Recent advances in research teleoperation, telepresence and virtual reality

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Robotic Teleoperation and Telepresence

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Abstract: In this paper, new research technologies in telepresence and teleoperation are presented. The aim is to provide a general idea of the current existing capability to design tools to perform teleoperation and telepresence tasks easily and comfortably.
First of all, this work reviews the state of the art of these sciences, according to global technological development existing nowadays. In addition, the most outstanding advances are detailed.
Teleoperation and telepresence are used to replace or enhance manual labors in many areas, hence teleoperation systems have applications in various fields, so it is going to be analyzed the importance of those advances in several disciplines like space exploration, medicine and hazardous workplaces, among others.
Finally, a conclusion about how telepresence or teleoperation can change our lifestyle is discussed.

Keywords: Teleoperation, telepresence, robotics, virtual reality, human-machine interfaces, applications, sensors, haptic feedback.

1. INTRODUCTION

First of all, the main concepts are going to be defined. According to (Sheridan, 1989), teleoperation is the extension of a person's sensing and manipulation capability to a remote location. Telepresence, which is a specific way of teleoperation, allows the operator feeling that he is present at the remote place. (Lichiardopol, 2007). To develop these feelings, it's necessary that the operator receives sufficient information about the teleoperator(remote controlled device) and the task environment, displayed in a sufficiently natural way that the operator feels physically present at the remote site. (Stassen et al., 1989). Furthermore, virtual reality is the sense of being at a location which does not actually exist, which instead is a compelling graphic or auditory illusion. (Sheridan, 1995). Virtual reality is a tool which helps to develop a telepresence task. In addition, augmented reality is an interactive communication between virtual and real world in real time. Immersion into virtual reality is the degree of perception of being physically present in a non-real world. Immersion refers to the technical capability of the system to deliver a surrounding and convincing environment with which the user can interact. (Hardiess et al., 2015)

When it is going to be performed a teleoperated task, it's necessary to analyze and define the different elements involved, such as:

- Control architecture: is focused on how the local place communicates with the remote place. The feedback between remote and local place is essential, because the way in which the operator is going to control the device depends on it. The communication between master-slave is the most important phenomenon in these operations. Factors like time delay, precision of the actuators,etc. must be taken into account when the control system is designed for the purpose of developing real-time communication to perform the task successfully. The human reaction time influences on the communication too. The 'simple' reaction time on a button click task is around 215 ms (Kosinski, 2008) but the mean of a human response delay in supervisory control can be much longer (5 to 16 seconds) and depends on the task. Telemanipulation is necessary in situations where tasks have to be performed at long distances, such as operation in the hostile environment of a nuclear plant or in deep sea and space environments. This means that a time delay will always occur in the human operator-telemanipulator-control loop.

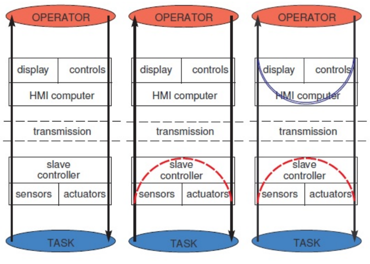

Fig. 1. Teleoperation control schemes. (Lichiardopol, 2007)

- Haptic feedback: Haptic is relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception, so haptic feedback is the feedback of the sensation of touch, contact and the orientation of muscles and tendons. When the haptic feedback is not correct, the absence of force perception in teleoperation systems results in an increase of the task completion time (Salcudean, 1997) and higher contact forces in comparison with direct manipulation (Wagner, 2002). To enable force perception during remote manipulation, teleoperation systems are equipped to transfer information about the environment back to the human operator. (Zandsteeg, 2010)

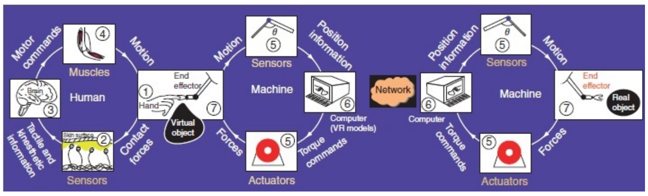

Fig. 2. Human–machine haptic interaction in teleoperated environments (Zimmer et al., 2009)

- Human-machine interface: its function is to order and provide the information from the remote place to allow the human controlling the manipulation and to do the task comfortably. This interface translates the information from the sensors in signals that estimulate the human senses. In telepresence, the operator has to feel that he's in the remote place, hence ergonomics and comfortability are critical.

