ACSIJ Advances in Computer Science: an International Journal, Vol. 5, Issue 1, No.19 , January 2016
ISSN : 2322-5157
www.ACSIJ.org

A Survey on Applications of Augmented Reality

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Abstract

The term Augmented Reality (AR) refers to a set of technologies and devices able to enhance and improve human perception, thus bridging the gap between real and virtual space. Physical and artificial objects are mixed together in a hybrid space where the user can move without constraints. This mediated reality is spread in our everyday life: work, study, training, relaxation, time spent traveling are just some of the moments in which you can use AR applications.
This paper aims to provide an overview of current technologies and future trends of augmented reality as well as to describe the main application domains, outlining benefits and open issues.
Keywords: Augmented reality; Computer augmented environment; User interfaces; Head-mounted display; Mobile and ubiquitous computing

1. Introduction

Virtual Reality (VR) and Augmented Reality (AR) are now well known concepts, but the relationship between real space, virtual space and all the intermediate forms of mixed space have been formalized by Milgram & Kishino in 1994 [1]. An augmented/mixed space "blends" together real and virtual objects; moreover, virtual elements are positioned and aligned in order to appear as part of the real world with respect to the user view.
Researchers and scientists have been discussing for a long time in order to establish a hierarchy between virtual and augmented reality and this discussion is not yet closed: it is out of the scope of this paper to compare these two paradigms. However, an unquestionable advantage can be attributed to AR: users of AR applications can keep a contact with the real world and this is an advantage both from the technical point of view (a part of the space to be presented already exists and it is not necessary a computer-generated model of it) and the physical point of view (a detachment form the real world can lead to physical and mind discomforts). If a sentence should characterize and define what the AR can do, a very good choice could be: "AR is able to bridge the gap between real and virtual objects". Therefore, every time it is necessary to represent real and computer-generated elements within the same space, augmented reality is the best solution.
The first prototype of an AR system can be dated back to 1968, when Sutherland [2] proposed an application based on a Head Mounted Device (HMD). A long time has passed from that first prototype and AR is now widespread in our everyday life. We use AR applications and technologies when we work, study, play, spend our free time and in many other situations. Moreover, AR technologies designed for very special purposes (e.g. military aircraft cockpits) are now available for commercial applications.
A first definition of what AR is has been provided in [3]: 1. AR combines real and virtual content, 2. AR is interactive in real time, 3. AR is registered in 3D. Virtual contents are usually named assets: a set of computer-generated information overlapped to the real word. Assets can be: text labels, audio messages, 3D models, animations and videos. The real world can be directly seen by the user or can be perceived through a camera. Other classifications of AR have been provided; for instance, a taxonomy based on functional purposes is presented in [4], a classification based on four axes (tracking, augmentation, content displayed and non-visual rendering) is presented in [5], whereas in [6] it is theorized that AR systems are composed by six sub-systems.
A lot of challenges have to be tackled to deploy an AR application (for more details see the next section) but it is immediately clear that the (exact) alignment of some assets (e.g. 3D objects) plays a key role in several AR-based applications. For instance, patient data are overlapped to the body in a lot of medical AR systems and the exact position-orientation is mandatory. The computation of the user's head with respect to the real world is the main problem an AR application has to tackle; this computation is usually in charge of the so called tracking system, which allows the application to know how the user is placed-oriented in the real world.
AR has found its initial application in six domains: medicine, manufacturing and repair, annotation and visualization, robot path planning, military applications and entertainment. Other important areas followed such as

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ISSN : 2322-5157
www.ACSIJ.org

tourism, architecture, cultural heritage, education and so on. This work aims to provide the readers a picture of AR technologies and the most important application fields in order to outline the potential impact in our everyday life. Although AR can enhance the user experience, several open problems have to be still effectively tackled; moreover, AR has introduced some issues concerning privacy and security, which have to be carefully considered.
Other AR survey papers have been published [3][7][8][9]; this manuscripts aims to provide an updated application-oriented vision, which should help readers to understand the potentially huge impact of AR on everyday life.
This paper is organized as follows: the next section shows the architecture of an AR application and discusses technologies available at the present moment, section Applications depicts the main application fields of mixed and augmented reality, whereas the last section presents future trends and emerging scenarios.

