DOE F 1430.22 Notice of Energy RD&D Project

GRANT #DE-FG07-96ER14728: Advanced Sensing and Control Techniques to Facilitate Semi-Autonomous Decommissioning of Hazardous Sites

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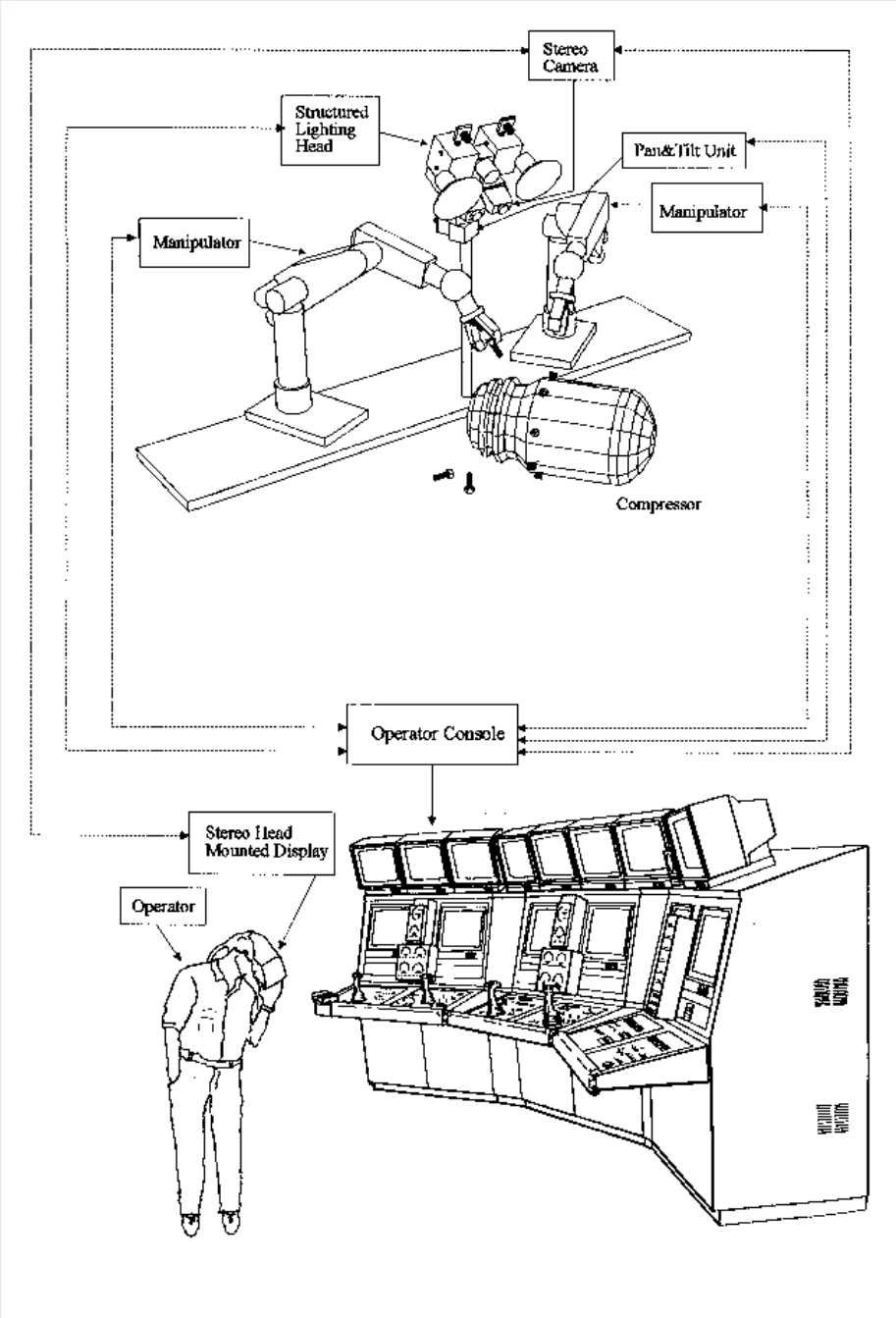
Overview

This research is intended to advance the technology of semi-autonomous teleoperated robotics as applied to Decontamination and Decommissioning (D&D) tasks. Speci£cally, research leading to a prototype dual-manipulator mobile work cell, as shown below, is underway. The overall goal of this phase of the research is to autonomously generate a speci£cation of scene geometry using a stereo pair of camera images suf£cient to produce a virtual replica of the sampled scene that is suitable for VR rendering and subsequent real- time robotic D&D operations, navigation, planning, and mission training.