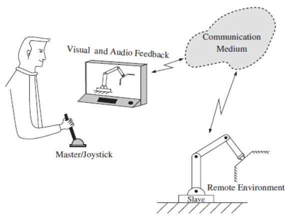

Fig. 3. Importance of the human-machine interface in a teleoperation scheme (Hokayem, 2006)

2. APPLICATIONS

The importance of teleoperation and telepresence in different branches of knowledge is presented, and how it has been developed along the history in parallel to communication and technological growth nowadays.

Space exploration, industry, medicine, military industry, dangerous jobs, education, entertainment, ... are examples of teleoperation applications.

2.1 Industry

According to the importance of R&D and quality at companies, new techniques have been developed to make uniques their products. Teleoperation can solve communication problems in this global world. For example, teleoperation can be used by a manufacturer to attend to customers from different countries, to guarantee the maintenance of the device they sell, etc. In addition, a robot is faster than a human, so it can suppose to decrease time production and production costs, but a big investment is required. The integration of computer science and communication technology in automation industry has a huge potential for increasing productivity.

Next, an example about how to integrate a teleoperation system in an industry is explained. (Aschenbrenner et al., 2015). It outlines the resulting teleoperation architecture which is an application of current robotics and control research. The automation industry are in need of being remotely accessible to solve maintenance problems or those that must be solved by an expert from abroad.

The objective is to develop a remote-control system that allows to control an industrial robot by an expert and to have a human communication channel and file-exchange in a production plant in case of problems.

The facility is formed by a six-axis cartesian industrial robot by Kuka Industries, a two-component injection molding system and an assembly unit. The plant, which belongs to Braun (Procter & Gamble), produces plastic parts for electric toothbrushes. The network is constituted by a VPN (Virtual Private Network) by TCP/UDP. The feedback, which is highly necessary for teleoperation, is developed by IP-cameras in a video feedback.

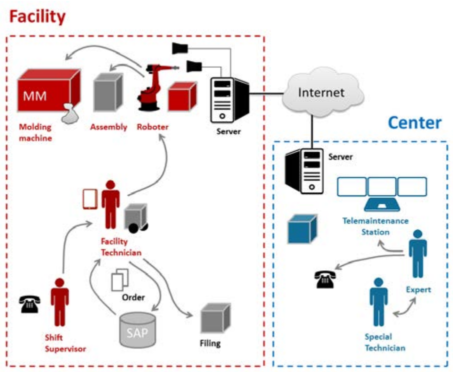

Fig. 4. Teleoperated industrial robot in a production line

2.2 Medicine

To be useful, robotics must enhance human abilities. In medicine, robots don't perform repetitive tasks and a human life is at stake. From two points of view, teleoperation and telepresence can change medicine:

- **Telesurgery**: a teleoperated robot is used to perform operations. For example: a heart operation. (Advanced Technology in Surgery, 2002)
- **Prevention and medical treatment of diseases: Virtual reality.** Virtual reality is highly related to telepresence in so far as its development is going to provide benefits like: virtual surgical training for medicine students, helping depressed people, diseases detection by an interaction with the environment like autism (Wang, 2016), Parkinson (Yelshynaa et al., 2015), ictus (Viñas, 2015) or Alzheimer disease rehabilitation (Plancher et al., 2012), etc.

Telesurgery

Without robotic aids, surgeons' abilities to perform microsurgery are limited by their physical capacities. Unaided, surgeons can suture blood vessels that are 0.5 mm in diameter, which requires precise positioning of the instruments within 50 to 100 μm. However, cellular-based surgical procedures require an accuracy of 10 microns or more, a full order of magnitude improved. (Urban et al., 1998). Also, accuracy in procedures such as orthopaedic or eye surgery is required, to ensure that the operated organ returns to its neutral state and to prevent damage to adjacent tissues. Damage to neighboring tissue can cause paralysis, psychosis or even death, especially in the area of neurosurgery. (Vu Thanh Le at al., 2011). Accuracy of haptic feedback systems in surgical application requires greater attention by the research community in the areas of technology development and evaluation of efficiency and effectiveness. As surgical procedures involve live human subjects, there is not room for error.

A surgical robot has the following skill-enhancing properties (Taylor et al., 1997):

- Position and reposition surgical tools with great accuracy.
- Apply precisely calibrated and controlled forces.
- Reduce the physiologic tremor of human hands.
- Scale the magnitudes of forces and motions to be either greater or lesser than are possible with human hands.
- Act as a stable platform for supporting and positioning surgical sensors, cameras, or instruments in a tireless manner.

