Multimedia and Virtual Reality Techniques for the Control of ERA, the First Free Flying Robot in Space

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Abstract. The commanding and supervision of complex automation systems for space as well as for terrestrial automation applications is a demanding task. Modern developments in the field of virtual reality (VR) based man machine interfaces have the potential to facilitate such tasks enormously. At the Institute of Robotics Research (IRF) in Dortmund, Germany a variety of practical applications regarding the control of robots over long distances by means of virtual reality based man machine interfaces have been developed and successfully tested. In April 1999, the experiences made were successfully applied to the commanding and supervision of the robot ERA on board the Japanese satellite ETS-VII. In a joint mission between the Japanese Space Agency NASDA, the German Space Agency DLR and IRF, the robot was successfully commanded and supervised by means of “projective virtual reality” methods. This paper described the key ideas and features of projective virtual reality as well as the metaphors used to augment the virtual world and to make the operation of the robot very intuitive. Before being able to apply the framework of projective virtual reality to this application, two major issues had to be addressed: First, it has to be made sure that the commanded robot can never damage itself or his environment — this was addressed by automatic collision avoidance strategies. Secondly, the virtual model has to generated and then to be calibrated — this was addressed by the “TV-view into reality”-metaphor and modern 3D vision algorithms to provide the required on-line world-model updates.

Key Words. Projektive Virtual Reality; Robot Simulation; Man-Machine-Interface; Collision-Avoidance; Stereovision

1 INTRODUCTION

The application of virtual reality (VR) techniques [6][4][5] has been investigated since 1990 at the IRF and it was found, that the potential for new virtual reality based approaches to man-machine interfaces is really promising. New virtual reality techniques offer the chance to convey information about an automation system in an intuitive manner and can combine supervision capabilities with new, intuitive approaches to the control of the system. Our basic idea of an intuitively operable man-machine-interface is to provide a virtual reality system that automatically translates actions carried out by a user in the virtual, graphically animated world into physical changes in the real world, e.g. by means of robots or other automation components. The less the user in the VR needs to know about the means of automation which carry out the task physically, the better was the design of the man machine interface. This idea actually is the background for the new „Projective Virtual Reality“-methodology [6] described in this paper: with the help of robots, the changes made in the virtual world are „projected“ into the physical world. The ideas developed in this field of virtual reality based commanding and supervision were successfully tested in April 1999 during the GETEX (German Technology Experiment), a mission carried out in Tsukuba, Japan as a part of the cooperation between the German and the Japanese Space Agencies. This paper describes the basic ideas implemented for and tested during the mission.

2 HOW TO REALIZE PROJECTIVE VIRTUAL REALITY

This chapter shortly describes the new task deduction approach for projective virtual reality by comparing it to a standard teleoperation approach. The arguments given here for the control of robots hold in a similar way for other means of automation.

2.1 A straightforward approach to controlling a robot via VR

A straightforward approach to controlling a robotic system via VR is to directly track the dataglove with the robot's TCP; this mode of operation will further be called „teleoperation or hand-tracking mode“. The — theoretical...
— advantage of this approach is its flexibility. With the robot directly tracking the operator’s hand, the robot should — in theory — be able to do the same things as the human operators. In practice, this mode of operation cannot really be recommended for most of the tasks that involve contact between a robot and the environment. If for example an assembly task shall be commanded by a virtual reality system in hand-tracking-mode, the following problems are encountered:

- time delays between the display of a robot’s movement in the VR and its physical movements are critical for the stability of this process, because, similar to standard teleoperation approaches, the user is still „in a realtime control loop”
- the graphical model has to be very precise
- the measurement of the position and orientation of the dataglove has to be very precise
- measures have to be taken to reduce „trembling” of the operator’s hand
- online-collision avoidance features are necessary to ensure safe operation
- a versatile sensor control is necessary to compensate for unwanted tensions when objects are inserted into tight fittings

One way to — partially — overcome these limitations are approaches based on the fusion of information of multiple sensors and prediction and estimation techniques [1][2][3]. The methods envolved are very complex and the necessary equipment is still expensive. During the commanding and supervision of the ERA robot, a different approach was pursued which builds on the new ideas of projective virtual reality.

2.2 Task deduction as a key technology to realize Projective Virtual Reality

In order to be able to safely control the robots with the virtual reality based man machine-interface, the task deduction mode was developed. The key idea is to make use of a planning component, developed in an earlier project under contract of the German Space Agency and to enhance the virtual reality system in a way, that it can exploit these capabilities. The planning component is able to work on high level task descriptions and to decompose them into so-called elementary actions which can directly be carried out by a robot or automation system. The solution was to enhance the VR-system in the way that while the user is working, the different subtasks that are carried out by the user are recognized and task descriptions for the planning component are deduced. These task descriptions are then sent to the action planning component and are then carried out safely by the multi-robot controller with its inherent capabilities. The details of this tight cooperation between task deduction and action planning are covered in great detail in [6] and [7]; in this paper, we would like to concentrate on the practical results during the mission, i.e. the experiences made during the control of the robot ERA on board the satellite ETS VII.