2. Technologies and architectures of AR systems

This section aims to analyze both the generic architecture of an AR system and the available technologies. High-level blocks characterizing an AR system are: a tracking system, an asset/scene generator and a combiner. A lot of AR systems rely on optical trackers; in this case, a camera is necessary to frame the real environment and then the video stream is received by a head tracking module. This module computes position and orientation of the head with respect to the framed objects; position and orientation are necessary to correctly align assets. When absolute values of the position are required, it is necessary to define a reference frame. Two approaches are used: marker-based and marker-less. Marker-based solutions require the camera to start by framing a well-known pattern (e.g. a QR code or an ARTag); this allows the tracker to define a World Coordinate System (WCS). Being the size of the marker known, the tracker is able to fix the camera position with respect to the WCS in an absolute way. On the other hand, marker-less approaches use environment features to correctly compute camera orientation and align assets. In this case, it is possible to compute relative positions, but the real sizes of a framed object have to be known in advance to determine absolute positions.
The output of the head tracking module is sent to the scene generator block. Head location and orientation information allow the scene generator to generate assets and accurately align them; of course, this is not an issue for audio messages or videos, but 3D objects, animations and also text labels have to be conveniently positioned. The last block, the combiner, overlaps assets to the user view; the combiner acts in different ways according to the used AR paradigm.
The first paradigm is based on see-through devices. A see-through device allows the user to see the real environment with his/her own eyes (see Fig. 1 left) and assets generated by the scene generator are overlapped by an optical effect. This solution allows the user to directly perceive the world surrounding him/her, but it requires special purpose devices such as AR glasses. Glasses can be monocular or binocular (in this second case also 3D assets can be correctly perceived) and assets can be projected over the lenses or displayed on semitransparent mini-monitors placed between eyes and lenses. Generally, AR glasses encompass a RGB camera, thus they directly feed the head tracker module. When an optical tracking is not available (AR glasses do not include a camera or the computation power is not sufficient to process in real time the video coming from the camera) other tracking systems can be used: inertial, mechanical and magnetic. Readers interested in a depth explanation about these systems are encouraged to read [10]; moreover, most handheld outdoor AR systems use GPS and compass sensors for tracking. Assets and real objects are mixed by an optical combiner when see-through devices are used to implement an AR system.
The second paradigm is based on hand-held (mobile) devices (see Fig. 1 right). Mobile devices (e.g. tablets and smartphones) encompass all the hardware necessary to implement an AR system: the camera to gather a video of the real world, a display to show the augmented environment and the computational power to: compute the camera position-orientation (by optical tracking), generate assets and combine virtual objects with the video. Mobile AR (MAR) has become very popular as cellular phones and personal digital assistants have been replaced by smart devices able to run computational intensive apps. With respect to the see-through paradigm, the MAR approach presents users a mediated reality where a direct perception of the surrounding world is not available. Assets and video of the virtual world are mixed together by a so called video combiner module.

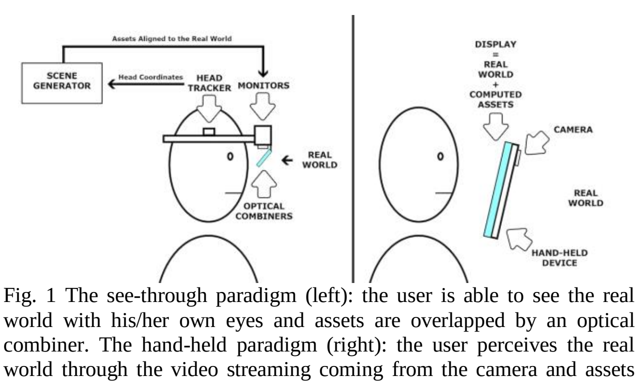

Fig. 1 The see-through paradigm (left): the user is able to see the real world with his/her own eyes and assets are overlapped by an optical combiner. The hand-held paradigm (right): the user perceives the real world through the video streaming coming from the camera and assets are overlapped by a video combiner.

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The third paradigm, called monitor-based AR, is conceptually comparable with the previous one, but camera, computational power and display (a monitor) are not encompassed in a single device. This paradigm is used when either large displays are needed or the camera must be independent (e.g. in augmented endoscopy).