The concept of telerobotic surgery was first developed with grants from the United States Department of Defense. The United States Army hoped to develop a mechanism by which combat surgeons could operate from a remote secure location on wounded soldiers on the battlefield. (Ballantyne, 2003). A well-known example is da Vinci robot, which was engineered from its inception to perform telepresence surgery. In this type of surgery, the surgeon is physically and visually separated from the patient. Their only contact are the video image and the haptic feedback. Nowadays, it is used to treat: bladder cancer, colorectal cancer, coronary artery diseases, kidney disorders, obesity or prostate cancer, among others. (http://www.davincisurgery.com/)

Fig. 5. Surgical robot da Vinci developed by American company Intuitive Surgical

Prevention and treatment of diseases: Virtual Reality

- Virtual Reality in surgery:

  Thanks to virtual reality, the idea is to get the medicine student or trainee surgeon to become familiar with the operation procedure, prior to commencement of a real process. This idea will be welcome because doctors will be better trained and they will have developed their practical abilities. There is an example of virtual surgical trainer for hearth operations, which belongs to Boston Dynamics.

Fig. 6. Virtual surgical trainer for hearth operations

These are the results of an experiment to show how doctors and student can improve their skills by using VR simulators (Craig, 2009):

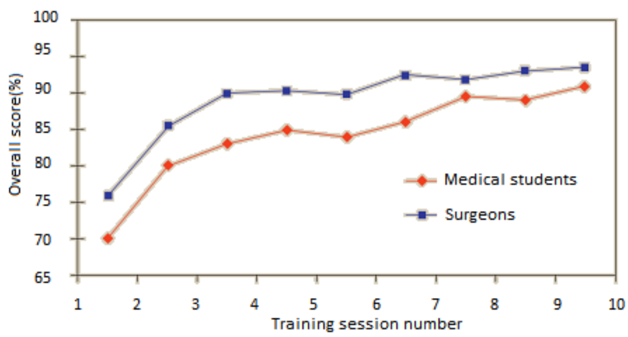

Fig. 7. Virtual Reality can change medicine

According to this study, we can affirm that, with enough practice, doctors' abilities can improve highly and students can get experienced at operations, without making mistakes by interacting with patients.

- Diseases treatment and rehabilitation with Virtual Reality.

  Virtual reality has changed the lifestyle of lots of ill people because it has allowed to develop new cheaper tools to treat diseases as autism, ictus, Alzheimer or disabled people. A specialized treatment is too expensive but, with tools based on Virtual reality, patients can develop their social cognition abilities, they can execute task according to their daily lives, by using a technological tool at home. Next, there is an example of a platform for training daily activities in controlled environments, which allow caregivers and therapists to follow the patients' performances and improvements along the time. (Simõesa et al., 2014)

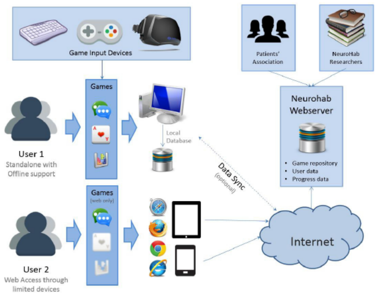

Fig. 8. Neurohab: A Virtual reality app to help people with Autism

2.3 Education

In this section, Virtual and Augmented Reality techniques are presented to change education through technology. Thanks to virtual reality, children can learn and assimilate new concepts by interacting with virtual environments. The role of play in young children has always been considered to be important. Early childhood educators should be aware of this educational potential, context for learning and social aspects of play. (Yelland, 1999). It has been demonstrated that toys have great importance in enhancing children's imagination. Integrating new technologies to learning environments brings some benefits for children. (Yilmaz, 2015). Desktop VR has begun to gain its way and popularity in modern education because of its ability to provide real time visualization and interaction within a virtual world that closely resembles a real world. (Lee et al., 2010). An example of these learning tools are called Educational Magic Toys (EMT). EMT has included puzzles, flash cards and match cards to teach animals, fruits, vegetables, vehicles, objects, professions, colors, numbers and shapes for average 5-6 age children in Early Childhood Education. The ideal learning experience comes from the combination of physical experience, virtual content and the imagination of the child. In addition, texts, images, videos and animations as well as 3D models can be used for educational augmented-reality applications. EMT providing opportunities for teaching has been developed for children so that they interactively learn and have fun. Interacting with toys is important in child development.

