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Antonio VASILIJEVIĆ
Bruno BOROVIĆ
Zoran VUKIĆ

Augmented Reality in Marine Applications

Review paper

Augmented reality (AR) system combines the real world with virtual information and provides expanded and information-rich view of the environment to the user. The AR systems have been around for a few decades but their number started to grow significantly only during the past few years. Recent advances in technology, lower cost of otherwise expensive equipment and especially development of the smart handheld-device market have propelled the rapid development of the AR. It has literally become a part of everyday life. This paper presents a systematic overview of AR technology. It covers AR system components, applications, outlook on future research and development as well as main technology challenges and limitations. The paper also includes several examples of Virtual Reality (VR), the technology similar to the AR, as well as existing and potential AR and VR applications in maritime sector.

Keywords: *augmented reality, virtual reality, tagging, navigation aids, simulators, marine, handheld devices*

Primjene proširene stvarnosti u pomorstvu

Pregledni rad

Sustav "proširene stvarnosti" kombinira prikaz stvarnog svijeta s virtualnim informacijama te korisniku pruža proširenu i informacijama bogatu sliku okoline. Sustavi za prikaz proširene stvarnosti u uporabi su tijekom nekoliko desetljeća ali se njihova uporaba značajno proširila tek tijekom nekoliko posljednjih godina. Brzi napredak tehnologije, manja cijena inače skupe opreme te posebno nagli razvoj tržišta pametnih prijenosnih osobnih uređaja osigurali su nagli razvoj proširene stvarnosti do te mjere da je doslovno postala dio svakodnevnog života. Ovaj članak daje sustavni pregled suvremene tehnologije proširene stvarnosti, pokriva komponente sustava, njihovu uporabu te diskutira budući razvoj i glavne tehnološke izazove i ograničenja. U članak je isto tako uključeno i nekoliko primjera primjene "virtualne stvarnosti", tehnologije vrlo slične "proširenoj stvarnosti", kao i primjene tehnologije proširene stvarnosti u pomorstvu.

Ključne riječi: *proširena stvarnost, virtualna stvarnost, označavanje, navigacijska pomagala, simulatori, pomorstvo, prijenosni uređaji*

Authors' address (Adresa autora):
Faculty of Electrical Engineering and Computing, University of Zagreb
e-mail: (antonio.vasiljevic, bruno.borovic, zoran.vukic)@fer.hr

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1 Introduction

Human interaction with environment is changing rapidly thanks to recent advances in technology called Augmented Reality (AR). AR combines different technological fields to enhance interaction between users and their surroundings. Augmentation is usually done by adding virtual, computer-generated objects or information tags into the real world environment. Something interesting or potentially useful can be learnt for every object or place the user comes across especially when adequate source of data is available in real time. The large number of information and social networks are constantly fed with information about almost every person or location available and that information is already used heavily in AR mobile applications. Furthermore, there is a lot of information around which is imperceptible to human senses. Combining the AR technology and computer-mediated translation of these otherwise imperceptible phenomena, we can make them visible to us.

The AR is a part of a broader concept called Mixed Reality (MR) which is again part of an even broader definition of a Mediated Reality. "Mediated Reality refers to the ability to add to, subtract information from, or otherwise manipulate one's perception of reality..." (Wikipedia: "Mediated reality"). Paul Milgram and Fumio Kishino have defined Milgram's Reality-Virtuality Continuum [1], [2] where a continuum spans from the real world to a totally virtual environment shown in Figure 1. A region called Mixed Reality (MR) [3] lies in between. Mixed Reality consists of Augmented Reality, near the "Real Environment" end of the continuum and Augmented Virtuality (AV), near the "Virtual Environment" end of the line.

