Mobile Autonomous Systems
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Human Factors and Virtual Reality Implications

by

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Abstract

Mobile Autonomous Systems are non stationary service robots that operate without continuous remote control by a human operator. Those systems use sensors and computers onboard and perform their tasks in a quasi intelligent manner.

To perform safely and efficiently, modern control stations use control strategies being designed and optimized according to latest Human Factors Engineering design considerations. Technologies applied for information display and input include Virtual Reality (VR) to achieve a certain degree of "immersion" into the system.

The paper defines the terms VR and robotics, their connection, and gives a number of examples for their use in both information technology and robotics. The connection of 3D worlds, the expansion to 4D and the introduction of system simulation to the control station level will be described.

The many application areas of coordinated use of VR and Human Factors design criteria in control stations for complex systems make believe that increasing hard- and software availability in modern systems will help developing more powerful systems, and that the future has just begun.

Introduction

Mobile Autonomous Systems are moving service robots that operate without continuous remote control by a human operator. They navigate on the basis a digital map which will be acquired using on board sensory systems and the required computing power connected with software to make it perform its tasks in a quasi intelligent manner. Though these systems a not really autonomous, they operate in a supervisory control type mode of operation (Sheridan, 1992).

System performance of such Mobile Autonomous Systems or Mobile Robots depend a great deal on the effective cooperation between the technical system and the human operator who will be responsible for safe and efficient operation. Virtual Reality (VR) is a modern technology to be applied in a lot of application fields, mostly to enhance and facilitate the interaction between a human operator and an existing or non existing three dimensional world, to navigate this world and to "immerse" into this world.

Late hardware and software technologies bring VR to the human operator at control stations for complex technical systems, such as mobile autonomous systems. Such modern control stations are being designed using VR technologies to enhance Human-Computer-Interaction, to give the operator a better view of system state, fault statistics, to decrease errors and to increase system performance.

Mobile Robots or Autonomous Systems will be used increasingly in the near future for different applications. They will do tedious and repetitive tasks not suitable or unpleasant to perform by human operators. Robot orientation and navigation are mostly implemented using internally stored maps and a number of landmarks. Those landmarks are detected by onboard sensors. The estimated and the true positions are compared and the position estimation is corrected. Onboard sensory systems are also used to detect obstacles in the driving path. Conventional mobile systems were wire-guided, modern systems use internal maps and sensors for route planning.

Such systems are more flexible and powerful for industrial and other applications. They are also more complex and difficult to be used safely.

Virtual Reality *and* Robotics?

What is Virtual Reality? What is the range of the term Robotics? Obviously both technical areas are not closely related, only slightly overlapping, having their roots in different professional areas of the mechatronics, electrical engineering, mechanical engineering, and computer science communities. But perhaps both research and application areas can be used in a synergetic manner to increase the benefit of using them.

Virtual reality relates to a world similar to the real world. It is looking like the real world. *Looking* contains the aspect that a virtual world is always made for and used by a human looker-on, somebody using her or his visual sense to perceive the situation and make use of it, either for information purposes, control inputs, or mere entertainment.

Sometimes a virtual reality is only displaying a part of a real world, perhaps the significant, the relevant part for a given purpose. This aspect will mostly be called abstraction. The degree of abstraction can be related to both the portion of the world modeled or to the fidelity of the model used. A VR world can also refer to something containing more information than normally visible in the real world, it could contain aspects and details of a not (yet) existing world, even a hyper-real world, something not known in a real environment.

Most modern application from this science and application areas refer to a world to look at, to navigate through or to interact with using an appropriate control station with a suitable user interface, mostly a *Graphical User Interface* at a computer terminal. Subsequently that Graphical User Interface will be called *GUI*. Frequently the looker-on is only performing a monitoring task, viewing the situation, with no means to interact, like in synthetic computer graphics cinema films.

VR and related terms

Now, as we know a little more about VR, we want to widen the view to a number of aspects taken into account in connection with this technology. Obviously VR worlds in their implementation depend on the following terms.

A term frequently used is *telepresence*. Telepresence means, that the human operator is given the sensation of being "right there", in the virtual world, at the location that he is looking at, in front of a building, at the machine desk, or very close to the production plant despite hazardous emissions or other dangers due to falling material etc. VR methods can offer a varying range of perceived telepresence according to the system's design perspectives.