In [6] it is pointed out that this new approach has the following advantages over direct hand-tracking — as was to be proven during the real mission:

- the user is no longer in the „realtime control loop”. Complete subtasks are recognized and carried out as a whole without the necessity for immediate feedback to the user
- robots with sensor-supported assembly strategies can compensate for inaccuracies of the virtual environment model
- the accuracy of the dataglove tracking device is not as important as for the direct tracking mode. The allowable tolerances when the user is gripping an object or inserting a peg in a hole can be adjusted in the VR-software
- if a heavy or fragile object is moved in the VR, the planning component is automatically capable of using the two robots in a coordinated manner to do the transport in the real world
- as the robot control system is versatile enough, there is no longer a need to even show a robot in the virtual environment displayed to the user; so the user more and more gets the impression of carrying out a task „himself”, which is the highest level of intuitivity, that can be achieved.

![Fig. 1: Two users cooperating in a virtual space laboratory](image)

Especially for the development of distributed virtual worlds this approach has the great advantage that different users working at different VR-systems can work on different tasks simultaneously. The deduced task descriptions are then sent to the planning component which can automatically generate, depending in the available resources, an adequate sequence of the tasks. Thus multiple users in a distributed virtual environment can work together to command and supervise one automation system as shown in fig. 1.

The only deficiency of this mode of operation is, that the planning component must principally know the different
types of tasks carried out by the user. Therefore, for special applications that are hard to describe as parameterized tasks — e.g. the shaking of a material sample — or for applications that were not foreseen by the developers of the action planning component, the hand-tracking mode is still available in the realized VR system.

3 COMMANDING THE JAPANESE ROBOT ERA

Already in 1996, the Japanese Space Agency NASDA and the German Space Agency DLR agreed on a Memorandum of Understanding (MOU) in the field of space robotics. A major part of this agreement was related to the Japanese ETS-VII (Engineering Test Satellite) which has been developed by NASDA to perform Rendezvous & Docking (RVD) and Space Robotics (RBT) experiments.

Fig. 2: Virtual Reality Simulation of the Japanese ETS-VII Satellite

NASDA and the German Space Agency agreed on a cooperation project where the German side contributes the on-ground robot control and command station, which combines enhanced robot control and latest virtual reality techniques to provide intuitive control and supervision of the robot arm ERA onboard the ETS-VII. In April 1999, a team of the DLR and the IRF traveled to Tsukuba, Japan, to install and run the ground control station based on the projective virtual reality methods described in this paper. The mission in April 1999 was a great success. In five mission time-slots, different experiments were carried out which were safely commanded and supervised by the IRF ground station. The experiments ranged from simple routine tasks like gripper attachment and detachment over assembly benchmarks to manipulation tasks under force/torque control. (Details about the missions and the experiments can e.g. be found under http://www.irf.de/getex).

Fig. 3: View of the projective Virtual Reality system to command and supervise the ERA robot

In cooperation with our Japanese colleagues, we even had a world premiere: For the first time, a space robot was commanded and supervised on-line by means of a “immersive virtual reality interface” based on helmet and dataglove — without previous off-line preparations and detailed pre-checks of the generated robot commands to be expected. Figure 4 shows Dr. Mitsushige Oda, Principal Investigator at NASDA, controlling the ERA robot by means of the IRF projective virtual reality system. Dr. Oda successfully commanded a mission of the ERA robot after only 10 minutes of introductory training.

Fig. 4: Dr. Mitsushige Oda, Principal Investigator at NASDA, controls the first IRF experiment by means of a data-helmet and a data-glove.

The basic ideas of projective virtual reality [6] comprising task deduction, task “projection” and commanding and supervision metaphors that will be discussed below could fully be applied to the ERA application; this new paradigm proved to be very successful.
On the one hand, the action planning component in task deduction mode hides from the user which means of automation is employed to carry out the task as a courtesy to users who are not robotic experts. On the other hand, experienced users and service personnel who supervise the robot testbed need to have comprehensive information about the automation system. In order to provide the supervision capability and to further simplify the user’s job to command different tasks images and metaphors – multimedia based user aids – in the virtual world were developed which support the intuitive control and supervision. In the following, examples of the practical operation of the VR system are given, depicting which kinds of augmentations were introduced in practice and how the intuitive supervision capabilities were implemented.

4.1 Handling of objects in the virtual world

The key idea of projective virtual reality for the non robotic expert is not to show the robot at all, but to let the user just handle objects in the virtual world like he would do in the real world. The sequence of images shown below was taken during the mission in Japan. The user grasps a peg, removes it from its original position and the just places it at the desired target position. This is all that has to be done to command the insertion of the peg into the second hole. The user doesn’t see the robot and he doesn’t need to worry about the state and position of the gripper or about potential collision danger for the robot on its way to the target position. All these details are taken care of by IRF’s action planning component, which is able to decompose the high-level task description “move peg into hole B” into the required sequence of movements and gripper commands to successfully complete the task.

