the creator of one of the world's first virtual reality systems stated "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal" sutherland68.

Figure 1: Adapted schema of a virtuality continuum. Inspire from Milgram et al. [14].

2.4. Mobile augmented reality

As computers increase in power and decrease in size, new mobile, wearable, and pervasive computing applications are rapidly becoming feasible, providing people access to online resources always and everywhere [10]. This new flexibility makes possible new class of applications that exploit the person's surrounding context [15]. Augmented reality already presents a particularly powerful user interface (UI) to context-aware computing environments. AR systems integrate virtual information into a person's physical environment so that he or she will perceive that information as existing in their surroundings [16]. Mobile augmented reality systems provide this service without constraining the individual's whereabouts to a specially equipped area [17]. Ideally, they work virtually

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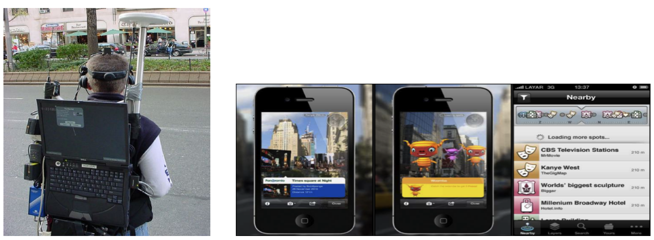
anywhere, adding a palpable layer of information to any environment whenever desired. By doing so, they hold the potential to revolutionize the way in which information is presented to people [7].

Computer-presented material is directly integrated with the real world surrounding the freely roaming person, who can interact with it to display related information, to pose and resolve queries, and to collaborate with other people. The world becomes the user interface [10]. Hence, mobile AR relies on AR principles in truly mobile settings; that is, away from the carefully conditioned environments of research laboratories and special-purpose work areas. Quite a few technologies must be combined to make this possible: global tracking technologies, wireless communication, location-based computing (LBC) and services (LBS), and wearable computing.



(a) (b)

Figure 2: Mobile AR: (a) user with Mobile AR system backpack; (b) example of AR application that uses mobile devices.

3. APPLICATIONS OF AR

Augmented Reality enhances a user's perception of and interaction with the real world. The virtual objects display information that the user cannot directly detect with his own senses. The information conveyed by the virtual objects helps a user perform real-world tasks. AR is a specific example of what Fred Brooks called Intelligence Amplification (IA): using the computer as a tool to make a task easier for a human to perform [18].

At the time of writing this paper, at least 12 distinct classes of AR application domains have been identified. These classes include well-established domains like medical, military, manufacturing, entertainment, visualization, and robotics. They also include original and new domains such as education, marketing, geospatial, navigation and path planning, tourism, urban planning and civil engineering. The following sub-sections describe recent research project that have been done in each field. While these do not exhaustively cover every application domain of AR technology, they do cover the areas explored so far.

3.1. Medical

Medical augmented reality takes its main motivation from the need of visualizing medical data and the patient within the same physical space. This would require real-time in-situ visualization of co-registered heterogeneous data, and was probably the goal of many medical augmented reality solutions proposed in literature *Figure 3(a)*. In 1968, Sutherland [19] suggested a tracked head-mounted display as a novel human-computer interface enabling viewpoint-dependent visualization of virtual objects. It was only two decades later when Roberts et al. implemented the first medical augmented reality system [20].

Another application for augmented reality in the medical domain is in ultrasound imaging [21]. Using an optical see-through display the ultrasound technician can view a volumetric rendered image of the fetus overlaid on the abdomen of the pregnant woman. The image appears as if it were inside of the abdomen and is correctly rendered as the user moves sielhorst2008. Moreover, Blum et al. describe the first steps towards a Superman-like X-ray vision where a brain-computer interface (BCI) device and a gazetracker are used to allow the user controlling the AR visualization [22]. More recently, Wen et al. propose a cooperative surgical system, guided by hand gestures and supported by an augmented reality based surgical field [23]. The authors establish a system-assisted natural AR guidance mechanism that incorporates the advantages of the following aspects: AR visual guidance information, surgeon's experiences and accuracy of assisted surgery [24].