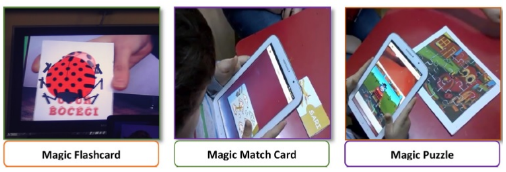

Fig. 9. Education Magical Tooy with Augmented Reality

At High School, for example, new simulators, based on virtual reality, have been developed to show students artworks, natural landscapes, traditional monuments, etc. (Craig, 2009).

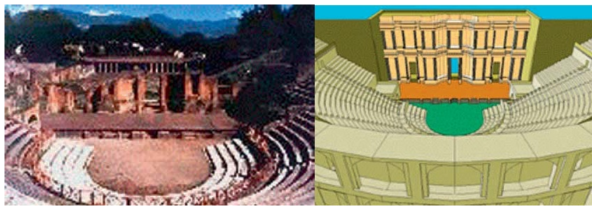

Fig. 10. Actual excavated Pompeian temple and its corresponding virtual model.

Finally, a study about how virtual reality can help engineering students is presented. Virtual reality by simulating interdisciplinary industrial projects aims at developing skills such as methodical approach to practical engineering problems, teamwork, working in interdisciplinary groups and time management. (Häfner, 2013). Engineering courses must be developed in line with the real and constantly evolving requirements of the industry so it's necessary to develop the main three concepts of Virtual Reality in engineering courses: immersion, interaction and imagination. (Burdea et al., 2003).

The experiment was hosted in a lab at the Karlsruhe Institute of Technology and the students interacted with: a distributed stereoscopic visualization in a three-sided CAVE, which has a size of 4,93 m x 1,95 m x and 2,6 m and uses circular polarization for the stereoscopic effect with 12 million pixel resolution, allows to dive into virtual worlds;a mixed reality lab consists of a mobile powerwall (2 m x 1,5 m) and two haptic devices, and finally, has 3D monitors, HMDs (Head Mounted Displays), depth cameras, data gloves and smart devices giving the possibility to experiment with low-cost VR environments. Students from studying mechanical, electric, electronics engineering formed gropus of 15 people and they were interviewed before starting the course. After they worked during 120h they were evaluated of those skills they learnt. During the project, they have the opportunity to experiment and learn from their mistakes to ensure that they are better prepared for their professional life.

2.4 Hostile environments and dangerous jobs

Space exploration

In this section, space telerobotics and telepresence are presented. A logical enhancement to manned space flight includes the use of robots in space. These are the reasons to use robots in space:

- Economic factor: to keep a man alive in space is very difficult and, as a consequence, too expensive, because oxygen, food, radiation protection, etc. are indispensable for life in this hostile environment.
- Productivity: robots can enhance the activities of astronauts in the same way that any tool increases productivity. Also, safety is a major concern in the space program.
- Social factor: a lonely life when an astronaut is insulated from Earth and family is a problem to

achieve the objectives of the mission but robots do not experience the fatigue associated with human task execution and they are more reliable. (Lumia and Albus, 1988)

The development of space robots is based on a gradual evolution from teleoperation to autonomy.

Most scientists make a distinction between teleoperated and remotely operated robots. On the one hand, a teleoperated robot has a real time operator interface, such as the joystick control that is used for operating underwater vehicles, for example. On the other hand, teleoperation is associated to include an immersive "virtual" environment, so that the human views the scene from the robot's point of view.

Telerobotic exploration will require a high-fidelity, high bandwidth connection to give the humans a fully detailed virtual presence in the robotic body. (Landis, 2008).

The tasks to perform by a robot in space are:

- Exploration: analyze ground composition looking for elements like water, study the orography of the surface, etc. (Landis, 2008).
- Satellites and space equipments repairing. (Hirzinger et al.,1998)
- Robotic surgical support system for astronauts: Several medical problems may arise involving the bone system, the gall bladder, the pancreas, the appendix, the urinal system or the blood circulation in space. (Haidegger, 2008).

The main problem in space teleoperation or telerobotics is: communication delay. The distance between master and slave is too long and there's a time delay in the control system from Earth to Mars, as we see in the figure below.(Fig. 11). Predictive models of the remote environment and task are necessary. (Arcara, 2002).