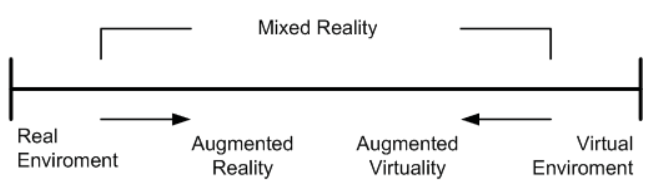

Figure 1 **Milgram's Reality-Virtuality Continuum**
Slika 1 **Milgramov realno-virtualni prostor**

In AR space the user maintains a sense of presence in the real world. It is predominantly real world augmented by virtual data or objects. Synthetic, computer-generated data is merged with the real view. On the opposite side, AV is predominantly virtual space created by merging of real world objects and data into virtual world in order to enhance or augment virtual environment. The extreme at the virtual end of continuum, i.e. everything is virtual, is often called VR. More recently, due to rapid technological improvement and increased interest of the general public in the field, the term AR has been blurred a bit with the term AV. In the other words, the distinction between AR and AV fades out as the virtual elements in the scene become less distinguishable from the real ones.

Commonly accepted definition of Augmented Reality is Ronald Azuma's definition [4]. It says that Augmented Reality combines real and virtual, it is interactive in real time and it is registered in 3-D.

In other words, real scene related virtual elements are superimposed into real view in order to augment user perception of a real world. The augmentation is conventionally done in real-time. Accurate registration of the virtual objects within the real world, which also has to be maintained while the user moves, is essential to provide realistic looking fusion of the real and virtual world.

Some simple examples of AR are virtual elements projected on the television screen during broadcast of a sport game. For example yellow line overlaid on video during the swimming event, scoreboard or advertisements overlaid over football game.

Although AR technology has been around for a while, it took recent development of mobile devices to propel AR towards wider audience. Harsh consumer market requirements and consequent rapid technological advancements dramatically improve AR on daily basis. According to ABI Research, handheld platforms will transform the AR world, with revenue growing from about $6 million in 2008 to more than $350 million in 2014.

Besides adding the virtual objects to a real environment, AR can also be used to hide the real objects from the scene. “Diminished Reality” technique removes or replaces them with an appropriate background image and frees the user from unnecessary information.

Even though the AR can be applied to all human senses, vision based applications are by far most numerous. This does not come as a surprise, since vision is used to gather the most information out of all of the human senses. Vision is the only sense enabling human to perceive shape, size, colour, distance, and spatial location simultaneously. Nowadays, the AR could be successfully extended to include hearing and touch while taste and smell are still not used in AR applications. Hearing is interesting for AR applications because it can provide far larger field of view than vision. In addition, some of the information received through human-imperceptible sensors may be processed and “presented” to human through hearing as they may be easier to interpret that way. On the other hand, using hearing unloads vision from receiving increased number of data. Touch is more limited than the hearing and only provides information within an arm's reach. Gloves with actuators that provide tactile feedback augment real forces in the environment.

In order to reasonably cover AR systems, their components and applications, the paper is organized as follows. Section 2 describes typical components of the AR systems. It is followed by description of applications of AR technology in marine sector. Section 4 discusses general challenges and limitations related to the AR systems. At the end, the AR is summarized and some conclusions are given.

2 Components of AR system

Expressed in the simple way, the AR system collects data from real world, processes them and presents new, augmented view of the real world to the user, as shown in Figure 2.