This high level description of an AR system clearly outlines possible challenges AR applications have to tackle. First of all, AR systems have to deal with performance, mainly concerning the real time computation of position and orientation of the camera. Then, a second issue concerns the precision of asset alignment: several applications can require a sub-millimeter accuracy (e.g. medical AR applications). The third issue is related to the user interface: users have to be able to interact with augmented contents but the traditional keyboard-mouse paradigm is not generally available. The last two challenges concern mobility and visualization; nowadays mobile devices seem to fully satisfy the best part of application fields. On the other hand, see-through visualization devices are not still fully compliant to contrast, resolution, brightness and field of view requirements.

3. Applications

Next sections provide an overview of the main application domains of AR. This analysis well depicts how AR is pervasive in our everyday life: we have to cope with AR applications when we work, play, travel, study and in many other activities.

3.1 Medicine

As their natural attitude is to bridge the gap between real and virtual, AR technologies were immediately identified as a valuable tool to bring patients and their medical data into the same space. The potential of AR in medical applications was foreseen by Steinhaus (an Austrian mathematician) in 1938 [11]: Steinhaus suggested a method to display a bullet inside a body by a very cumbersome overlay process. On the other hand, the first real application of AR in medicine can be dated back to 1986, when a system to integrate data from computer tomography into an operating microscope was proposed. Readers interested in examining in depth applications of AR in medicine can refer to [12].

Recent advances in medical imaging have provided scientists and physicians a huge amount of data that could be profitable used to support several activities. Anatomical and functional data can be a support in surgery as well as in diagnostic of preoperative and intraoperative data or in training tasks. The use of AR in surgery is strictly related to the display technology the surgeon opts for: computer-generated assets can be directly overlapped onto the operating microscope or can be displayed over a monitor (augmented endoscopes can be considered as a particular case of monitor-based AR). Fig. 2 shows an example of medical application: the patient's medical record is shown and the radiography image is overlapped to the face with precise positioning. The projection of assets directly on the patient is apart from a particular visualization technology, but it involves very complex setups, which need accurate calibrations.

Much more than other application fields, AR in medicine has to overcome three main issues: tracking precision, misperception and interaction with synthetic data. The precision required for several surgical operations is of the sub-millimeter order, therefore assets must be overlaid very accurately. On the other hand, medical AR generally involves very limited and controlled working indoor volumes and current tracking systems are able to provide the required precision under these conditions. The misperception is basically related to a wrong perception of depth (although assets are correctly aligned, the user perceives them in a wrong position), but this issue can be mitigated by using stereoscopic visualization devices. The interaction issue is more generally related to user interface design problems; for instance, a surgeon cannot interact with assets by using touch, therefore natural and multimodal user interfaces have to be implemented. Multimodal interfaces allow the user to choose among different input modes: gesture/pose recognition and speech recognition can be two alternatives to naturally interact with computer-generated contents. Unfortunately, these alternative input modes can introduce robustness issues, which have to be taken into account when safety-critical systems such as medical ones are designed.

Fig. 2 Medical application for dental surgery. The application shows the medical record for a patient, overlapping the radiography image to the face; points of interest are highlighted as well as doctor's annotations.

3.2 Assembly, maintenance and repair

Technicians involved in complex maintenance and repair tasks often need to refer to instruction manuals to correctly complete assigned procedures. This might entail a high cognitive load deriving from a continuous switch of the attention between the device under maintenance and the manual. In other words, mistakes are more likely and repair times (and hence the costs) can grow up.

A first attempt to mitigate these issues was the introduction of Interactive Electronic Technical Manuals (IETMs) able to replace paper instructions. On the other hand, also IETMs cannot be completely part of the interaction between technician and equipment to be maintained.