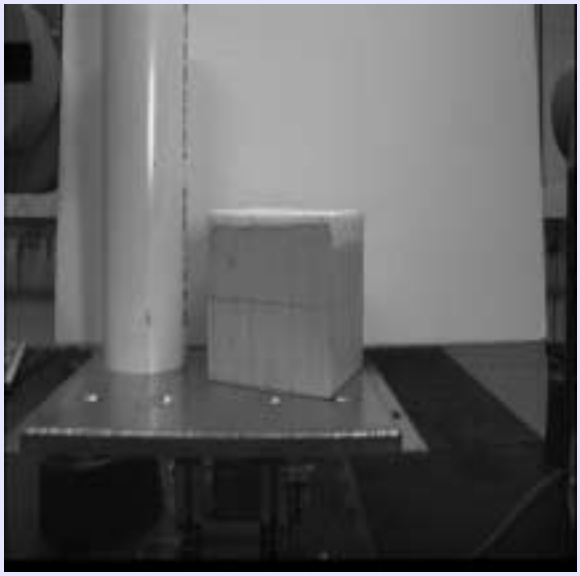
Using VR-Enabled Telepresence Following Site Virtualization

Status

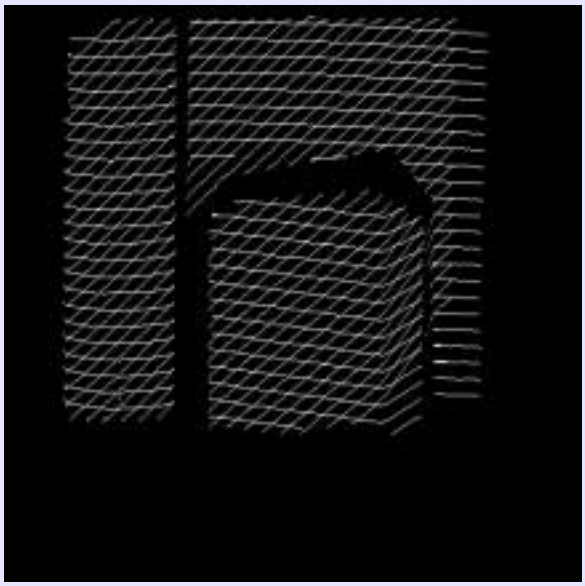
- The fourth generation of a vision sensing head for geometric and photometric scene sensing has been built and tested.
- Currently, we are developing estimation algorithms for automatic sensor calibration updating under robot motion.
- We have modi£ed the geometry extraction component of the rendering pipeline. Laser scanning now produces highly accurate points on segmented curves. These point-curves are input to a NURBS (non-uniform rational B-spline) skinning procedure to produce interpolating surface segments. The NURBS formulation includes quadrics as a sub-class, thus this formulation allows much greater ¤exibility without the attendant instability of generating an entire quadric surface. We have also implemented correction for diffuse lighting and specular effects.
- The QRobot joint level control was extended to a

complete semi-autonomous robot control system for D&D operations.

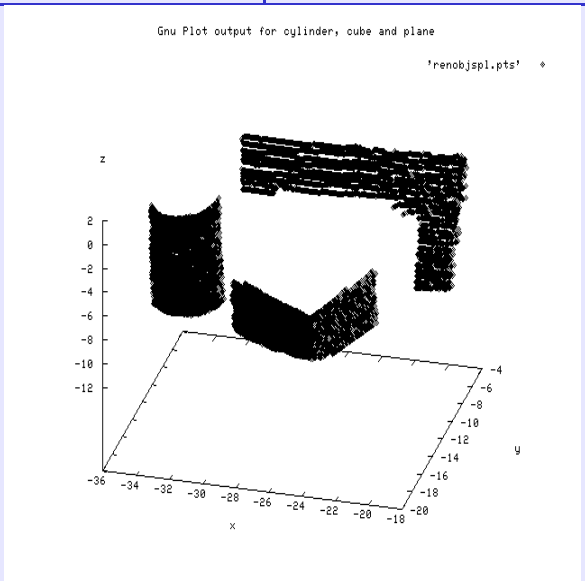
- Currently, the project is at the critical stage where the three subsystems (imaging, VR and robotics) are being integrated and tested.
- We have also had extensive discussion with INEEL personnel who have expressed interest in this work in conjunction with the DOE DDROPS effort.



Gray-level rendition of initial scene (single viewpoint): 2 objects and planar background

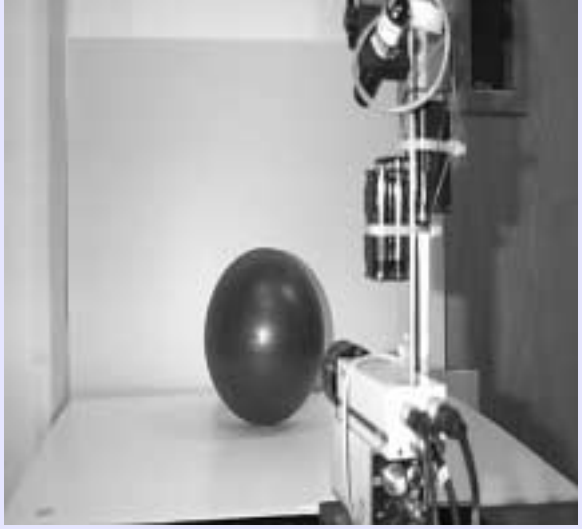


Composite of stripes used in geometric characterization.

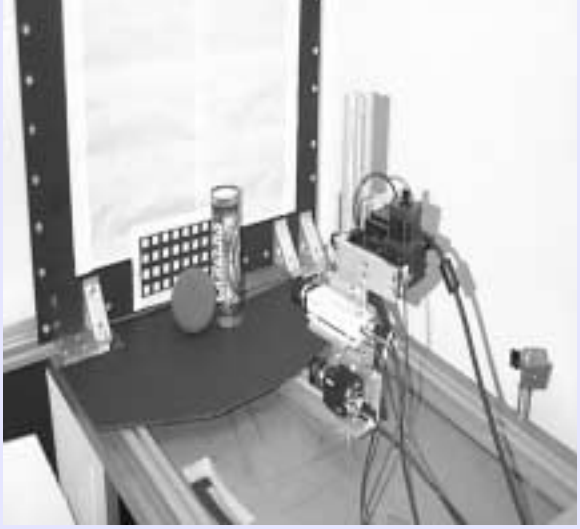


3-D plot of estimated object points from different viewpoint.