3.2. Military

AR can be used to display the real battlefield scene and augment it with annotation information [25]. Some HMD's were researched and built by company Liteye for military usage. In [26] hybrid optical and inertial tracker that used miniature MEMS (micro electro-mechanical systems) sensors was developed for cockpit helmet tracking. In [27] it was described how to use AR technique for planning of military training in urban terrain. Using AR technique to display an animated terrain, which could be used for military intervention planning, was developed by company Arcane. The helicopter night vision system was developed by Canada's Institute for Aerospace Research (NRC-IAR) using AR to expand the operational envelope of rotor craft and enhance pilots' ability to navigate in degraded visual conditions [28]. HMD was developed to a display that can be coupled with a portable information system in military [29].

Extra benefits specific for military users may be training in large-scale combat scenarios and simulating real-time enemy action, as in the Battlefield Augmented Reality System

(BARS) by Julier et al. [30]. The BARS system also provides tools to author the environment with new 3D information that other system users see in turn[31].

3.3. Manufacturing

Research on the manufacturing applications of AR is a strong and growing area [?]. The challenge in the manufacturing field is to design and implement integrated AR manufacturing systems that could enhance manufacturing processes, as well as product and process development, leading to shorter lead-time, reduced cost and improved quality [4]. The ultimate goal is to create a system that is as good as the real world, if not better and more efficient.

AR can enhance a person's perception of the surrounding world and understanding of the product assembly tasks to be carried out [32]. Using an AR approach, graphical assembly instructions and animation sequences can be pre-coded at the design stage for typical procedures *Figure 3(b)*. These sequences can be transmitted upon request and virtually overlaid on the real products at the assembly lines as and when they are needed. The instructions and animations are conditional and can be automatically adjusted to actual conditions at the assembly lines. These instructions and animated sequences can be updated periodically with updated knowledge from the manufacturers. This approach can reduce the information overload and the training required for assembly operators. It can reduce product assembly time, thus reducing product lead-time. Authors in [33] compared three instructional media in an assembly system: a printed manual, computer-assisted instruction (CAI) using a monitor-based display and CAI using a head-mounted display. They found that, by using overlaying instructions on actual components, the error rate for an assembly task was reduced by 82% [33].

3.4. Visualization

AR is a useful visualization technique to overlay computer graphics on the real world. AR can combine visualization method to apply to many applications [34]. A vision-based AR system was presented for visualization interaction in [35]. A device, GeoScope, was developed to support some applications such as city, landscape and architectural visualization in [36]. AR visualization for laparoscopic surgery was approached in [37].

AR also enables visualization of invisible concepts or events by superimposing virtual objects or information onto physical objects or environments [38]. AR systems could support learners in visualizing abstract science concepts or unobservable phenomena, such as airflow or magnetic fields, by using virtual objects including molecules, vectors, and symbols. For example, Augmented Chemistry allowed students to select chemical elements, compose into 3D molecular models, and rotate the models [39]. Clark et al. proposed an augmented paper-based coloring book with 3D content and provided children with a pop-up book experience of visualizing the book content [40]. These augmented real objects create new visualizations that have potential to enhance the understanding of abstract and invisible concepts or phenomena.

3.5. Entertainment and Games

Augmented reality has been applied in the entertainment industry to create games, but also to increase visibility of important game aspects in life sports broadcasting. In these cases where a large public is reached, AR can also serve advertisers to show virtual ads and product placements. Swimming pools, football fields, race tracks and other sports environments are well-known and easily prepared, which video see-through augmentation through tracked camera feeds easy [13]. One example is the Fox-Trax system [41], used to highlight the location of a hard-to-see hockey puck as it moves rapidly across the ice, but AR is also applied to annotate racing cars, snooker ball trajectories, life swimmer performances, etc [42]. Thanks to predictable environments (uniformed players on a green, white, and brown field) and chroma-keying techniques, the annotations are shown on the field and not on the players [43].

3.6. Robotics

AR is an ideal platform for human-robot collaboration [44]. Medical robotics and image guided surgery based AR was discussed in [45]. Predictive displays for telerobotics were designed based on AR [46]. Remote manipulation of using AR for robot was researched in [47]. Robots can present complex information by using AR technique for communicating information to humans [48]. AR technique was described for robot development and experimentation in [49]. In [50], authors describe the way to combine AR technique with surgical robot system for head-surgery. An AR approach was proposed to visualizing robot input, output and state information [51]. Using AR tools for the teleoperation of robotic systems was described in [52]. It was developed how to improve robotic operator performance using AR in [53]. It was explored for AR technique to improve immersive robot programming in unknown environments in [54]. Robot gaming and learning based AR were approached in [55]. 3D AR display during robot assisted Laparoscopic Partial Nephrectomy (LPN) was studied in [56].