AR can efficiently tackle this issue and manufacturing-repair has been immediately identified as one of the most promising application field of AR [3]. Assets are overlaid and correctly aligned with respect to the device to be maintained and can be conveyed to technicians while they are performing the procedure. Moreover, AR applications for maintenance and repair are often completed by tele-presence systems; in this way, a remote expert can interactively support maintainers when AR aid is not sufficient. Fig. 3 provides a technician’s view of an AR maintenance application with the head-mounted paradigm: audio, 3d model animated and textual assets describe the instructions the technician should follow to perform the maintenance procedure. Benefits of the AR support in maintenance, repair and assembly tasks have been deeply analyzed in [13]. First attempts of supporting technicians by AR tools can be dated back to 1990s and they were all based on special purpose hardware (e.g., HMDs). On the other hand, recent advances of mobile technologies have opened new challenging and intriguing scenarios for this type of applications. Tablets and smart-phones allow users to perform easier some tasks such as routine maintenance of a car, furniture assembly, installation of electrical appliances and so on. If we consider the huge amount of money related to these activities, it is immediately clear the tremendous impact the AR might have on our everyday life. At the present time, the spread of AR in maintenance and repair tasks is very limited; this is mainly due to the time needed to create, change and improve the procedures. A first attempt to mitigate this issue has been presented in [14], where a procedure is managed as a set of sequential states: each state is related both to a tracking configuration and to a set of assets to be played when the tracking system recognizes the configuration in the real world. Existing states can be deleted and new states can be easily added; an asset library allows content makers to quickly associate an object configuration with a set of aids to be conveyed.

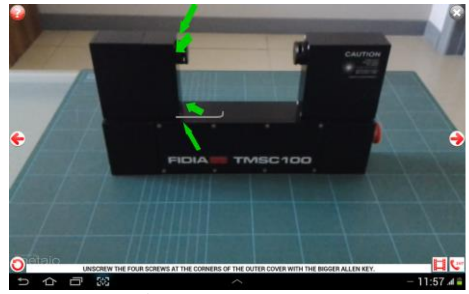

Fig. 3 AR application for maintenance procedures. The application supports the technician through the repair task of an industrial device; textual and 3D assets are shown.

3.3 Entertainment, sport and marketing

The entertainment industry is one of the most important drivers of ICT technology progress and a lot of improvements in augmented reality can be related to it. Video game players have a desire: they want to be part of the game. If the player is more involved in the game, then the game experience will be enhanced. This idea has inspired the design of all modern game consoles; in other words, players do not control characters but they are the characters.

AR aims to bridge the gap between real and virtual, therefore it is the best tool to provide users a new game experience. The real world can become the set for a game (see for instance ARQuake [15]) and the player can experience a completely new and exciting game modality; moreover, beyond a more natural and intuitive interaction, AR-based games can be played, in general, everywhere, without any space limitation. Another important benefit concerns the development step: all game scenarios have to be completely modeled and rendered in a traditional game; on the other hand, AR games use the real world as a scenario and only virtual characters and assets have to be created. Fig. 4 shows an example of this type of augmented game: a number of enemies is placed in the scenario and move towards the player, who have to shoot them down to gain points and to move to avoid the monsters and save is life.

Modern game consoles also implement AR by using different types of cameras to augment computer graphics onto live footage. Also the market of stickers can take advantage from AR: when a sticker is framed by a personal device running a specific AR application, the user can play on the device multimedia contents about the *star* (e.g. a football player) or the personality depicted on the sticker.

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Fig. 4 Entertainment application. The game requires the player to move in the real space in order to aim and shoot at the enemies; alien enemies are placed in the real environment.

AR is often used for augmenting live broadcast of sport events [16]. For instance, computer-generated aids are added to the raw video images in order to show the off-side line in a football match or the trajectory of the puck in hockey games. Maybe, the most famous system for the augmentation of sport events is Hawk-Eye; Hawk-Eye is a system used in tennis matches, which provides the tracking and the visualization of balls trajectories, thus enabling players to challenge the Referees' decisions. In the augmentation of many sport events, assets have to be overlapped to raw images in real time; this means that the AR system has to be able to identify and track a given object in the scene in a very performing way.
AR plays also a very important role when advertisements and logos have to be inserted in live video broadcasting: messages as well as 3D objects/animations can be aligned to real objects framed by the set of different cameras used to film the event.
AR is also often used by marketers to promote new products [17]. Such systems are already widely used and they aim to present products in an engaging way. For instance, by a sort of magic mirror [9], customers can virtually wear clothes or shoes; in this way, the need to try on anything in stores it is replaced by a sort of virtual shop, thus saving time for clients.