Another technical term is *immersion*. Where telepresence gives you the impression "to be right there", immersion describes another quality of information display and input. Immersing into a display means forgetting that you are "in front" of a system, mostly a screen display or a video projection but making believe to be "inside". Immersion can be a strong psychological factor of understanding a situation, making believe that you are part of it, facilitating to take decisions being an integral part of a system consisting of man and machine. Needless to say, that immersion will never be absolute, but will be restricted to a partial sensation, for technical and design considerations.

Of course, telepresence and immersion can be used jointly, giving the human console operator a wide choice of parameter selection, system state understanding, and high performance interaction.

Virtual Reality is also cited in close connection with Multimedia (MM) technologies. Sometimes VR and MM seem to be used as synonyms. Yet, MM is an older term, stemming from the times of Lisa and Macintosh computers breaking the dominance of main frames, proving that desktops displays, icons, drag and drop technologies can successfully replace paper and pencil, pictorial information can better represent documents and the real world than columns of alphanumeric information. MM since then meant alphanumeric *and* graphic information, it meant paper and pencil versus viewgraphs and computer slide presentations, audio and still video display, and films, even force feedback joysticks for flight simulators. So VR can be seen as a part of MM technologies, further refined, using the available hard- and software, arriving at a high standard of display fidelity (Holzhausen, 1997).

VR always relies on a model, a mathematical description of the described or displayed world. This model is subsequently used as a basis for a *virtual journey*, moving through and investigating it. What we see on the screen is not the real world, but a view "into" the virtual one. That is the reason why VR is frequently mentioned in connection with simulation. Though a flight simulator would still be a flight simulator without a visual system, with all the meters behaving realistically, it can be further enhanced, to a higher level of simulation fidelity, using a simulated outside view, which is again as aspect of VR. Thus, simulation existed long before VR was a common term, but VR includes simulation to a certain extent.

Modern computer technologies support the display of a lot more of one graphical process output on the screen at a given time. Visual information can be superimposed mixing simulated VR information and a partial view from a video camera as taken from a real vehicle or other system. Using that technology, real world information and VR model outputs can be viewed at the same time thus comparing the model output with some real process. It is even a very conventional approach to superimpose video information with synthetic display data like in the case of a head-up-display common to military aircraft and often suggested in automotive equipment.

3D versus 4D VR control station design

Control stations for many industrial processes were very basic 20 years ago. Many were not computer supported, the Personal Computer was not yet available. Relevant processes were controlled using costly process computers, the majority of which were based on the famous PDP 11 series made by Digital Equipment, now a subsidiary of Compaq Computers. At that time even the most advanced control stations were text input/output terminals, with an exception for the so called semigraphic displays even used a couple of years ago. Subsequently, the level of sophistication of *Human-Computer-Interaction (HCI)* was rather basic.

Advances in computer hardware and software brought pixel graphic terminals, X terminals and later workstations to the factory floor. The earlier graphics stations were expensive monochrome vector technology, later followed cheaper 2D pixel oriented terminals. With the availability of cheaper color CRTs acceptable color monitors became available. 3D graphics engines followed later with prices reducing quickly. The PC was sold in ever rising quantities and the manufacturing industry earned the merit of consumer interest in cheap computers with full color graphics support. Quickly, the term 4D became common. 4D, „the 4th dimension", stands for adding time to the displayed dimensions, frequently geometric dimensions such as x, y- and z . So not only could a machine part be constructed and rotated on the screen in acceptable time, or *real time* for the kind of job or process, but the shape changes of a structure under exposition to heat or pressure in a simulated experiment could be monitored over the time, thus adding a further dimension to the graphics on the screen.

Using these technologies, user interfaces changed into GUIs with an increasing color graphics performance, in terms of both higher resolution, advanced geometry in three dimensions (3D) and sufficient computing power to display subsequent picture frames in real time. Of course, real time is a term closely related to the underlying process, and has to be defined differently for a slow industrial process as compared to a high speed fighter airplane.