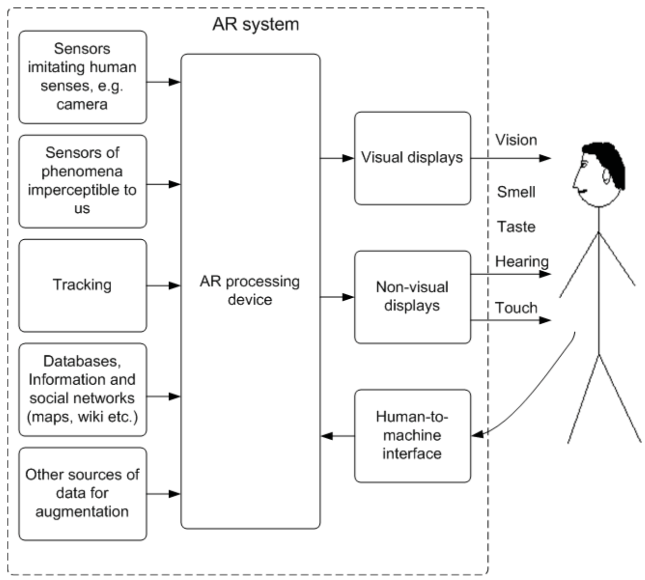

Figure 2 **AR system inputs and outputs**
Slika 2 **Ulazi i izlazi AR sustava**

A good example of contemporary AR system is Handheld Device. It is a computing device with a display small enough to fit in a user's hand. AR handheld devices have built-in tracking sensors such as GPS, compass and inertial navigation system (INS) for registration. It can be linked to various databases available on the web. Relatively powerful computer uses sensor inputs, web information and video see-through techniques to overlay the virtual graphical information to the real world image. At the moment, handheld devices, including mobile phones, are the most promising platform and the first commercial success of AR technology.

Summarized, the handheld AR system comprises inputs (sensors, tracking devices and database links), AR processing devices (computer) and system human interface (video display and headphones).

2.1 Information inputs

Inputs can be divided into three distinct groups, sensors imitating both human senses as well as senses imperceptible to humans, tracking sensors and links pointing to various databases.

Sensors that substitute and amplify human senses are video camera, microphones, force sensors (tactile) and temperature sensors. Video camera replaces the vision, a human most trusted sense, and is typically included in almost all AR applications. Sensors such as infrared camera or ultrasound microphone are examples where sensing is expanded beyond human bandwidth.

Tracking sensors are used for accurate determination of user's position and attitude (orientation) in the real world. The AR systems use one or more of the following tracking technologies: GPS, digital cameras, inertial navigation system (INS) which typically include accelerometers, gyroscopes or solid state compasses.

The links pointing to various databases or other available sources provide auxiliary information for augmentation of the AR scene. These links provide access to information such as previously stored maps, data about historical buildings or consumer reviews of various products or restaurants.

2.2 AR processing devices

AR processing devices collect all relevant information from camera, sensors and associated databases, process data and generate augmented output in real time. It is computationally intensive task which requires powerful processors (CPU). Software that runs on those CPUs is usually dedicated to the specific device and AR applications.

2.3 System-to-human interface

System-to-human interface handles all communication between human and the AR and can be divided into two categories. The first one includes various visual, audio and tactile displays where data flows from the AR system towards human. The second group are interfaces where human gives inputs to the AR system e.g. mouse or keyboard.

The most common display device used in AR applications is computer monitor or TV. Although widespread, it is characterized by the lack of immersive experience. On the other hand, a Head Mounted Display (HMD) provides the best immersive experience. The HMD is worn on the user's head and has a small display device in front of each eye presenting virtual objects over the view of the real world. A nice example of HMD are AR glasses shown in Figure 3 (source: *Vuzix* web site). Another well known example of HMD is a Head Equipment Assembly (HEA) used by military pilots. Different AR display also adopted from military aviation is Head-Up display (HUD). It renders augmented information directly on the windshield as shown in Figure 4 (source: *BMW* web site). Information is read faster, and the user's attention is never taken away from the main task, i.e. driving.

Another type of displays are Spatial Displays. They project the AR onto an object in space, i.e. integrate extra information into environment. This way, the object becomes augmented with the projected data. One of the advantages of spatial displays is that they are not associated with the single user but allow multiple users to collaborate and mutually "enjoy" augmented scene.

Figure 3 **AR glasses *Vuzix* Wrap 920AR**
Slika 3 **AR naočale *Vuzix* Wrap 920AR**

Figure 4 ***BMW* Head-Up display**
Slika 4 **HUD zaslon u *BMW* vozilu**

Finally, so called non-visual displays may be used in AR systems. All displays that are not visual belong to this group. Loudspeakers, or even more commonly used headphones, are audio displays that generate sound which creates audible perceptions for the user. On the other hand, haptic displays interface with the user through the sense of touch. The typical device from this group are hand worn gloves with sensors that provide tactile feedback for interaction with AR systems.