3.4 Collaborative visualization space

Data visualization is a very broad discipline encompassing several different fields; for instance, information visualization aims to find new paradigms to efficiently display huge amount of data (e.g. the network traffic over the Internet), whereas scientific visualization aims to present users phenomena that are very hard (or impossible) to perceive (e.g. air flows around to a plane wing).
The intrinsic nature of AR provides visualization a worthwhile tool to display virtual objects within a physical space; moreover, AR is particularly suitable for collaborative visualization. Collaborating users communicate by using speech, gaze, gesture and other nonverbal cues. These "communication channels" are often inhibited or limited when traditional collaborative work tools are adopted: tele-presence and screen-based collaboration often create barriers between physical and virtual space. On the other hand, virtual collaborative spaces migrate both objects and users (represented by avatars) in a cyber space, thus altering usual communication channels. Face-to-face AR collaborative applications are able to avoid this problem, thus allowing users to communicate each other by usual verbal and nonverbal cues within a physical space [18]. Moreover, AR applications can provide the users with custom visualizations, thus enabling custom views of the dataset. This is basically obtained by organizing data to be displayed on layers: each layer should contain computer-generated objects, which share one or more attributes (e.g. they share the same material or they are sub-parts of the same object) and each layer can be activated/deactivated.
A key role in collaborative work is often played by annotation: users have to be able to add their own textual comments to parts of the augmented space as well as they have to be able to share these annotations with other collaborating users. Figure 5 shows an example of collaborative application, based on a 3D model of a city's district: the users can share notes attaching them to the different parts of the 3D model (e.g. buildings, streets, squares). AR applications for collaborative visualization often provide users tangible interfaces. A tangible interface links a real object to a computer-generated one; for instance, a building could be related to a physical object such as a small box: transformations applied to the box (e.g. translations and rotations) will be propagated to the associated virtual object. Of course, the tracking system of the AR application has to be able to track both users' heads and artifacts selected as alter egos of virtual objects; at this purpose, marker-based approaches are mainly used.

Fig. 5 Collaborative application. The application allows users to visualize a virtual collaborative space and to add notes in order to share information with other users.

Features of an AR collaborative visualization application are: virtuality (computer-generated objects can be displayed and examined), augmentation (virtual objects can be displayed in a physical space and real objects can be annotated), cooperation (several users can cooperate in a natural way), independence (each user can customize the dataset to be displayed) and individuality (each user can customize the graphic metaphors used to represent data). The first example of collaborative AR visualization is the Studierstube [19].

A main issue still concerns AR collaborative visualization tools: a better interaction form is obtained by using the see-through paradigm, but AR-glasses (e.g. binocular glasses and HMDs) often partially cover the user's eyes, thus inhibiting (or strongly limiting) gaze communication, which represents an important form of nonverbal cue. Monocular glasses can mitigate this issue, but they are not able to provide stereoscopic visualization of 3D objects.

3.5 Tourism

AR can play a key role in tourism mobilities [20] and a significant improvement has been obtained by new generation smartphones and tablets, which are often equipped with GPS sensors, and fast network connections. These devices are therefore able to support location-based AR services.

A Tourist experience can be enriched (and mediated) by adding multimedia and customized contents according to the tourist's needs [21]. Basically, three types of AR applications for tourism can be categorized.

Augmented guides are the first type of AR application for tourism; an augmented guide searches, retrieves and visualizes information gathered from several Internet sources (e.g., touristic portals). Information are arranged in order to provide the users with all the support necessary to: organize travels, reserve tours, rent cars, and so on. The first example of an augmented guide is Tuscany+: the official augmented reality application of the Italian region Tuscany. Information gathered by the AR application can be also used to generate a sort of *hybrid* space: the physical space (e.g. a square of a city) is filled up with information coming from the cyber space (e.g. the Net). Fig. 6 shows a Tourism application that provides the user his current location and a set of nearby Points of Interest (POIs); an arrow near the POI tag indicates the direction to reach it; each POI is grouped by color and icon to simplify recognition.

Several augmented guides allow the user to mark and share a POI; moreover, multimedia contents can be completed by manual annotations and comments. If the AR application allows the user to share POIs and annotations, it is said a *social* application. In this case, the impact of AR technologies might be magnified by the Net as users generally ask for a direct link between applications and their own profiles on social networks.

Sometimes, AR applications for tourism and entertainment have a strong relationship. In this second type of AR applications, a tour is organized as a multi-level game and users have to solve mysteries and answer questions related to the tour itself; users receive information about the next stage of the tour only when they are able to complete the current level. This approach provides the so called space gamification.