4.2 Visualizing the locations of physical objects

During the mission, the robot was commanded and supervised by robotics experts who did not just want to command routine tasks, but who wanted to get a detailed insight into the working of the robot and of the different components playing together. A first and simple measure to make the experienced user feel comfortable is to display the position of the physical robot, the TBTL and the tools in the virtual world as yellow, transparent bodies as depicted in fig. 6. The user may actively switch on or off the representation of the robot by making a special gesture with his data-glove.

Fig. 6: Metaphors for physical objects as transparent images

Fig. 6 shows that the current configuration of the physical robot is visualized as a transparent yellow images of the robot. The right part of Fig. 6 shows that when the user manipulates e.g. the slider on the taskboard, a transparent image of the slider — as a “placeholder” of the physical slider — remains at the original position, until the physical robot starts to move the physical slider. As soon as the physical slider moves, the transparent image will move as well, always indicating the current position. As soon as the physical slider reaches the desired target position, the yellow image will vanish and thus visually indicate that the task was carried out completely and successfully. With just on glance at the virtual world, looking for yellow, transparent objects, the operator can check for pending or unsuccessfully completed tasks.

4.3 Simulating before executing

A key feature to be able to judge the correct generation of elementary actions for the ERA robot is to be able to simulate a task before it will be carried out by the physical robot. IRF’s projective virtual reality system therefore manages “different worlds” in the same virtual reality system. By means of the central world model, the central database and information node of the system, the states of the different worlds can be visualized in the same virtual world and all states can — with the push of a button — be reset to the state of the physical world.

Fig. 7 shows the simultaneous visualization of five different states of the robot ERA. Thus it is even possible to simulate the planned next motion while the current motion of the physical robot is being supervised on-line. As explained before, the yellow, transparent robot always visualizes the state of the physical robot.
4.4 Augmenting the virtual world to display and adjust additional system- or sensor-information

Furthermore, the expert operator may also employ the “visor”-metaphor to get even more detailed information about the current state of the robot. The visor is intended to be a transparent display for all kinds of textual status information that a user might need to operate ERA. Fig. 8 shows how the visor is being used to display the numerical values of the robot’s joint angles and the robot’s TCP position in world coordinates. Other numerical information that may be displayed comprises sensor-information like measured distances, or forces and torques exerted at the robot’s wrist.

4.5 Metaphors supporting world-model updates

A third field where powerful metaphors come in handy is the support for world-model updates.

Fig. 10 shows an example of the use of the “TV-View into Reality”-Metaphor which can be used for the intuitive comparison of the virtual world and the real world. The key idea of the “TV-View into Reality”-Metaphor is to display real world information inside the virtual world [8]. Fig. 10 shows the view of the physical robot’s hand camera above the taskboard, mapped as a texture onto the surface of a virtual LCD TV-screen. By looking at the screen and at the virtual model, the user can intuitively compare the virtual model to the real world and check, if the virtual model is modeled correctly. In the first place, this is only a qualitative check, e.g. for the presence of objects, but it helps very much to gain confidence into the virtual reality based supervision idea.
Fig. 11 further helps to understand the idea: If the user grasps and moves the flat “TV-Screen” underneath the robot’s gripper, the planning system will guide the robot’s hand camera to the location, where the user placed the screen. By looking onto the screen the user will then see the objects in the real world located at the corresponding position. If the virtual model is correct, he should see the video image of the same objects as are located behind the screen in the virtual world.

Currently developments are going on at the IRF to further extend the “TV-View into Reality” metaphor. We would like to provide the necessary image processing algorithms to “pull objects from the real world into the virtual world”. This means, that the user may point to an object which will, by means of stereo vision algorithms be measured and modeled, so that a virtual model can automatically be generated and inserted into the virtual world. This approach should very much simplify the tedious work of the generation and calibration of the virtual environment.

5 CONCLUSION

Experiences during the mission to control to Japanese robot ERA on board the ETS-VII satellite showed, that modern virtual reality techniques are a promising approach for the development of intuitively operable man machine interfaces. The methods of “projective virtual reality” – enhanced by modern multimedia techniques to realize powerful control- and supervision metaphors – provide a new quality of a man machine interface for complex robotic and automation systems. During the mission in April 1999 in cooperation with colleagues from NASA and from DLR, it was demonstrated how to make the connection between VR- and robot control technology in a way that the robot serves as the „prolonged arm“ of the user handling objects in the virtual world. With the corresponding task deduction and action planning components it was possible to „project“ the user’s actions from the virtual world into the physical world by means of the ERA robot, which means that ERA physically carried out the task that the user conducted in the virtual world. The feasibility of this approach was thoroughly tested during the mission.

Summarizing the mission, we can only state that the results were almost unbelievable. We completed more experiment sequences than previously planned, we were allowed to use the virtual reality interface for on-line commanding and all experiments were successful at the first try. We owe a good deal of this success to our Japanese friends, who did an excellent job preparing this mission and - what is most important - who build an excellent space robot, as all the collected data impressively proved.

Doumo Arigatou Gozaimasu to Dr. Oda, Mr. Takano and their coworkers.

REFERENCES


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