Besides acquiring data from the AR system through displays, there are many ways human can input data or give commands to the system. Microphone with speech recognition capability, handheld device with gesture recognition are just few of the new consumer-grade types of interfaces which could make conventional input devices such as keyboard, mouse, joystick and touchscreen redundant. An example of the military high tech interface is the High-Off-BoreSight (HOBS) system. It enables pilot to accurately direct onboard weapons against enemy aircraft just by pointing the head at the target.

3 Marine AR and VR applications

Many fields already benefit from AR technology. Significant achievements have already been done in agriculture [5], architecture [6], art, collaboration [7], games [8], exposure therapy [9], education, medicine, military, sales & e-commerce, tourism and, especially interesting for us, the use of AR at and under the sea. Hence, the marine AR applications are described in more details below.

3.1 Ship simulators

Ship simulators are maybe the best known and exploited marine application though they are closer to the virtual than the real end of the Milgram's Reality-Virtuality Continuum shown in Figure 5 (Source: Kongsberg web site). Ship's bridge simulators are commonly used to simulate movements into and out of major ports around the world and train maritime officers to use ship systems in a controlled real time environment. It is also an important training tool that prepares deck personnel for what they could expect once they step onto a vessel. The ship's bridge simulator is usually integrated with the Dynamic Positioning, Engine Room, and Cargo Handling simulators, which allows a broad range of realistic training scenarios.

Figure 5 **Ship bridge simulator for personnel training**
Slika 5 **Simulator brodskog zapovjedničkog mosta za uvježbavanje osoba**

3.2 Shipbuilding

Virtual Reality is used as a tool for design review by some of the leading shipyards in Germany. Participants of various disciplines and stakeholders have an opportunity to test and evaluate present model while design is still in a developing stage [10]. Virtual models that replace real ones may be used to inform customers and public about new products, i.e. ships and offshore installations.

3.3 Electronic Navigational Aids

Electronic Navigational Aids available on board today's ships provide extensive information to help navigation but often force deck officers to turn their attention away from watch-keeping duty. Fusion of all added information into a one easy-to-perceive display of the ship's navigational and voyage related data would ensure optimal use of all resources available without interrupting ships operational procedures. It improves safety of navigation, collision avoidance, ship security and environmental protection by integrating together a variety of electronic navigational and communications systems, e.g. automatic identification system (AIS), vessel traffic services (VTS) or automatic radar plotting aids (ARPA) with nautical charts, satellite photos or other on board systems and sensors [11], [12].

Figure 6 **Foggy day augmented with computer generated Navigational Aids**
Slika 6 **Stvarnost maglovitog dana proširena virtualnim sredstvima za navigaciju**

The video may also be augmented with information such as route waypoints, distance and bearing to next waypoint, local hazards, buoys, lighthouses, etc. In AR these virtual objects are overlaid on video and are positioned in their real geographic location. Navigation aid, in a form of virtual "rails" on both sides of the ship track, helps steering in low visibility conditions [13] as shown in Figure 6 (*Technology Systems Inc*. "ARVCOP" software: http://www.arvcop.com/).

LYYN system is a simple example of AR technology providing such navigational aid. It enhances visibility in real-time in fog as shown in Figure 7 (Source: LYYN web site), dust, lowlight, snow, smoke and in underwater environment.