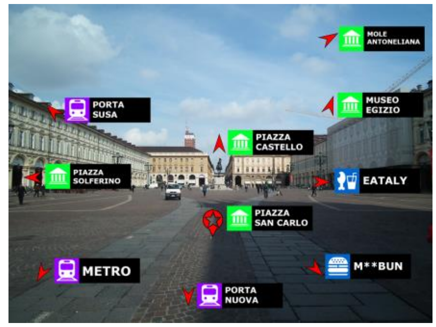

Fig. 6 Tourism application. The application shows the user's location and a selection of points of interest in the nearby area, such as: museums, restaurants and transport's lines.

The third type of AR application for tourism is related to the concept of fictionalization. In this case, tourist experience is augmented referring to very special places such as film sets or locations described in literature: AR can improve and enhance the fictionalized landscape visits.

A main issue affects the spread of AR for tourism: the lack of interoperability among applications; this impacts both on developers and content aggregators. If this problem is shared by all application domains of augmented reality, tourism is the one more affected because of the huge amount of information gatherable.

3.6 Architecture and construction

AR reality technologies find an important application field in architecture and construction tasks, which are usually classified under the category "architectural design and urban planning". Architects and designers deeply stress issues related to spatial communication: they would intuitively convey information about appearance, scale and features of a proposed project. Unfortunately, neither scale models nor virtual models completely tackle all the needs of spatial communication.

AR can be a valid support and several types of application are well known:

1. the first and simplest type aims to display buildings, from their early designs to final constructions, by representing them as virtual objects into the real world. These applications allow architects to plan and evaluate in advance the impact of a new construction (urban planning); moreover, this approach enables the so called walking tours, thus allowing users to move in a real scenario and observing a virtual building

as if it were real. Figure 7 shows an example of this type of application, with a 3D model overlapped to its blueprint through AR.

2. AR applications can also enable a sort of x-ray view. Hidden features such as structural supports, pipes and electric cables can be overlapped to a building. In this case, it is very important the integration of the AR application with BIM (Building Information Modeling) data.
3. Collaborative design. The final goal of architects and designers is to obtain a seamless transition between individual work with CAD tools and collaborative work. Collaborative work can strongly reduce design times and improve the interaction between designers and customers. Magic meetings refer to augmented/mixed spaces where people can cooperate to model, analyze and assess CAD projects. An example of magic meeting is MR^2, a mixed reality meeting room [22].
4. As presented in section "Assembly, maintenance and repair", AR can be used for maintenance tasks; in this case, special purpose applications are tailored to support building maintenance.

At the present time, a very few architects and designers use AR, and in the most of the time AR is only used to enhance presentations and marketing. This is due to a lack of integration of AR technologies in the design workflow. Although this problem has been investigated since the last decade [23], a lack of standards prevents from a real integration of AR in CAD software.

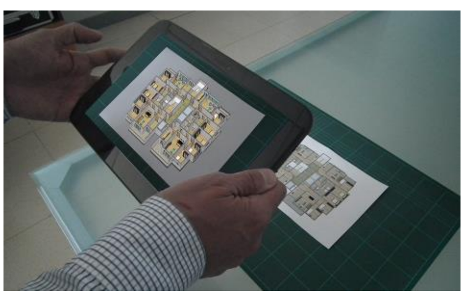

Fig. 7 An architecture application, which allows the user to visualize a 3D model of the apartment's blueprint framed by the camera.

3.7 Cultural heritage and museum visits

AR applications for tourism and cultural heritage share a lot of requirements and characteristics; on the other hand, some distinguishing features can be identified.

First of all, it is important to define the concept of cultural heritage attraction. It can be a monument, a ruin, a battlefield and everything can assume a cultural value. At the present time, videos and virtual tours are the main supports to promote cultural heritage; printed info and scale models can be also available for on site visitors. Augmented reality can strongly enhance this support by providing the users with multimedia contents ranging from the temporal reconstruction of a site to a virtual reconstruction of a battle. This kind of applications can be categorized as an augmented guide (see for instance [24]). Fig. 8 shows an example of an augmented guide that provides textual, audio and video information to the user, depending on the work of art framed by the camera.