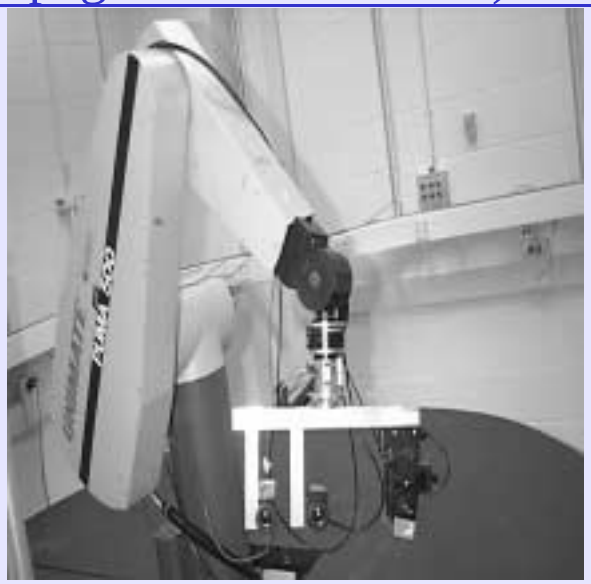
Figure 1: Illustration of the Geometric Characterization of a Scene (prelude to virtualization).



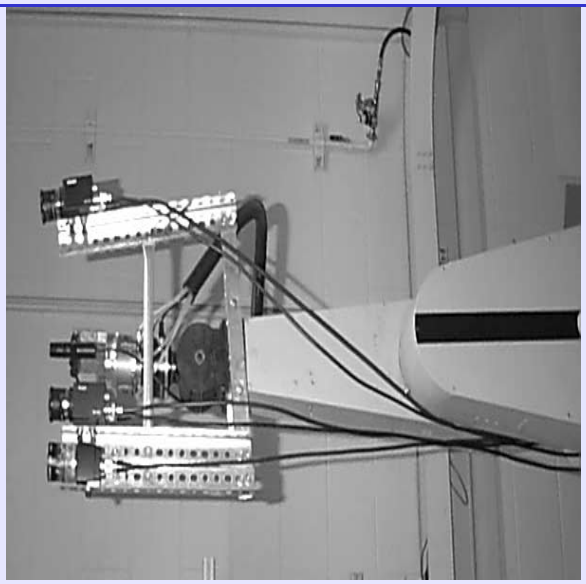
Early prototype used for ”blue ball” experiment (mpeg available on web).



First generation virtualization head with movable laser and calibration unit.



Third-generation wrist-mounted package. Laser motion is independent of wrist position.



Current virtualization sensing package. Passive cameras are arm mounted and movable.)

Figure 2: Evolution of Virtualization Sensor Package

Virtual Reality Environment Creation

- The goal of this task is to receive input that consists of a speci£cation of scene geometry, a stereo pair of camera images, and the associated camera calibration matrices and to produce from these a virtual replica of the sampled scene that is suitable for real-time navigation, planning, and mission training.
- A suitable rendering equation, in terms of radiance, is of the form

$$c = B/\pi + k_s(H \bullet N)^m \tag{1}$$

  where B denotes radiosity (exiting irradiance), computed through a classical formulation of environment patch interaction, and the remainder is a layered £rst-order specular component whose magnitude is determined by the surface normal, N, and the vector, H, that points half-way between light source and eye position.
- The goal is to use automatically gathered

radiometric and geometric information from a real environment to recover the necessary parameters for using (1) to produce a virtual replica.

- Laser scanning produces highly accurate points on segmented curves. These point-curves are input to a NURBS (non-uniform rational B-spline) skinning routine to produce interpolating surface segments. The segments do not extend beyond the range of the point collection, but, since the NURBS formulation includes quadrics as a sub-class, this formulation allows much greater ¤exibility without the attendant instability of generating an entire quadric surface.