Some VR examples

At the conference, a number of examples for VR worlds are demonstrated using modern tools to make them available to the participants, in the format of .JPG, .MPG. or .AVI files to name a few. Internet technologies add a new dimension to displaying graphical information. Authoring systems and 3D CAD systems are additional tools to arrive at a high standard of generating and presenting computer graphics. Again, the power and sophistication of the many available tools including programming languages with strong graphics support are ranging in a wide scope and should be carefully compared to find the most suitable one, the resulting information display is sometimes similar and does not make all the difference for the user.

One of the example shown is a house optimized using passive solar architecture (Dießenbacher, 1997). A VR model describing the geometry and typical equipment of that house was developed and subsequently navigated through at a desired path. 3D Modeling and Animation of that house using passive solar energy with an advanced design and construction could thus be perfectly demonstrated. SOFTIMAGE was the tool used for that film. Yet, the display was the result of a long and tedious rendering process, a lot of computation frame by frame, far from being capable of real time performance as required if we would aim at 4D fidelity as described before. But 4D fidelity is also available for this problem, only with a different tool, and lesser image resolution, fewer objects in the scenery, smart use of texturing with respect to texture memory in the graphics engine, and use of a programming language, for which a lot of graphics commands are implemented in firmware in available graphics controllers. One such programming language is OpenGL, a language initially developed by Silicon Graphics Inc. and now supported by many manufacturers. The programming effort to implement the solution to navigate in real time requires a lot of programming effort, of course.

This example tries to clarify the scope of possible applications of a VR model like the solar house for both a demonstration film with high fidelity and a lot of a priori computation and an interactive model, a simulation, that the user can navigate using a joystick in order to get to know a certain industrial plant or a city or landing on the moon.

One other interesting technology is the computer animation of still videos. The basis is merely a scanned photography. The animation depends on a time dependent transformation of portions of that still video to arrive at the required effect, for instance the anthropomorphic movement of image parts of a human face to simulate human speech realistically. The image transformation of relevant portions of that still video can be based on a dynamic system model or motion information acquired by suitable data input techniques. In the example, Wilhelm Maybach, the famous automotive inventor, who cooperated with Nikolas August Otto and Gottfried Daimler at Deutz, Köln, 1872, who also built the Zeppelin engines, can talk to us as if he were alive (Vierte Art, 1998). Again, this example demonstrates a technology which has a high market relevance because consequently even actors, who had passed away a long time ago, can perform again. On the other hand, a scanned photography of an industrial plant, or a complex system like a ship, can be displayed at a control station with actual process information included looking realistically but using a number of sensors instead of cameras distributed in the facility.

The examples so far show that connecting virtually real worlds on 4D GUIs with the real world can be used for a lot of advanced functions in a modern industrial console. It can be used to represent real or simulated processes, a connection or elements of both, *hands on* operation of those processes, testing real components in combination with simulated processes, quantifying system performance and detecting bottlenecks of system safety and security.

As described before, the GUI can even use real camera inputs adding or superimposing computer graphics, which is sometimes called "video imaging augmented by synthetic graphics". So it can „run" a computer simulation of a process as well as display the state of a real process: the GUI can even be identical for both. Finally, simulated *and* real system components can both appear on the screen simultaneously.

Discussing technologies displaying real and/or simulated VR worlds on a GUI, the Human-Operator-Interaction aspect is crucial. Operator Input has to be carefully designed to match the output side of the GUI. Operator Input can be performed using any of the widely known computer input devices such as simple keyboard devices, computer mice, joysticks, pointing devices, etc. They can also be „Spaceboards", platforms to stand upon and control navigation by full body movements (Neumann, 1998), complete moving base simulator cockpits, or virtual environments like stereo vision „Cave" type worlds (GMD, 1992). With these conventional or sophisticated control devices, a complex system can be efficiently controlled from a 4D GUI workplace.

System Control can be fully manual, putting the Human Operator at the Control Station in the role of a teleoperator. It can be fully automatic, having the Operator in a monitoring loop or it can be in a state in between called Supervisory Control using simple HCI or complex simulation cockpits.

Now we know that VR is a *Human-Machine-Interface* (HMI) Technology for non interactive visual information presentation or Human-Operator-Interaction with automatic, semi-automatic or manually controlled systems using augmented video or full scale 4D Computer Graphics including simple or sophisticated controls for HCI.