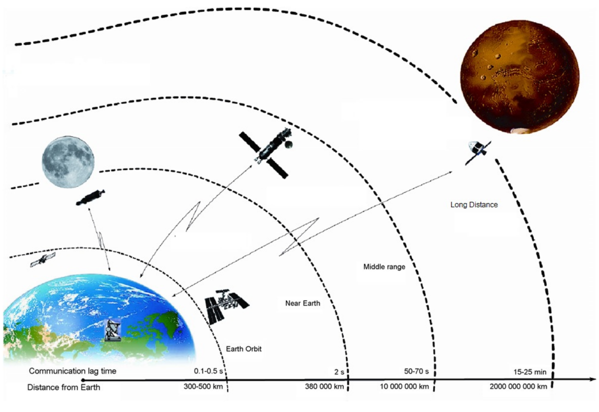

Fig. 11. Communication delay in space (Haidegger, 2008)

The communication delay hinders haptic feedback and control due to this non-real time process. It's not a comfortable task, so simulation models are developed to increase ergonomics.

This is Curiosity rover developed by NASA: a well-known example of teleoperated robot in space exploration:

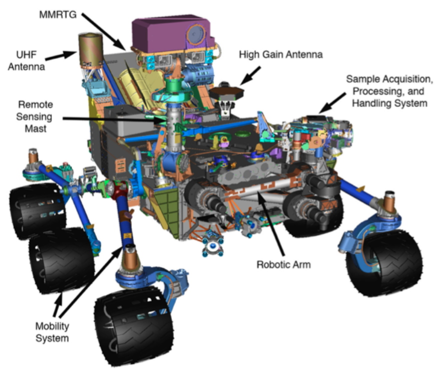

Fig. 12. Space Robot Curiosity, courtesy of NASA

UAVs(Unmanned Aircraft Vehicles)

Due to their presence in mass media and as a well-known example of teleoperated device, a particular study of UAVs has been performed: requirements, structure and applications are presented.

An UAV is an unmanned aircraft vehicle, in other words, an aircraft with its aircrew removed and replaced by a computer system and a radio-link. (Austin, 2010). An UAV is a system formed by:

- A control station which guides the system operators, the interfaces between the operators and the rest of the system
- The aircraft and the payload.
- The communication system between the control station and the aircraft. As an UAV is a teleoperated system, feedback is essential. In this case, it will be visual feedback and by the information that sensors provide.
- The navigation system.
- Support equipment (such as maintenance and transport items).

The design of an UAV is a complex task. Stability control, navigation system, aerodynamics are factors that must be taken into account.

The noteworthiest applications (Austin et al., 2003) of UAVS are:

- Aerial Photography: analysis of the terrain, aerial photos of monuments and natural landscapes, etc.
- Agricultre: crop monitoring, use of pesticides, herd monitoring.
- Electricity: power lines maintenance.

Fig. 13. Power line inspection (www.SkyKaptr.com)

- Environmental conservation: control of pollution.
- Gas and Oil Supply Companies: surveillance labours.

- Local civic authorities, police, traffic agencies.
- Landmine Detection and Destruction.

Dangerous jobs and military industry

For the purpose of ensuring public safety in society, virtual reality can help to achieve this goal providing tools to save lifes indirectly by training firefighters, police, airplane pilots and military personnel, as well as in educating the population, in how to act in hazardous situations like natural disasters (hurricanes, earthquakes, in case of fire), acts of terrorism, etc.

Furthermore, teleoperation and telepresence are used in these situations to protect people by insulating them from danger.

These tools have a requirement: being coupled to the real world. That's the reason because haptic feedback devices can be very important. Hence, many public safety and military applications are coupled to real-world input and output devices such as treadmills, bicycles, and other devices to provide a realistic sense of physical exertion, with the objective of interacting with virtual systems like in real environments. (Craig, 2009).

Depending on dangerousness, hazardous jobs and military industry are going to be analyzed separatey.

· Hazardous jobs: police, firefighters, rescue equipment, submarine exploration are defined as risk professions. The possibilities are multiple: thanks to virtual and augmented reality, public safety applications are being developed such as: augmented vision systems to provide firefighters additional information that indicate where they are in the building floor plan, where volatile materials are stored, or where the home base indicates that victims are caught in the building; robots equipped with a camera, shotgun, microphone, speaker, and other facilities to assist in seeking out villains in hostage situations for police; or flight simulators to learn how to fly a Boeing 747 for commercial pilots. (Craig, 2009).