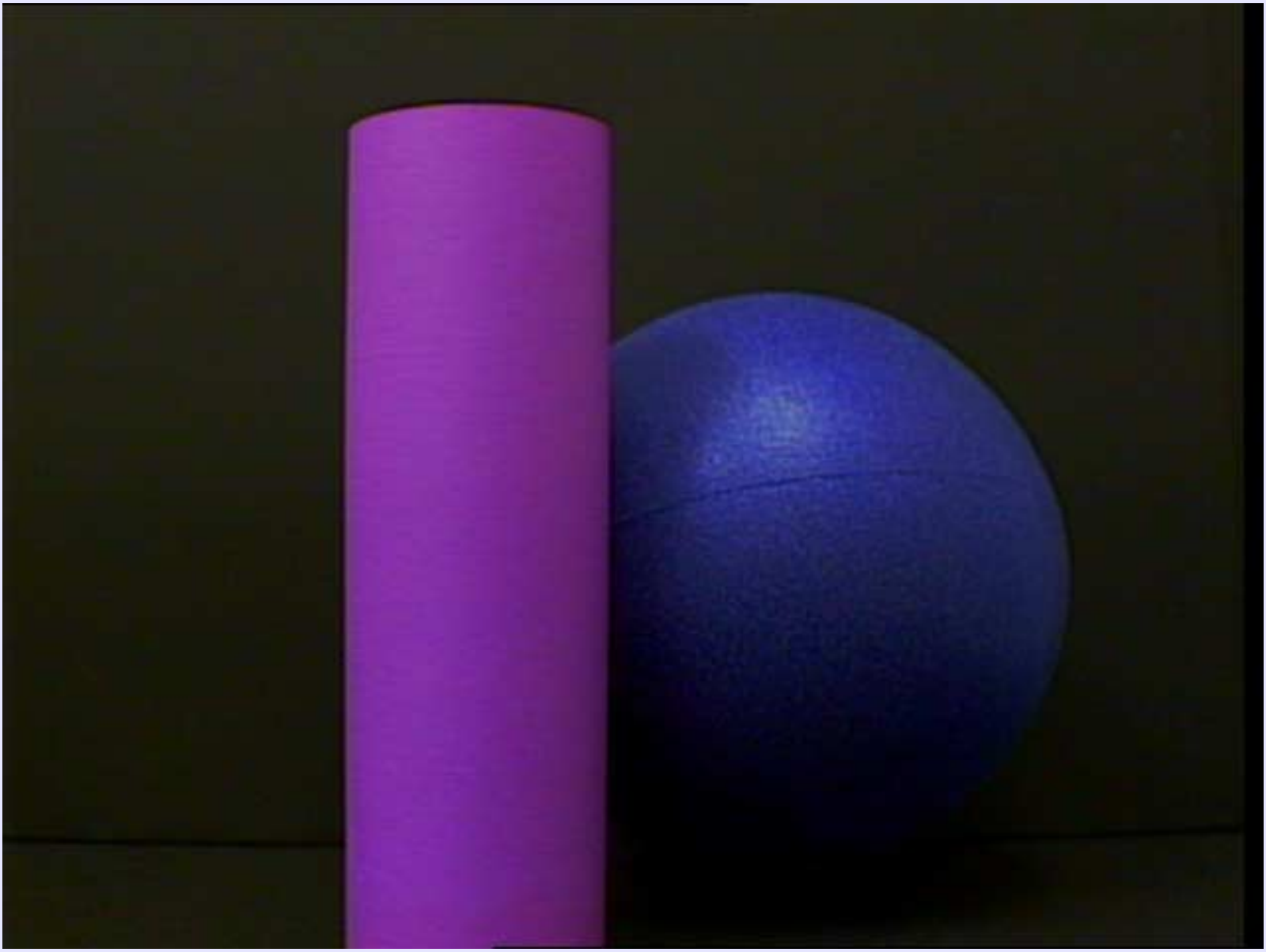


Figure 3: Photograph of test scene.