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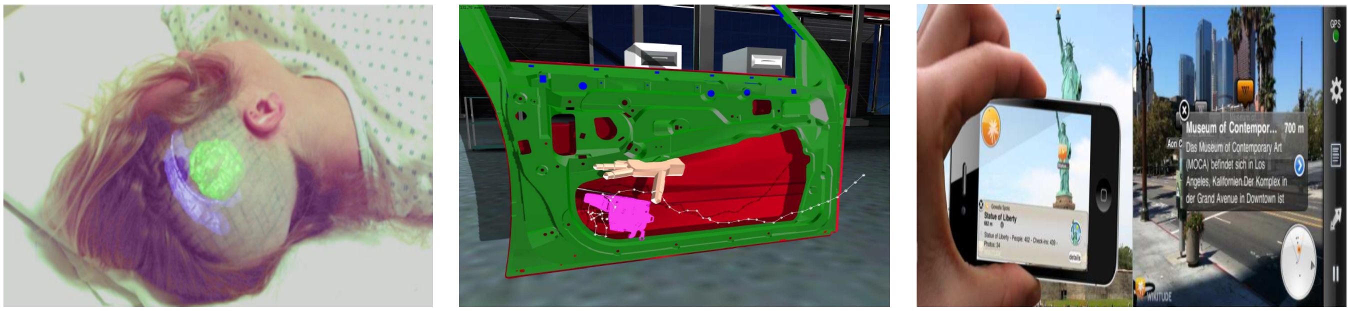

(a) (b) (c)

Figure 3: Applications of AR in (a) guided surgery; (b) product assembly; and (c) navigation in urban environments.

3.7. Education

New possibilities for teaching and learning provided by AR have been increasingly recognized by educational researchers. The coexistence of virtual objects and real environments allows learners to visualize complex spatial relationships and abstract concepts [16], experience phenomena that is not possible in the real world [57], interact with two and three dimensional synthetic objects in the mixed reality [58], and develop important practices that can not be developed and enacted in other technology-enhanced learning environments [59]. These educational benefits have made AR one of the key emerging technologies for education over the next five years [60].

3.8. Marketing

Augmented reality was first used for advertising in the automotive industry. Some companies printed special flyers that were automatically recognized by webcams, causing a three-dimensional model of the advertised car to be shown on the screen [61]. This approach then spread to various marketing niches, from computer games and movies to shoes and furniture [62]. The ubiquitous QR-code is a very simple example of such augmented reality: a black-and-white illustration that turns into more complex information when analyzed by a mobile phone or computer [63]. An example of more complex augmented reality is virtually trying on shoes. The user wears a special pair of socks, then walks in front of a camera and sees his own image on the screen wearing a desired pair of shoes. The model, color and accessories of the shoes can be changed in an instant, allowing the user to easily find the most attractive footwear [64]. On a larger scale, AR techniques for augmenting for instance deformable surfaces like cups and shirts [65] and environments also present direct marketing agencies with many opportunities to offer coupons to passing pedestrians, place virtual billboards, show virtual prototypes, etc. With all these different uses, AR platforms should preferably offer a filter to manage what content they display.

3.9. Navigation and Path Planning

Navigation in prepared environments has been tried and tested for some time. Rekimoto [66] presented NaviCam for indoor use that augmented a video stream from a hand held camera using fiducial markers for position tracking. Starner et al. [67] consider applications and limitations of AR for wearable computers, including problems of finger tracking and facial recognition. Narzt et al. [68] discuss navigation paradigms for (outdoor) pedestrians and cars that overlay routes, highway exits, follow-me cars, dangers, fuel prices, etc *Figure 3(c)*. They prototyped video see-through PDAs and mobile phones and envision eventual use in car windshield heads-up displays. Tonnis et al. [69] investigate the success of using AR warnings to direct a car driver's attention towards danger (Fig. 15b). Kim et al. [70] describe how a 2D traveller guidance service can be made 3D using GIS data for AR navigation. Results clearly show that the use of augmented displays result in a significant decrease in navigation errors and issues related to divided attention when compared to using regular displays [71]. Nokia.s MARA project31 researches deployment of AR on current mobile phone technology.