Figure 7 **It is not easy to see through fog. AR system extracts hardly visible features and cleans them.**
Slika 7 **LYYN AR sustav „čisti" u realnom vremenu video sliku u uvjetima slabe vidljivosti.**

Another interesting AR concept focuses on the augmentation of the existing buoy network by implementing virtual buoys. VTS broadcasts a message with buoy's number and geographic coordinates on AIS channels and virtual buoy pops up on your electronic chart or camera screen. Virtual buoy network can improve safety of navigation but can also save significant amount of money because the cost of real buoy purchase, deployment, recovery and repair is substantial. Concept has a great potential and has been discussed by marine authorities worldwide. However, a lot of simulation and testing need to be done in a controlled environment before reliable deployment of the system [11].

Some other interesting projects employing AR are Galileo Augmented Manoeuvring, Galileo Augmented Rescue and Galileo Augmented Logistics [14]. They all exploit high accuracy and reliability of Galileo, the Europe's navigation satellite system.

3.4 Dynamic positioning

The use of AR technology as aid for **Dynamic Positioning Operator** is more concept of the future than of the present. Potential is, however, enormous**.** The concept is well described in [15].

"... what about if the DPO (dynamic positioning operator) were wearing AR goggles? In addition to seeing the sea, the ships and structures on it – we could lay on information about the sub-sea environment, the current, the cable route, the fact that the vessel ahead was having problems holding station, etc, etc… all the information that exists, but which we maybe never know or never see visualised suddenly becomes part of our decision making process.

With the AR system working in tandem with the human element and the DP equipment we can trigger warnings, develop scenario and simulate the outcome of actions."

3.5 Maintenance with AR

Another promising application of AR is the assistance in assembly, maintenance and repair of complex systems. Instructions, drawings, procedures and 3-D virtual guides overlaid in real time on see-through image of the actual equipment can help engineers to complete their job safer, easier and faster. First applications of this type were developed almost 20 years ago at *Columbia University* and *Boeing* [4].

A new AR system developed at Columbia University helps marine mechanics carry out repair work. Marine mechanics perform maintenance and repair of complex machinery, very often in a tight space. Instead of carrying laptop and paper documentation with them, mechanics wear a head-worn display while AR system generates virtual layers of text instructions, labels and warnings, 3-D guiding arrows and 3-D models of the appropriate tools. A smart phone with touch screen is attached to the mechanic's wrist and is used for user-AR system interaction. Initial testing of the AR application suggests that it can help users to perform their maintenance tasks in almost half the usual time [16]. Similar systems are in use in auto industry as shown in Figure 8 (source: http://www.bmw.com/com/en/owners/service/augmented_reality_introduction_1.html). AR guides the mechanic through the entire repair procedure. Special AR googles integrated with headphones allow the mechanic having all information, tools and animated components overlaid on the actual vehicle.

Figure 8 **Maintenance with AR**
Slika 8 **Proširena stvarnost u održavanju**

3.6 Augmented Reality under water

Creating an underwater AR system is still a challenge. It has to fulfil some additional requirements. The system has to be waterproof, has to withstand the high pressure of diving depth and cannot rely on GPS. These requirements result in the AR system which has to use specialized sensors, has to be robust, and is therefore difficult to design and expensive.

Researchers from the *Fraunhofer Institute for Applied Information Technology FIT*, Germany developed the system which allows people to discover underwater word of corals, fishes or fairy-tale wrecks in a swimming pool in a comfortable and safe way [17], see Figure 9 (source: *Fraunhofer FIT* web site, page: Underwater AR). Augmented Reality techniques visually enhance a regular swimming pool with virtual objects, upgrading it to a virtual coral reef with shoals, mussels and weeds. The system main components are waterproof display and camera integrated into diver's mask, mobile PC in the divers backpack and inertial and magnetic tracking system. Based on camera image, diver's orientation and pre-programmed scenario, the system generates visual representations of the virtual 3-D scenes.

Figure 9 **Virtual underwater world**
Slika 9 **Virtualni podvodni svijet**

Another interesting application of AR underwater is Underwater Augmented Reality (UWAR) system developed by [18]. During underwater work, divers are exposed to demanding physiological circumstances such as high pressure, poor visibility, weightless condition, water temperature, hearing limitations and lack of orientation. This can have a significant impact on behaviour and mental processing of divers, causing psychological effects e.g. anxiety, panic or memory disorders.