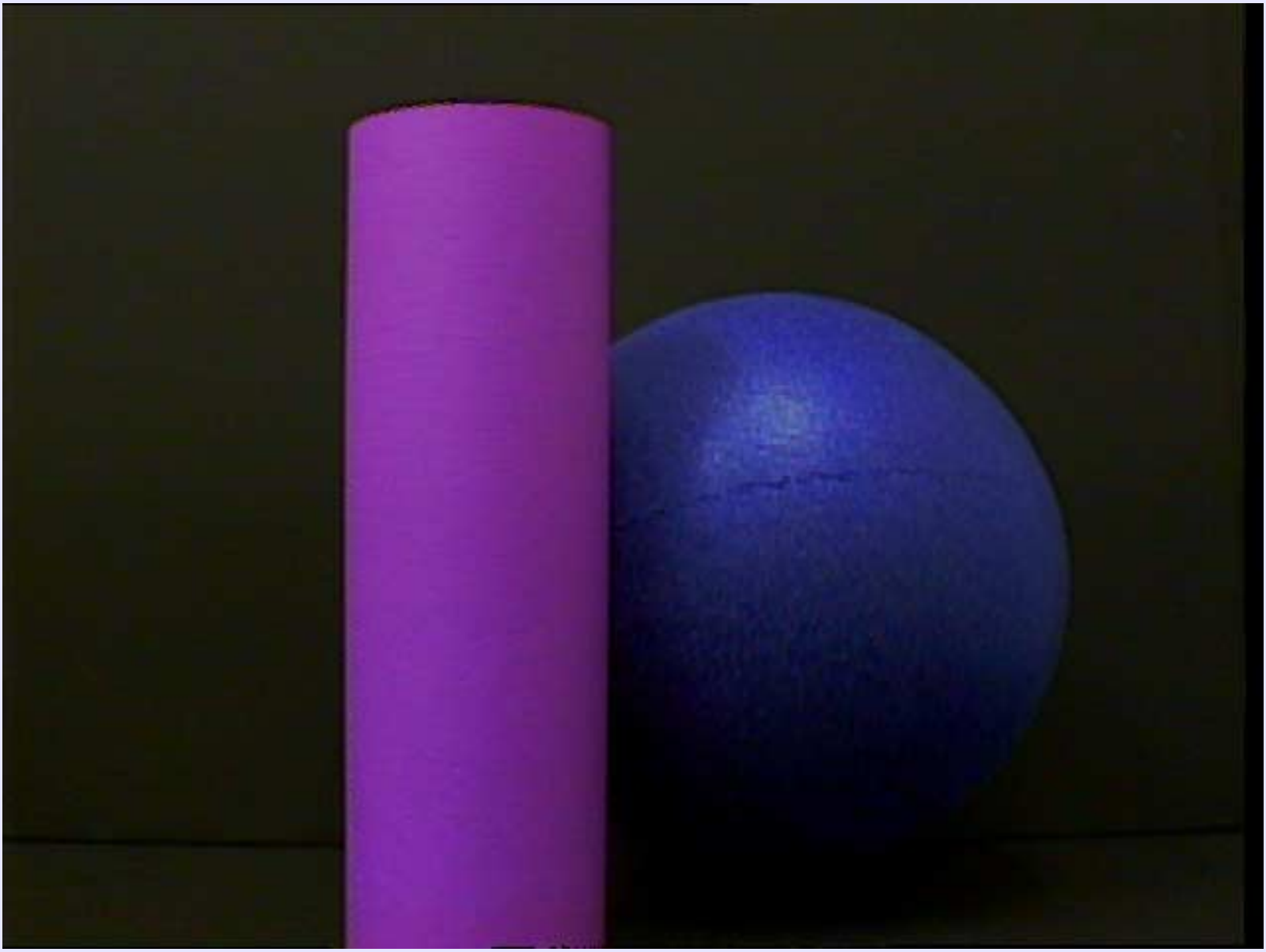


Figure 4: Virtual replica of test scene.

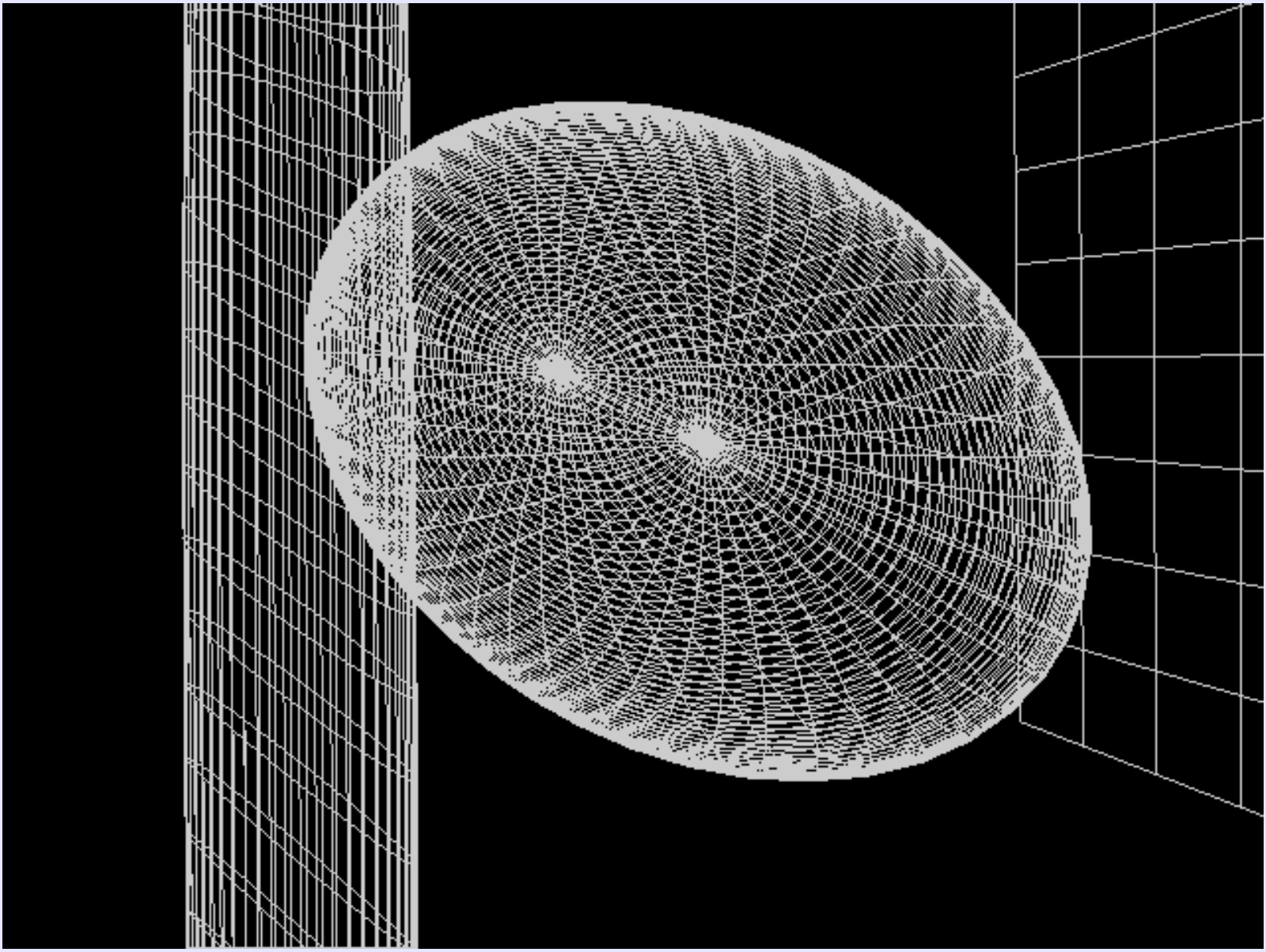


Figure 5: Virtual replica from another view.

