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COMPUTATIONAL VIRTUAL REALITY (VR) AS A HUMAN-COMPUTER INTERFACE IN THE OPERATION OF TELEROBOTIC SYSTEMS

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This presentation focuses on the application of computer graphics or "virtual reality" techniques as a human-computer interface tool in the operation of telerobotic systems. VR techniques offer very valuable task visualization aids for planning, previewing and predicting robotic actions, operator training, and for visual perception of non-visible events like contact forces in robotic tasks. The utility of computer graphics in telerobotic operation can be significantly enhanced by high-fidelity calibration of virtual reality images to actual TV camera images. This calibration will even permit the creation of artificial (synthetic) views of task scenes for which no TV camera views are available.

OVERVIEW

- VR as real-time control technique; fusion/ calibration issues
- VR as training method; kinesthetic/tactile features/interfaces
- VR as task logistician; protocols and audio/vocal interfaces
- VR as visualization tool for abstract, non-visible things; displays
- Conclusion

VR AS REAL-TIME CONTROL TECHNIQUE WHEN FUSED WITH TV CAMERA IMAGES

Task visualization is a key problem in teleoperation since most of the operator's control decisions are based on visual information. The capability of previewing motions enhances the quality of teleoperation by reducing trial-and-error approaches in the hardware control and by increasing the operator's confidence in control decision making during task execution. Predicting the consequences of motion commands under communication time delay permits the command of longer and safer action segments as opposed to the command of short action segments adopted in the move-and-wait control strategy in time-delayed teleoperation without predictive displays.

Fusion of graphics and TV camera images can be generated by overlaying graphics images over actual TV camera images. A high-fidelity overlay requires a high-fidelity TV camera calibration and object localization. For this purpose, a reliable operator-interactive camera calibration and object localization technique has been developed at JPL during the past few years. It currently uses a point-to-point mapping procedure, and the computation of the camera calibration parameters is based on the ideal pinhole model of image formation by the camera. The technique uses the robot arm as the calibration fixture and assumes the use of a few selectable, good static TV camera views. The technique was demonstrated to a broad audience in May 1993 when a JPL control station was connected to an ORU exchange mock-up 4000 km away at GSFC through the NASA-select TV channel and the Internet computer network. The task was successfully performed under varying communication time delay conditions.

The calibration technique and its application potential gained technical acceptance and is now being commercialized through a technical transfer agreement with DENEB Robotics, Inc. More on this calibration technique and its demonstration in Refs. 1 and 2. A narrated VCR tape is available on the demonstration in the JPL Audio-Visual Library (no. AVC-93-165C1D).

- Motivation
  - Communication time delay: predict actions
  - Planning complex tasks: preview actions
  - Intelligent automation: supervise/monitor actions
- Method of fusing VR images with TV images: create high-fidelity overlays of graphics images over TV camera images
  - Calibration technique: point or feature mapping
  - Motion control of graphics overlays
- Extra benefit: enables artificial or synthetic views or scenes

(See VCR tape for performance results)

VR AS TRAINING METHOD WITH KINESTHETIC/TACTILE FEATURES/INTERFACES

Operator training using a VR display system is a convenient tool for initial familiarization of the operator with the teleoperated system without actually turning the hardware system on. Using proper physical modeling, even sensors and sensor fusion can be simulated and graphically shown to the operator. Computer graphics simulation of proximity sensor signals is a relatively simple task since it only implies the computation of distance from a fixed point of a moving robot hand in a given (computed) direction to the nearest environment surface in the graphics "world model". Force-torque sensor signals can also be simulated by computing virtual contact forces and torques for given geometric contact models using a spring or a spring plus damper description of the actual contact interaction. For some detail, see Ref. 3.

Modeling of soft things, like tissues, and graphically showing their deformations as a function of pressure is a very demanding undertaking. Some useful information on this topic can be found in Ref. 4.

- Modeling of contact forces/moments and tactile area pressure - and showing them graphically
- Modeling of "soft" things, like tissues - and showing their deformations graphically as a function of pressure
- Application potential of manual force/ moment and tactile feedback from VR interaction scenes is increasing for
  - training operators (and surgeons)
  - "sensitive" teleprogramming

VR AS VISUALIZATION TOOL FOR DISPLAYING ABSTRACT, NON-VISIBLE THINGS

Visualization of non-visible events enables a graphical representation of different non-visual sensor data and helps management of complex systems by providing a suitable graphical description of a multi-dimensional system state. For instance, the constrained and orientation restricted motion space of a dual-arm robot working in a closed kinematic chain configuration can be visualized as a complex 3-D object with hidden unreachable holes or cavities of varying shapes. An automated visualization method has been developed to find and visually represent this complex geometric object from a computed numerical data base. The method is an inverse computer vision technique in the sense that it creates rather than recognizes visual forms. More on this can be found in Ref. 5.

- Several abstract, non-visible things can be present during telerobotic operations originating from
  - Internal system constraints - which can translate to complex task space constraints
  - Different multidimensional sensor data spaces - which, by some mapping, contain task/subtask goals as single event points or restricted small volumes
- Visualization of non-visible things may require the use of
  - Complex computational procedures
  - Some artistic creativity for designing graphic forms
- An example: visualization of a constrained dual-arm geometric work space treated as an inverse computer vision problem

VR AS TASK LOGISTICIAN SURROGATE WITH AUDIO/VOCAL INTERFACES

In an emerging field of R&D, researchers embed task protocols or task scripts within a suitable VR representation. This requires to map a sequence of VR scenes to a sequence of required actions. In a related effort, researchers already initiated the idea of providing the operator with performance feedback messages on the operator interface graphics, derived from a stored model of the task execution protocol. A key element of such advanced feedback tool to the operator is a program that can follow the evolution of a teleoperated task by segmenting the sensory data stream into appropriate task performance phases. Task segmentation programs have already been implemented using Hidden Markov Model representations (Ref. 6) and Neural Network Architecture (Ref. 7) with very promising results.

- VR with embedded task protocols/scripts - emerging field of R&D work
  - Mapping the sequence of VR scenes to sequence of required actions
  - Mapping the actual performance shown on VR scenes to required performance
- Audio/vocal interface to VR-embedded task logistician is possible and desirable, with some operational restrictions
  - Fixed content both ways
  - Short statements both ways
- Consideration of human factors

CONCLUSION

The application of Virtual Reality techniques/tools in the operation of telerobotic systems enables the performance of more tasks, safer, faster, and inherently cheaper.

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