When cultural heritage gives rise to cultural tourism, AR provides a set of undeniable advantages [25]:

1. printed info and other unnatural objects placed in a cultural site involve costs and, moreover, alter the site itself; AR applications do not need information boards or other "artifacts" and can be modified/updated more efficiently than traditional info.
2. AR does not limit the amount (and the type) of information for users, whereas info boards have a limited size, thus reducing the information potential.
3. AR applications, generally, enhance the user experience and this can trigger a virtuous circle where costs due to the development of an AR application are balanced by the positive publicity of satisfied users that visited the site.
4. Cultural heritage AR applications are often social, thus allowing users to share their experiences by social networks.

Fig. 8 A multimedia guide for museums that provides textual, audio and video information for the work of art framed by the camera.

A characteristic feature has to be mentioned for AR applications designed for museum visits. Every type of multimedia guide has to be supported by a navigation mechanism able to determine position and orientation of the user. Basically, a guide has to answer to the following two questions: 1) Where can I find the object for which I see multimedia content is available? 2) Where are the information related to a particular artwork that I can see?

Navigation systems based on Wi-Fi, Bluetooth, RFID and infrared technologies can either fail (or they can be

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ISSN : 2322-5157
www.ACSIJ.org

strongly limited) when the user is moving in crowed environments or provide a not sufficient precision in the computation of the user's orientation. AR tracking systems can mitigate these problems, thus providing developers an efficient solution for localization in GPS-denied environments.
Issues related to AR applications targeted for cultural heritage and art are almost the same as AR applications for tourism.

3.8 Teaching, education and training

Teachers, educators and trainers are always searching for new technologies able to enhance the learning experience of their students. AR proved to be an effective and efficient tool to improve traditional learning and training paths. AR changes the way users and machines interacts and this can stimulate students to approach the study of course material in a different and more pro-active way. Moreover, AR applications tailored to support teaching and learning can incentivize cooperative and collaborative learning, thus improving the teacher-student and student-student collaboration. In the same way as virtual reality, AR helps instructors to simulate and visualize microscopic or macroscopic scale systems; moreover, dangerous and/or destructive events can be represented. A lot of examples of projects and publications are known in the literature (readers can examine in depth this topic by two survey papers [26][27]) that provides a clear vision of how AR might impact on teaching and training methods. Medicine, Engineering, Architecture, Chemistry, Mathematics and Geometry, Physics, Geography, Astronomy, History, Archeology, Music and Art are just some examples of disciplines that might be taught in a different and more exciting way by AR.
All domains previously presented as application fields can take advantage from AR technologies for education purposes. Maintenance AR applications can be used to support expert technicians as well as to train beginners and AR games could have an educative value. AR is often used in the *discovery-based learning* where the recognition of a place (geo-referenced AR applications) or of a person is the starting point to present, for instance, historical events or personalities. On the other hand, the most common use of AR in education is related to interactive course material (often providing 3D visualizations), which allows educators to reduce the gap between real and virtual. Magic books (also called AR books) are the best example of interactive material: some pages present animations, audio contents and 3D objects, students can interact with. The magic book allows teachers to implement the so called *blended education*, that is a hybrid approach that uses two (or more) different teaching technologies (e.g. the traditional book and the augmented reality). Figure 9 provides an example of Magic book application: a 3D model of planet Earth is visualized on top of a 2D image of Earth itself depicted on the physical book; the application allows to rotate the model and to change its size to provide further interaction.

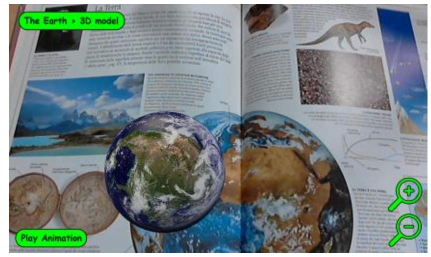

Fig. 9 A magic book that provides multimedia content related to the current page framed by the camera, e.g. a 3D model of planet Earth the user can interact with.

Despite of all these encouraging aspects, a main issue has constrained and limited the spread of AR in education so far: the difficulty for educators to make quickly deployable AR contents. AR applications and their contents are, at the moment, quite rigid, therefore it is very difficult for teachers to change and adapt them to the students' needs.