These effects can be mitigated by assisting divers in locating the work site, keeping them informed about their position and orientation, and providing a 3-D virtual guide for the working task. UWAR system provides such visual aids, as shown in Figure 10, to divers improving both performance and safety of the underwater work. A virtual red arrow and a yellow line points to the underwater work-site acting as an navigational aid for the diver. A red grid is an artificial horizon which makes divers aware of their orientation. A 3-D model of an assembling task (flange) makes a job easier to do.

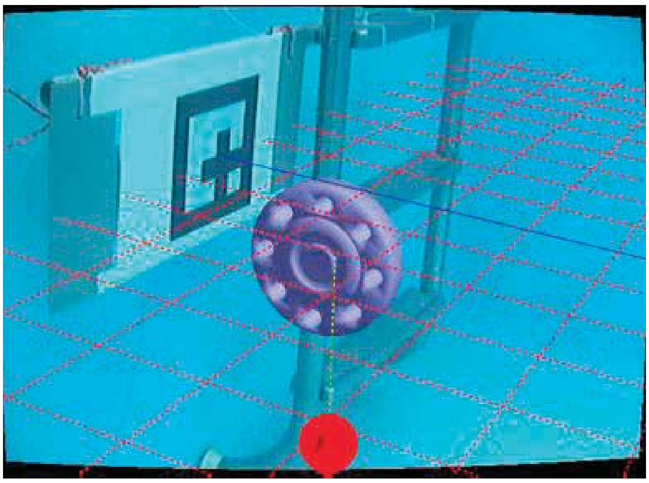

Figure 10 **UWAR aiding system for divers** (Courtesy Rogelio Morales-García)
Slika 10 **UWAR sustav za ronilačku potporu**

Finally, there has been AR systems developed for remotely operated underwater vehicles (ROV). One interesting example is AR developed by *Mobile & Marine Robotics Research Centre* (*MMRRC*) at the *University of Limerick* [19]. Application is primarily developed as a support for ROV pilots and could be used as navigational and manoeuvring aid as well as prior mission training. The AR display also improves situational awareness of the ships navigation officers during the ROV mission or/and sonar operators during multibeam and sidescan transects. Prior to mission, a ROV pilot is able to practice with the virtual ROV in a realistic environment, for example diving to desired depth or following trajectory. During the mission, the topside 3-D augmented reality display, mounted inside the Control Cabin, shows real time measurements presented in the form of intuitive visual indicators, such as 3-D compass, desired and actual velocity vectors, waypoints and trajectory traces. On the bridge display, ships navigation officers are able to see information relevant to their activity, such as ROV's position, speed and heading in relation to the ship.

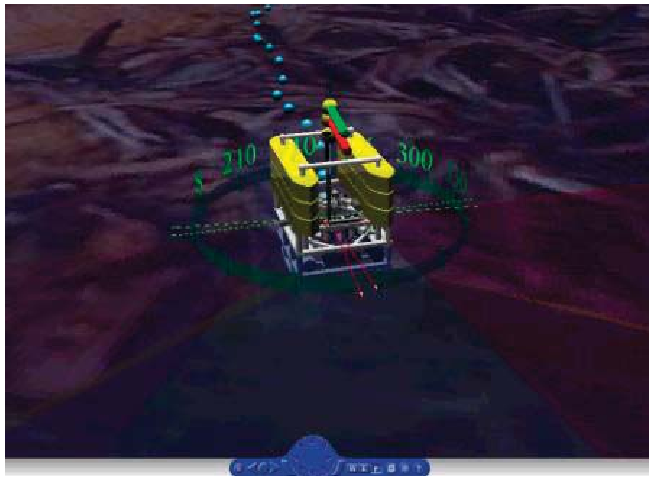

Figure 11 **Navigational and Manoeuvring aid for ROV pilots (Courtesy MMRRC, University of Limerick)**
Slika 11 **Sučelje namijenjeno ROV pilotu za pomoć u navigaciji i manevriranju**