Fig. 14. Kidnapping simulator. Fire simulator

· Military industry: As a result of the current technological advances, military industry has been developed too. Several tools have been fabricated to guarantee the security of population or as a war weapon, for instance: robots that can defuse a bomb, automatic exploration systems, etc. Telepresence and teleoperation are present in these environments, because these tools like UAVs, robots, etc. have to allow the operator to feel he is in the remote and hostile place. Virtual and augmented reality have an incipient future in military industry: for example, augmented reality night-vision glasses have been developed to help soldiers to find enemies or dangers. (Craig, 2009). The main problem is immersion, which complicates navigation because we can lose our overall sense of location, so, developing a mental model, or cognitive map of the overall virtual space is a fundamental task, underlying successful travel and interaction with the environment. (Baker et al., 1998)

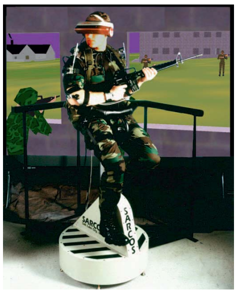

Fig. 15. War environment simulator

2.5 Entertainment and at home

In the same way that teleoperation, telepresence and virtual reality have been developed in different branches of knowledge like medicine, education, industry or hostile environments, entertainment has also progressed with this technology. Not only surgeons, soldiers or firefighters, the rest of population are going to have the opportunity to enjoy the immersion in a virtual world.

- Virtual shopping: you can buy and try on clothes in a virtual way.

Fig. 16. Buying clothes will be in a virtual way

- Games: VR offers the opportunity for immersion into the game with stereoscopic imagery, and natural user interfaces such as allowing the participant to physically jump rather than press a button on the controller to make their character jump. In general, traditional computer games operate from a second-person point of view (the participant is controlling their character that they see on the screen via a controller device). VR offers the opportunity for the game player to jump into the game and participate from the first-person point of view. (Craig, 2009)
- Disabled people: Virtual reality can provide disabled people several tools to make their life easier. There are somes examples like: sensorial substitution, which is a tecnhnique which aims to provide sensory disabled people with information they cannot adquire from

the environment (Rodríguez-Hernández et al., 2010) like blind or deaf people thanks to brain plasticity; stereo vision and real-time feedback to reflect natural movement of the visual world are the evidences demonstrates that a transfer of training from the virtual to the physical environment is greater if the learner is immersed in the training environment (Keshner, 2004); virtual scenarios can be created, in which patients suffering from motor disturbances like pareses or apraxias perform motor tasks for diagnosis and rehabilitation purposes. Therapy of ataxia and strabism can also profit from special VR facilities. Using VR datagloves people with speech disabilities can communicate by hand gestures, which are translated into spoken words. (Kuhlen and Dohle, 1998). As wee see, in the future, handicapped people's lives will be easier and more comfortable.

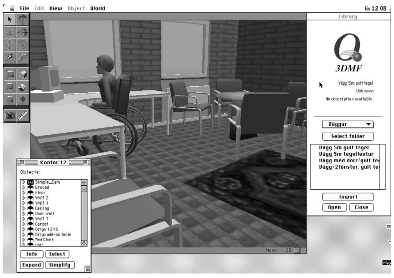

Fig. 17. Virtual environment to test Virtual reality tools for disabled people (Davies et al., 1996)

- Flight simulators to lose the fear of flying.
- Cinema: with Virtual Reality tools, it can change the idea of cinema we have. 3D-glasses are a real-current example of virtual reality tecnhlogy used to favor the immersion and to allow the viewer to feel he is the protagonist of the film. (Marsh et al.)

3. CONCLUSION

In this paper, the importance of Virtual Reality is a result of the following assertion: virtual reality applications are developed and the immersion is getting better, then, telepresence will be able to take all these advances to enhance their methods and techniques. Furthermore, Virtual reality can be developed as an independent category parallely and, thereby, enjoy all the possibilities.

A complete tour in teleoperation, telepresence and virtual reality applications has been performed. To sum up, the branches of knowledge that have been analyzed are:

- Industry: the main advantages of teleoperation and telepresence in industry are: decreasing costs due to maintenance and increasing productivity and reliability by replacing humans by robots, and, consequently, increasing incomes to guarantee the payback.
- Medicine: On the one hand, teleoperated robots can perform operations in remote places like war environments, in space, etc. or in a cellular scale. On the other hand, through virtual reality, prevention and treatment of diseases can be achieved with commonly-used devices based on VR.
- Education: traditional methods of teaching are changing by cause of technlogical progress in order to achieve better educated people.
- UAVs: according to their current importance nowadays, many future applications can be developed to make our life more comfortable like: avoiding dangers at working, performing task automatically, etc.
- Hostile environments and dangerous workplaces: thanks to teleoperation, telepresence and virtual reality, astronomy has progressed owing to space exploration, a better and effective performance in case of natural disasters, fires, accidents, kidnappings or other emergencies.
- Entertainment and at home: it has been demonstrated that Virtual reality can change our lifestyle at entertainment (cinema, TV, computer games...), but, specially, virtual reality can change handicapped people life radically: rehabilitation of motor disturbances people, home appliances with stimuli for deaf or blind people, etc. VR offers us the opportunity to bring the complexity of the physical world into the controlled environment of the laboratory. (Keshner, 2004)

The aim of this paper is to demonstrate all the posibilities of teleoperation, telepresence and virtual reality in an increasingly technological society by studying several branches of knowledge such as industry or medicine, even entertainment.

Finally, I think that teleoperation, telepresence and virtual and augmented reality are modern sciences, like robotics too. In the future, the scientist community will be aware of those outstanding advances already achieved.

REFERENCES

T. B. Sheridan. Telerobotics. *Automatica*,Vol 25, nº 4, pp.1–20, 1989.

S. Lichiardopol. A Survey on Teleoperation. *DCT report.* Technische Universiteit Eindhoven. Department Mechanical Engineering. Dynamics and Control Group.Eindhoven, December, 2007

H.G. Stassen and GJ.F. Smets. Telemanipulation and telepresence. *Control Engineering Practice*,Vol 5, nº 3, pp.364–375, 1997.

T.B. Sheridan. Teleoperation, telerobotics and telepresence: A progress report. *Control Engineering Practice.* Vol 3, nº 2, pp. 205–214, 1995.

Gregor Hardiess, Hanspeter A. Mallot, Tobias Meilinger. Virtual Reality and Spatial Cognition International Encyclopedia of the Social and Behavioral Sciences, 2nd edition, Volume 25. 2015.

Advanced Technology in Surgery. Currents Problems in Surgery, August 2002. pp.745-830.

Salcudean S, Ku S, Bell G. Performance measurement in scaled teleoperation for microsurgery. *Lect Notes Comput Sci.*pp 205:789–98.1997

Wagner C, Stylopoulos N, Howe RD. The role of force feedback in surgery: analysis of blunt dissection. *Proceedings of the 10th symposium on haptic interfaces* *for virtual environments and teleoperator systems.* pp. 68–74. 2002.

R.J. Kosinski. A literature review on reaction time. *Clemson University, South Carolina* . 2008

C.J. Zandsteeg, D.J.H. Bruijnen, M.J.G. van de Molengraft. Haptic tele-operation system control design for the ultrasound task: A loop-shaping approach. *Mechatronics.* Vol. 20. pp.767-777. 2010.

R Zimmer, M A Srinivasan. Machine haptics. *Elsevier* pp.589-595. 2009.

Peter F. Hokayem, MarkW. Spong. Bilateral teleoperation: An historical survey. *Automatica* Vol 42 pp. 2035 – 2057. 2006.

Doris Aschenbrenner, Michael Fritscher, Felix Sittner, Markus Krauß, Klaus Schilling. Teleoperation of an Industrial Robot in an Active Production Line. *IFAC* pp. 159–164 2015.

Xianhui Wang, , James Laffey , Wanli Xing , Yanfei Ma , Janine Stichter. Exploring embodied social presence of youth with Autism in 3D collaborative virtual learning environment: A case study. *Computers in Human Behavior.* Volume 55, Part A, February 2016, pp 310–321.

Darya Yelshynaa, Miguel F. Gago, Estela Bicho et al. Compensatory postural adjustments in Parkinson's disease assessed via a Virtual Reality environment. *Behavioural Brain Research.*. Accepted date: 17-8-2015.

S. Viñas-Diz y M. Sobrido-Prieto. Realidad virtual con fines terapéuticos en pacientes con ictus: revisión sistemática. *Neurología.* Elsevier. Accepted 12-06-2015.

G. Plancher, A. Tirard, V. Gyselinck, S. Nicolas, P. Piolino. Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment and Alzheimer's disease: Influence of active and passive encoding. *Neuropsychologia.* Volume 50, Issue 5, April 2012, Pages 592–602.

Taylor R, Stulberg D. Excerpts. Final report for the Second International Workshop on Robotics and Computer Assisted Medical Interventions. June 23-26, 1996; Bristol, England. *Comput Aided Surg.* Vol.2. pp.78-85.1997.