3.9 Military applications

AR applications for military purposes share a lot of issues with AR-based games and AR-based training systems. The term often used is BARS: Battlefield Augmented Reality System [28]; in other words, AR is used to synthetically create battlefields within the real world, which can be navigated without the limitation common to virtual environments. Usually, training scenarios for soldiers are made by projecting a virtual environment and virtual actors on walls within training facilities. This needs significant infrastructures and it is limited to indoor contexts. AR allows to overcome these constraints, thus allowing soldiers outdoor training activities where users can physically move through real environments.
Another use of AR is ordinary in military applications: the overlapping of information with the environment. For instance, soldiers can receive on their AR vision systems (mainly AR glasses) information about objects in the battlefield and the threat level related to each element of the environment. Figure 10 shows an example of military application: different kind of information is overlapped to the real scene to provide additional data on the surrounding area, such as target position, distance from the base camp and previous events in the area.
Some characteristic issues are related to the use of AR in military applications. First of all, if AR applications basically aim to track the position of a camera with respect to the real world, also weapons have to be often tracked in AR-based military systems. In first person shooting systems (see for instance [29]), the soldiers' heads have to be tracked as well as the positions and orientations of their

weapons. This is necessary to exactly determine what targets have been shot.

Fig. 10 A military application that provides soldiers additional information on the surrounding area, such as: target position, distance from the base camp and previous events in the area.

Moreover, information conveyed to the user has to be carefully managed; in fact, a huge amount of data might be available and an indiscriminate visualization of them will have a negative effect in terms of cognitive overload. This last issue can be partially mitigated by implementing a natural input interface based on speech and/or gesture recognition that enables soldiers to intuitively select and configure information to be overlaid to the battlefield.
Another important characteristic of AR-based systems deployed for military applications is the collaboration function. Soldiers have to be able to exchange information (e.g. each soldier should know the positions of the other ones, thus discriminating between them and potential foes), therefore affecting what assets are displayed on the interfaces of the other collaborating users.
AR-based systems for military applications should be also able to monitor each soldier's stress level, thus adapting the output of the interface in order to provide the best support.

4. Conclusion and future trends

The evolution of AR technologies is strictly related to component miniaturization. For instance, the availability of extremely small cameras now allows designers to provide users AR glasses almost unnoticeable from usual glasses. In a near future, contact lenses will be able to incorporate all functionalities now provided by AR glasses and this clearly introduces some privacy and security issues.
When users are in a public place, they are surrounded by a number of bystanders: they could be friends, acquaintances or strangers. These bystanders could be uncomfortable with the user recording them. One of the main concern of bystanders is to be located and tracked on the Internet through AR devices, similarly to what happens with video camera surveillance in public places (e.g. inside and outside banks). If using contact lenses is the case, bystanders could even not be aware of the AR device: their behavior would probably be different if they were aware of the AR device. Moreover, the user could cheat bystanders extorting and recording information (e.g. audio and video) without their consensus: this use will make the AR device similar to an advanced spy cam, with more data on the target (e.g. the location). The same concerns that affect bystanders could be applied to public and private places. A malicious application could be used to get information on a location to plan a robbery. For example, a user could enter a bank and get data about employees, security exits, alarm positions and much more. The capability to record huge amount of data unseen could even be used to plan terrorist attacks.
Beyond a technological development, the spread of AR depends on another key factor: the content availability. At the present time, AR applications are quite rigid and it is very difficult to change/adapt augmented content to users' needs. This lack of flexibility is a constraint for AR diffusion as only software developers are able to generate augmented contents; authoring tools are still very limited and tailored for a few application fields. For instance, teachers, educators and trainers could take advantage of AR by providing their students more effective and interesting course material; unfortunately, it is not easy neither to write a magic book nor to integrate AR tools in the traditional publishing pipeline. The lack of integration is another key issue and CAD tools should be modified to simplify asset generation. Maintenance, repair and assembly tasks would be strongly simplified by AR procedures but automatic (or semi-automatic) generation processes should be available. Unfortunately, a standard to describe AR contents still misses and this limits the integration of AR technologies with the existing tools. The Augmented Reality Markup Language (ARML) is an attempt to overcome this issue but it has not been still accepted by AR technology makers.
On the other hand, AR has got the potential to become a pervasive technology and a lot of everyday activities could be efficiently supported by AR. Ordinary car maintenance, furniture assembly as well as appliance installation are just three examples of routine activities that could be simplified, thus reducing efforts, costs and time spent.

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