In Figure 6 we show a (synthetic) photograph as an example target image. This is the left-eye view of a stereo pair.

Figure 6: Target test image.

A raw texture sample, taken from the target striped ellipsoid, is shown in the left image of Figure 7.

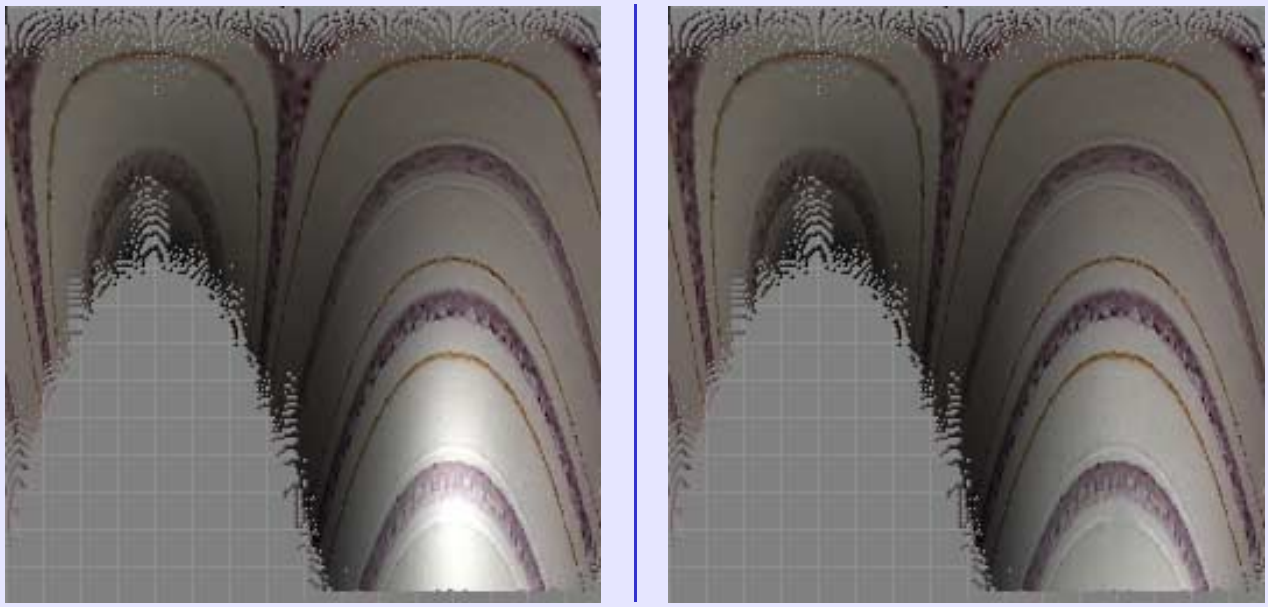


Figure 7: Texture extraction.