Urban V, Wapler M, Neugebauer J, Hiller A, Stallkamp J, Weisener T. Robot assisted surgery system with kinesthetic feedback. *Comput Aided Surg.*pp.3:205-9. 1998

Vu Thanh Le. Saied Nahavandi SMIEE. A Haptic Training Environment for the Heart Myoblast Cell Injection Procedure. Center for Intelligent Systems Research Deakin University. 2011.

Garth H. Ballantyne. The da Vinci telerobotic surgical system: the virtual operative field and telepresence surgery. Surgical Clinics of North America. Vol. 83. pp. 1293–1304. 2003.

http://www.davincisurgery.com/

Alan B. Craig,William R. Sherman,Jeffrey D. Will. Developing Virtual Reality Applications: Foundations of Effective Design. Morgan Kaufmann Publishers. pp. 1 - 391. Elsevier. 2009

Marco Simõesa, Susana Mouga, Fábio Pedrosa et al. Neurohab: A Platform for Virtual Training of Daily Living Skills in Autism Spectrum Disorder. *Procedia Technology.* Vol. 16, 2014, pp. 1417–1423

Rabia M. Yilmaz. Educational magic toys developed with augmented reality technology for early childhood education. *Computers in Human Behavior.* Vol 54. pp.240-248. (2016).

Nicola Yelland. Technology as play. *Early Childhood Education Journal*, Vol.26. Num. 4. pp. 217-220. 1999.

Elinda Ai-Lim Lee, Kok Wai Wong, Chun Che Fung. How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach. *Computers and Education.* Volume 55, Issue 4, December 2010, Pages 1424–1442.

Polina Häfner, Victor Häfner, Jivka Ovtcharova. Teaching Methodology for Virtual Reality Practical Course in Engineering Education 2013 International Conference on Virtual and Augmented Reality in Education.Procedia Computer Science. Vol.25. pp.251–260 . 2013.

Burdea G, Coiffet P. Virtual Reality Technology. *Presence: Teleoperators and virtual environments.* Vol 12(6). pp. 663-664. 2003.

Ronald Lumia and James S. Albus. Teleoperation and Autonomy for Space Robotics *Autonomous Systems for Space.* Robotics.pp. 27-33.(1988)

Tamas Haidegger, Zoltan Benyo. Surgical robotic support for long duration space missions. *Acta Astronautica.* Vol. 63. pp.996–1005. 2008.

Teleoperation from Mars orbit:A proposal for human exploration. *Acta Astronautica.*Vol. 62. pp.59–65. 2008.

G. Hirzinger, B. Brunner, K. Landzettel, J. Schott Preparing a new generation of space robots - A survey of research at DLR *Robotics and Autonomous Systems.* Vol.23.pp.99-106. 1998

Paolo Arcara, Claudio Melchiorri. Control schemes for teleoperation with time delay: A comparative study. *Robotics and Autonomous Systems.* Vol.38. pp.49–64. 2002.

Reg Austin Unmanned Aircraft Systems. UAVS Design, development and deployment. *John Wiley and Sons.*Aeronautical Consultant. 2010.

R. G. Austin and G. Earp. Powerline Inspection by Unmanned Aircraft – a Business Case. *Nineteenth Bristol International UAV Systems. Conference.* Bristol University, 2003.

M. Pauline Baker, Robert J. Stein, Albert Khakshour, and William B. Sherman. Virtual Environments For Army Tasks.

Timothy Marsh, Peter Wright, Shamus Smith and David Duke. A Shared Framework of Virtual Reality. Department of Computer Science .University of York

A. Rodríguez-Hernández, C.Merino, Ó. Casanova, C.Modrono. Sensory Substitution for Visually Disabled People: Computer Solutions. *WSEAS Transactions on Biology and Biomedicine.* ISSN: 1109-9518 Issue 1, Volume 7, January 2010

Emily A Keshner. Virtual reality and physical rehabilitation: a new toy or a new research and rehabilitation tool? *Journal of NeuroEngineering and Rehabilitation.* pp. 1:8. 2004

T.Kühlen and C.Dohle Virtual reality for physically disabled people. 1998.

R C Davies and J Eriksson. Using virtual reality in the adaptation of environments for disabled people. Proc. 1st Euro. Conf. Disability, Virtual Reality Assoc. Tech., Maidenhead, UK, 1996 ECDVRAT and University of Reading, UK ; ISBN 0 7049 1140 X.