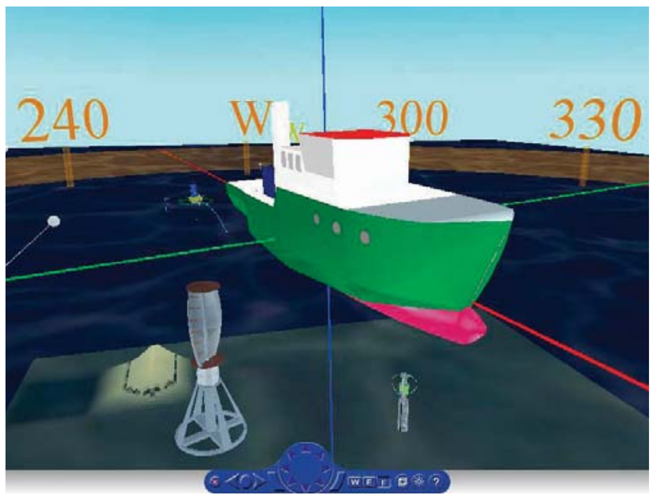

Figure 12 **Screen for ships navigation officers (Courtesy MMRRC, University of Limerick)**
Slika 12 **Sučelje namijenjeno časniku palube**

The robot manipulators (arms) are very often mounted on a ROV for interaction with underwater environment. Based on data collected with stereovision, acoustic or laser sensors, the 3-D AR visualization system can be used to assist operators or to automate arm movements.

4 Challenges and limitations

4.1 Technological

There are still several technical challenges AR needs to overcome. Geo-tagging is based on accurate positioning of a mobile device. Unfortunately, a GPS used in handheld devices is only accurate to within 3-15 meters. There are more accurate options (DGPS, WASS etc.) available on the market but both size and price are still not capable to satisfy the handheld market. Inability to work indoors or underwater is yet another GPS constraint.

4.2 Sociological

What may happen, for instance in tourism, is that people may prefer to use their AR applications rather than an experienced tour guide. People can even prefer to take a virtual tour of interesting destination instead of travelling there and experience it on their own. This phenomenon may lead to some kind of social alienation where people, instead of socializing and travelling, stay in their rooms. On the other hand, the AR experience of the popular destination could make them more eager to travel to the spot.

4.3 Privacy

AR applications that support face-tagging, allow users to instantly see information about people around them from their social networks online profiles (Facebook, LinkedIn etc.). People willingly put personal information online but it may be quite shocking to just meet someone who already knows so much about you, your life and family. Further development of face-tagging and similar applications will bring up a lot of privacy issues to the world or AR.

There are many other issues related to AR. Unauthorized advertising, security and spam are just examples of new, emerging problems whose number will increase together with the number of users and applications.

5 Conclusions

AR is not a new technology but has not had a chance to get widespread until now. Need for advanced and typically expensive computing technology was a reason why AR has been hiding for a long time in academic and industrial research laboratories finding its way only into military applications. The attractiveness of AR caused technological and academic proponents to continuously raise expectations and come up with new ideas which sometimes sounded like science fiction. Unfortunately, AR often failed to deliver such a product. Today, however, technology required for AR applications has matured and, as a consequence, the number of commercial AR applications and especially consumer AR applications is exponentially growing.

The quality, size and cost of AR system components such as camera, screen, tracking devices, computing power and, fast and flexible data links to databases made AR available to general public. Moreover, the components of the AR system are expected to improve dramatically, open new horizons and bring at-present-unimaginable AR applications to the market in the near future. One can expect that virtual layers will be indistinguishable from the real ones, and the future applications may easily become complete reality based virtual environments. AR is definitely technology of the future which will find its use in almost every segment of our life and is at present, according to many market analysts, one of the top ten most disruptive new technologies.

Acknowledgement

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