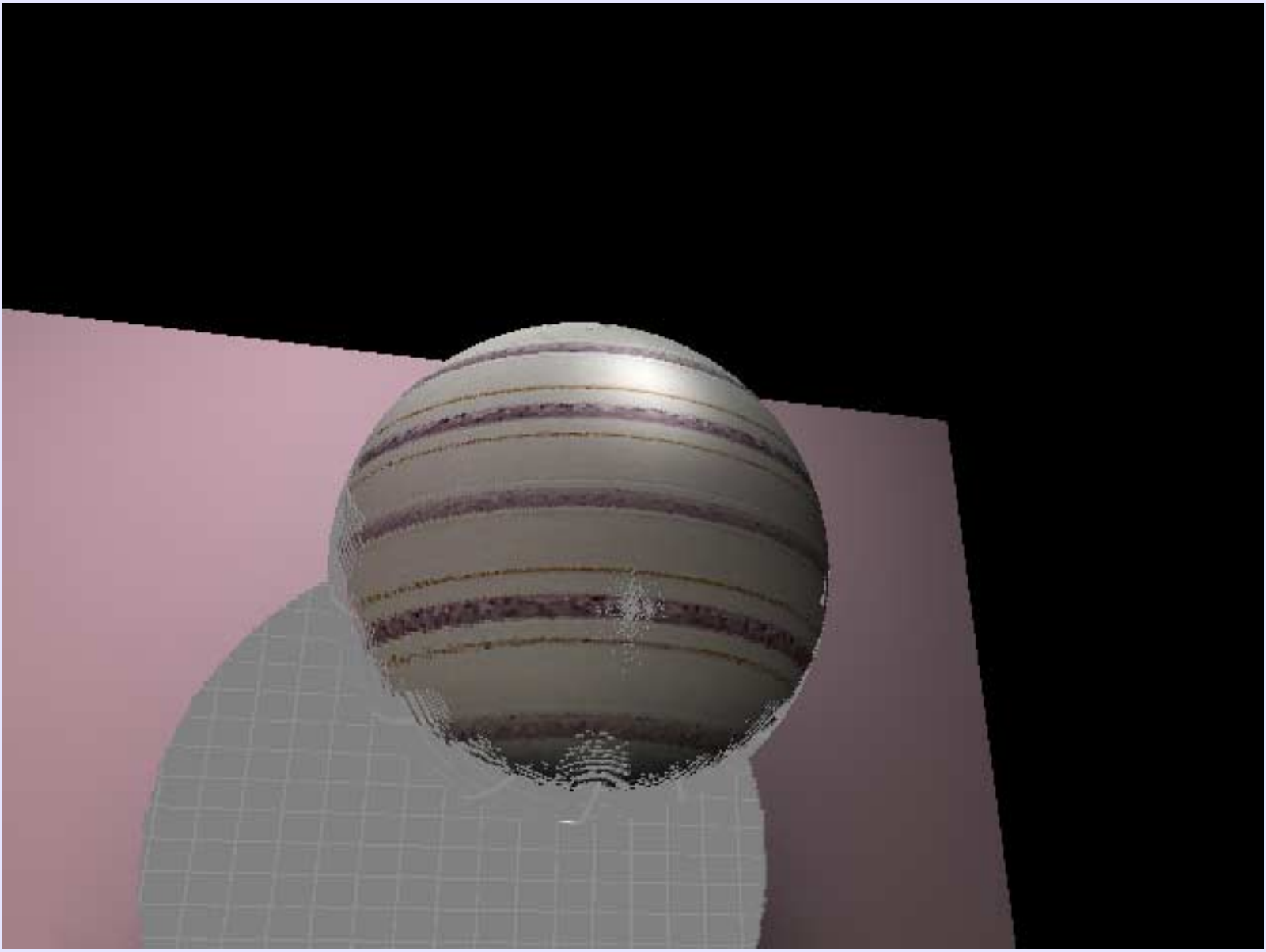


Figure 8: Virtual replica of the scene of Figure 6. The view point has been changed, and the ellipsoid has been rendered with non-extrapolated textures in order to show the part of the ellipsoid that was initially invisible. Note that the specular highlight has moved, as is appropriate.

Overview of the Robotics Software

Figures 9 and 10 show the software and hardware components that are distributed across three PCs. The VR Operator Interface PC runs Windows NT, while the Robot Control PC and the WebCam PC run QNX, a real-time OS. The VR Operator Interface and the Robot Simulator are integrated into one Windows NT program. The Video Operator Interface contains the actual disassembly program and communicates with the VR Operator Interface over Internet Domain TCP/IP sockets.