3.10. Tourism

The ARCHEOGUIDE, a project AR based cultural heritage on-site guide, was described to provide cultural-heritage sites with archaeological information to visitors [72]. An interactive visualization system based AR technologies was developed to enhance cultural tourism experiences including historical tourism on mobile devices in [73]. One design, Augmented City, with information sharing and filtering was proposed for tourist guide based on AR technology in [74]. The design of AR interfaces was approached for guided tours

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(visiting cultural heritage places) using multimedia sketches in [75]. An accessible and collaborative platform was provided for tourist guide based on AR technology and mobile devices in [76]. AR technologies were used to enhance tourists's knowledge exploration experience, exhibitions, mobile multimedia museum guide and viewing in museum in [77] respectively.

3.11. Geospatial

Hardware and software were described for collaborative geographic data representation and manipulation using two interfaces based AR [78]. AR can be used for planning of military training in urban terrain [27]. How to demonstrate ecological barrier and show their locations in the landscape was discussed based on AR technology in [79]. An approach was proposed for realistic landscape visualisation based on integration of AR and GIS [80] where using AR to represent GIS-model-based landscape changes in an immersive environment. AR interface paradigms were addressed to provide enhanced location based services for urban navigation and way finding in [81]. A tangible augmented street map (TASM) based AR was developed in [82]. One system based MAR techniques was developed for building and presenting geographical information in [80].

3.12. Urban Planning and Civil Engineering

AR is a decision support way of in architecture and interior design. A system was presented for constructing collaborative design applications based on distributed AR in [83]. AR technique was developed to explore relationships between perceived architectural space and the structural systems in [84]. It was developed for using AR systems to improve methods for the construction, inspection, and renovation of architectural structures in [85] *Figure 4*. An approach is using AR to visualize architecture designs in an outdoor environment in [86]. A prototype system was developed to use AR for an architectural application in facility management and maintenance [87]. In [88] calibration-free AR based affine representation was described for urban planning. It was approached for using a tangible interface and a projection-based AR tabletop interface to research urban simulation and the luminous planning table [89]. A System based on AR with a tangible interface was demonstrated for city planning in [90]. AR user interaction techniques were developed to support the capture and creation of 3D geometry of large outdoor construction structures in [91]. A co-operative AR design system, A4D, for AEC (architectural, engineering and construction) was approached in [92]. It was presented that a system with human computer interaction, AR visualization and building simulation can interact with buildings [93]. AR as tool was approached to be used in architecture, building performance visualization, retrieving information of building equipment and construction management in [94] respectively. In [95], one system based AR was designed to support complex design and planning decisions for architects. 3D animation of simulated construction operations based AR was investigated in [86]. The research spatially AR design environment can be used in urban design [96]. How to use AR technique to aid construction management was described in [97]. Using AR and GIS in architecture was discussed in [94]. Technologies and theories of using AR in architecture were described in [98].

4. CHALLENGES AND ISSUES

Despite the growing interest in AR and the large body of advances and research, several challenges and issue still exist and need to be addressed. In this section , we classify the limits that characterize the current state of the art of AR based on the following aspects: technology, social acceptance, usability. Considerable advances made in each of the areas described in this paper. However, there are still limitations with the technology that needs to be overcome. AR system has to deal with vast amount of information in reality. Therefore the hardware used should be small, light, and easily portable and fast enough to display graphics. Also the battery life used by these complicated AR devices is another limitation for AR's uses. Also, AR tracking needs some system hardware such as GPS to provide accurate marker, ask them to be both accurate and reliable enough. These hardware obstacles need to be resolved for practical AR use. AR systems usually obtain a lot of information, and need software to filter the information, retain useful information, discard useless data and display it in a convenient way.

5. CONCLUSION AND FUTURE TRENDS

Several possible future directions are speculated for further research. Many HMDs created specifically with AR in mind need to be developed. HMDs are still too clumsy and have limited field of vision, contrast and resolution. HMDs and other wearable equipments, such as data-gloves and datasuits, is a limitation for the user. All wearable equipments need be developed to be lighter, smaller and easier to work with the user. Also the AR system researchers need consider other challenges such as response time delays, hardware or software failures from AR systems. One limitation of AR systems is registration error. Occlusion detection is an active area of study of AR systems. Analyzing various tracking methods, possible tracking research directions are identified that allow researchers to effectively capitalize on knowledge in video frames, or integrate vision-based methods with other sensors

(a) (b) (c) (d)

Figure 4: Applications of AR in the field of ACE (Architecture, Construction and Engineering).

in a novel way. It is important to incorporate a recognition system to acquire a reference representation of the real world. Further research on this direction could provide promising results, but it is mostly a top-down process and hard to deal with object dynamics, and evaluation of different hypotheses. The challenge is to construct a pervasive middleware to support the AR system.

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