Robotics?

As VR was discussed to some extent, the term *robot* has to be defined and the connection between VR and robotics must be clarified.

Robots are working machines. To some extent they perform autonomously, completely automatic, or manually controlled. Some robots are anthropomorphic, i.e. look like a human being or at least like one limb of a human. Sometimes they are shaped to suit a specific task. Robots can be classified as Fixed Base vs. Moving Base Robotic Systems. The field of robotics is a research area and a technical field to develop, build, and apply machines from those categories.

Fixed Base Robots are the well known Manufacturing Robots, robots for safety and security applications, robots for medical applications and manipulators. The latter are also known under the term Master-Slave-Manipulators.

Mobile Robots have a wider range of application, though they are more difficult to energize, to control, to position precisely. It is also more difficult to define and control their missions. They are objects of many researchers (Buhmann, 1995). Today a wide variety of such mobile autonomous systems for space, air, land, and sea applications are available respectively under development. There primary purpose is for transportation, manipulation, and use as safety and security systems.

VR combined with Robotic Systems

VR technology can help to program manufacturing robots, plan missions and control these missions for complex robotic systems. Here is the connection between VR and seemingly automatic machines. Human operators using GUI based interactive Human-Machine-Interfaces including powerful 4D real time computer graphics support should achieve high performance low error system control. One example for that technology is from stereo vision augmented master-slave manipulation using augmented video (Milgram, 1995).

The next examples are from the kiss-lab Mobile Robots Research Testbed. Kiss-lab mobile robot research vehicles are multi sensoric devices consisting of base units and enclosures to house various sensors from different wavelength spectra. A mobile autonomous system named "kiss-mobile"(Holzhausen, 1995A and 1995B) is being used mainly for research in multisensorics and route planning. The blue-kiss robot research vehicle is a flexible machine concept comprising a base unit for locomotion and a payload carrier capable of various payloads for multiple purposes (Diers, 1996). Other robots like the red-kiss robot research vehicle is a mini rover to study sensor data processing, map building, radio Ethernet communication, and multiple robot interaction, kiss-mobile sensor visualization and multi-robot coordinated navigation. The examples show clearly the superior performance of robot mission control using 4D GUI technology thus combining VR and robotics.

Robotic systems with different degrees of autonomy, robots for repetetive tasks, fully automatic when taught, fixed base industrial robots for welding and manipulation, safety and security robots for sensing and monitoring are available.

There are also many mobile systems available. All of those robots do not use a fixed base , they are not designed for simple repetetive tasks, but operate in semi-autonomous modes. There are deep sea investigation robots, searching objects on the ground of the sea, discriminating automatically between different categories of targets (SPAWAR, 1999). Space robots perform navigational and research tasks on planets of the earth (Cooper, 1997). Air applications of robotic vehicles include automatic takeoff, trajectory following, and landing, vision based stability and control, advanced aerial mapping as well as object recognition and manipulation (CMU, 1998).

Even numerous medical applications are already state of the art. Individual voxel registration of MR/CT scans for tissue property identification, mapping, and visualization using saggital slicing imaging process constructing 3D models of human body areas are available. Automatic surface detection and display by selecting a virtual viewing camera location and orientation in the MRI coordinate frame can be called upon by the medical personnel (MIT, 1999).

Quo Vadis VR and Robotics?

Future advanced technical systems will be more sophisticated and complex than today. They are supposedly more highly automated and partly autonomous. They will be operated through powerful and human-engineered Human-Machine-Interfaces using telepresence, immersion, semi-autonomy, and will be increasingly equipped with supervisory controlled strategies of operation and monitoring.

The benefit of VR equipped GUI in control station will not only make ever more complicated missions and technical systems feasible. It will also reduce operator induced errors and increase safety even with less critical tasks and make those systems more fault tolerant, more robust against errors, and allow for less well trained personnel in technologically simpler environments. Access to high technology and industry may not for ever be limited to highly qualified staff but also render job opportunities for average employees.

Many hazardous jobs in a wide variety of industries and even in domestic applications may in the future be done by intelligent machines, leaving the responsibility with the human operator, encouraging his intuition and requiring less dangerous and hard manual labor for the aim of a humanitarian technology being friendly to their users.

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