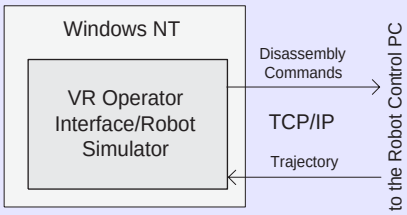


Figure 9: The VR Operator Interface PC

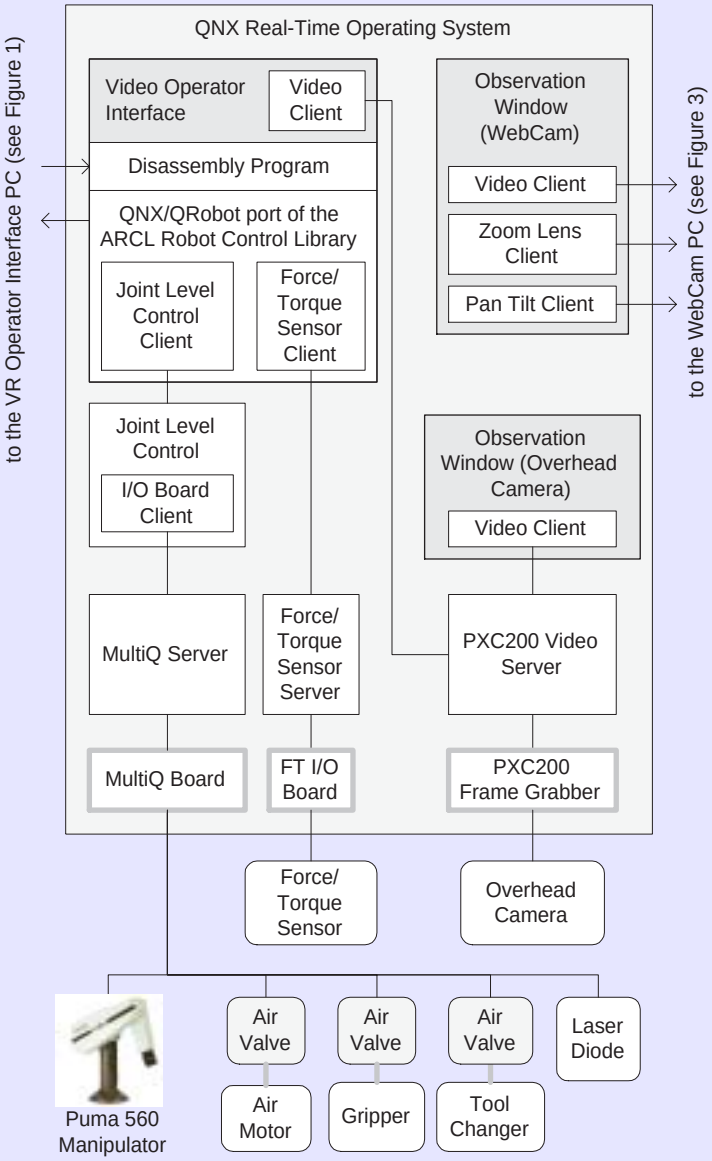


Figure 10: The Robot Control PC

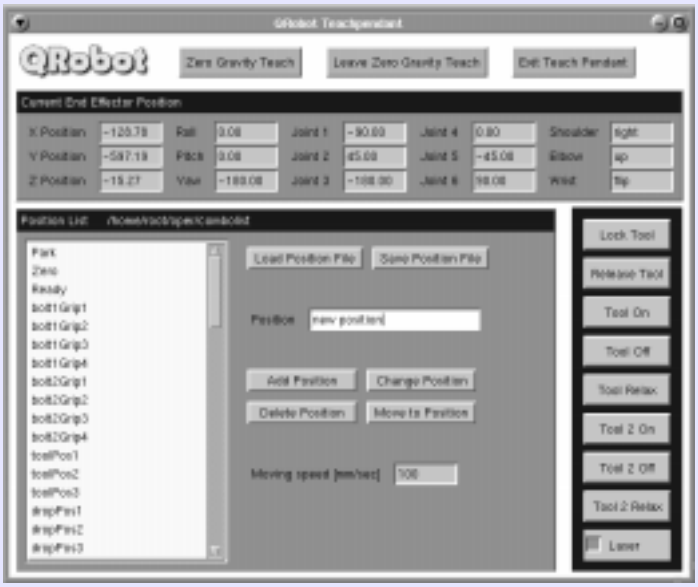


Figure 11: The QRobot Teachpendant

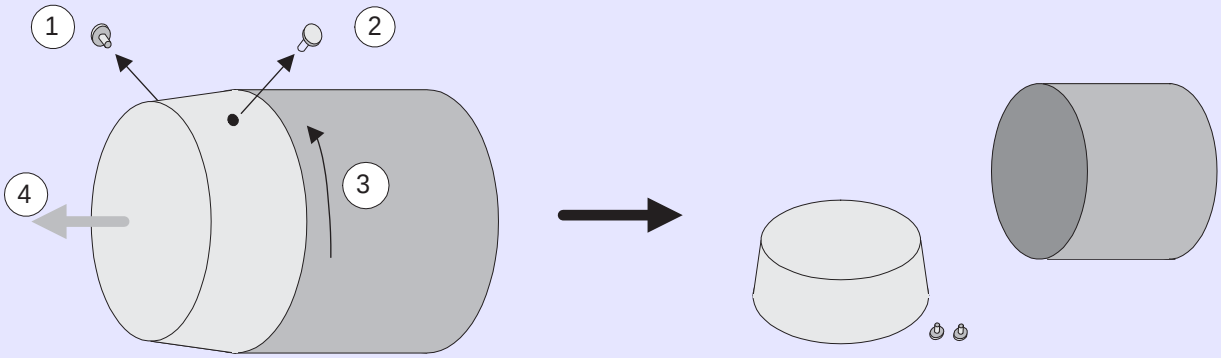


Figure 12: Steps to Disassemble the Motor

Figure 13: Observation Window

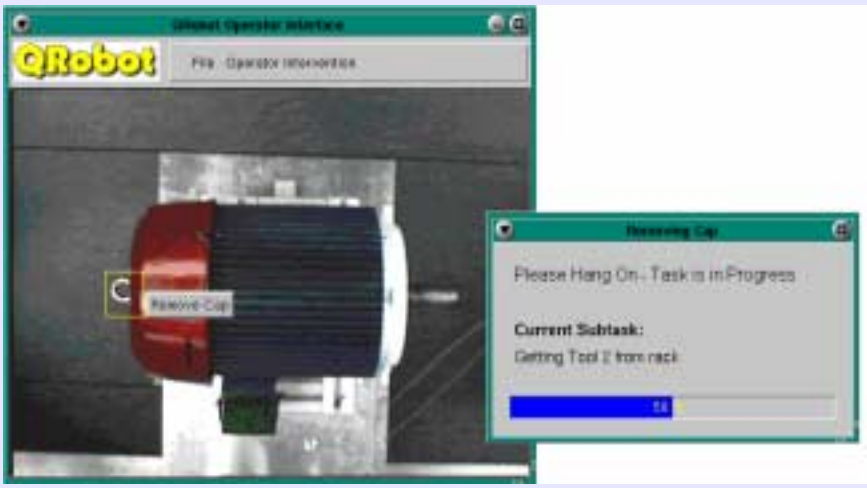


Figure 14: Video Operator Interface

Planned Activities

Future research focuses on the synergistic integration of the component technologies. Presently, we are combining fundamental manipulator control research with visual feedback/virtual reality research and applying the technologies to an industrial PUMA 560 robot manipulator. We plan a laboratory demonstration during the Summer of 2000.

Additional Resources

Coverage of our effort is available on the Web. Relevant pages are:

http://ece.clemson.edu/iaal/doeweb/doeweb.htm

This page includes MPEG clips of calibration and mapping using the PUMA-mounted virtualization head and an early virtualization example.

Other resources are:

http://chip.eng.clemson.edu/vr/cpsc/cpsc.html (virtual reality),

http://ece.clemson.edu/crb/research/robotics /doevr/index.html (robotics)