

## **RoboLab and Virtual Environments**

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### **ABSTRACT**

A useful adjunct to the manned space station would be a self-contained free-flying laboratory (RoboLab.) This laboratory would have a robot operated under telepresence from the space station or ground. Long duration experiments aboard RoboLab could be performed by astronauts or scientists using telepresence to operate equipment and perform experiments. Operating the lab by telepresence would eliminate the need for life support such as food, water and air.

The robot would be capable of motion in three dimensions, have binocular vision TV cameras, and two arms with manipulators to simulate hands. The robot would move along a two-dimensional grid and have a rotating, telescoping periscope section for extension in the third dimension. The remote operator would wear a virtual reality type headset to allow the superposition of computer displays over the real-time video of the lab. The operators would wear exoskeleton type arms to facilitate the movement of objects and equipment operation. The combination of video displays, motion, and the exoskeleton arms would provide a high degree of telepresence, especially for novice users such as scientists doing short-term experiments.

The RoboLab could be resupplied and samples removed on other space shuttle flights. A self-contained RoboLab module would be designed to fit within the cargo bay of the space shuttle. Different modules could be designed for specific applications, i.e., crystal-growing, medicine, life sciences, chemistry, etc.

This paper describes a RoboLab simulation using virtual reality (VR.) VR provides an ideal simulation of telepresence before the actual robot and laboratory modules are constructed. The easy simulation of different telepresence designs will produce a highly optimum design before construction rather than the more expensive and time consuming hardware changes afterwards.

## INTRODUCTION

The RoboLab concept is that of a free-flying laboratory with a telepresence robot operated by a human from the ground or the space station. RoboLab can be considered as part of a complementary space operations triage:

- Work requiring **continuous** human presence — Space Station
- Work requiring **part-time** human presence — Space Shuttle
- Work requiring **no** human presence — RoboLab

RoboLab is complementary to the space station and space shuttle. The space station is ideal to support RoboLab especially when tens or hundreds of labs are linked. Full time astronaut support would then be required to:

- Link new modules
- Reconfigure existing modules
- Enhance modules with new equipment
- Resupply equipment and raw materials
- Harvest finished products
- Repair and maintain modules
- Provide detailed, on-the-spot assessment of unusual problems

RoboLab has been implemented in a software simulation using virtual reality (VR). Simulation has proven very successful in rapid prototyping and testing the feasibility of concepts. In particular, simulation is a valuable tool before hardware is constructed since it is much cheaper to do a software simulation than construct expensive hardware, especially in space.

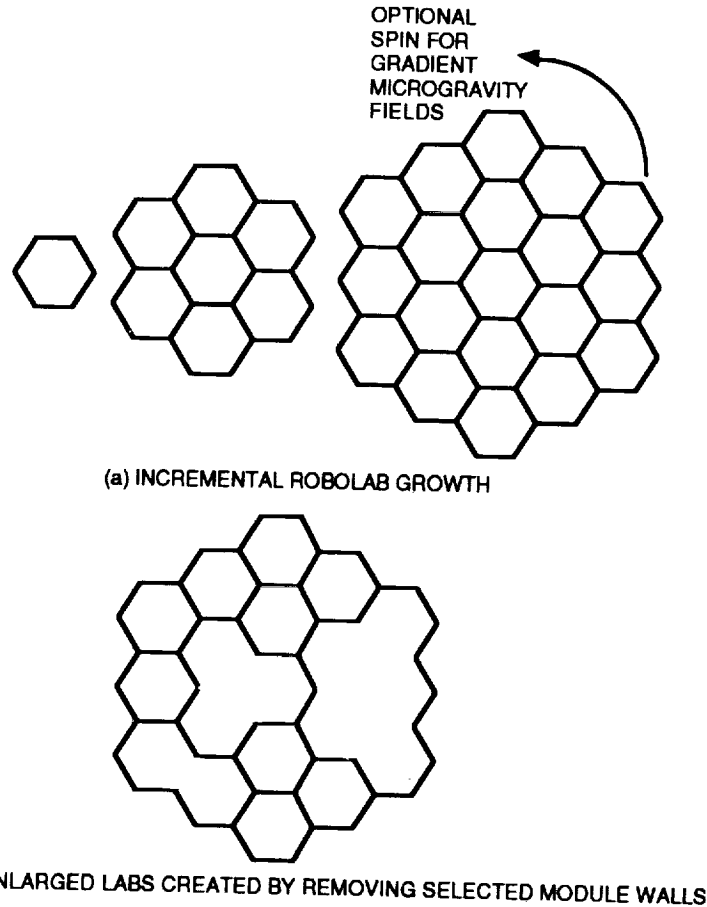
Virtual Reality is a technology that is now being applied to many fields. In common VR systems, the user wears a special helmet which is motion sensitive and provides a 3D-real-time display of a simulated scene. A special glove is worn containing sensors that are sensitive to hand motion. Other types of gloves are available which provide force feedback and other sensations so that the user can "feel" simulated objects and their characteristics such as temperature and texture.

A virtual reality simulation can be used very effectively for testing proof of concept of telepresence in space. The idea of telepresence is to allow a human operator to remotely operate a robot as if the human was present. Telepresence is very useful when the robot must operate in a hostile or dangerous environment. In space, Telepresence is also useful from an economic point of view since an astronaut's time is valued at about \$40,000 an hour.

The telepresence can be performed from earth or the space station. If done on earth, no special training or background as an astronaut would be required. Ordinary scientists and engineers can use RoboLab 24 hours a day from anywhere in the world.

# ROBOLAB EXTERNAL ARCHITECTURE

The RoboLab concept is to provide a low-cost, object-oriented approach to hardware development. The initial goal is to mass produce an economical, self-contained hexagonal laboratory module that can fit within the cargo bay of the space shuttle. Modules from successive flights can be linked together to produce a larger laboratory by incremental growth. Fig. 1 illustrates different configurations of RoboLab as module shells are added.



**FIG. 1**  
**ROBOLAB GROWTH AND OPTIONS**

In Fig. 1, the lab is shown in stages as a complete new outer shell is added. However, the lab is always fully operation even if a shell is not complete. Individual labs may be linked together to provide larger spaces by removing lab walls as desired. Some labs may have zero-g and larger lab spaces, while others have smaller spaces and micro gravity. Of course, if the lab spaces are made symmetric with regard to the center of mass, then these larger labs can be spun as illustrated in Fig. 1.

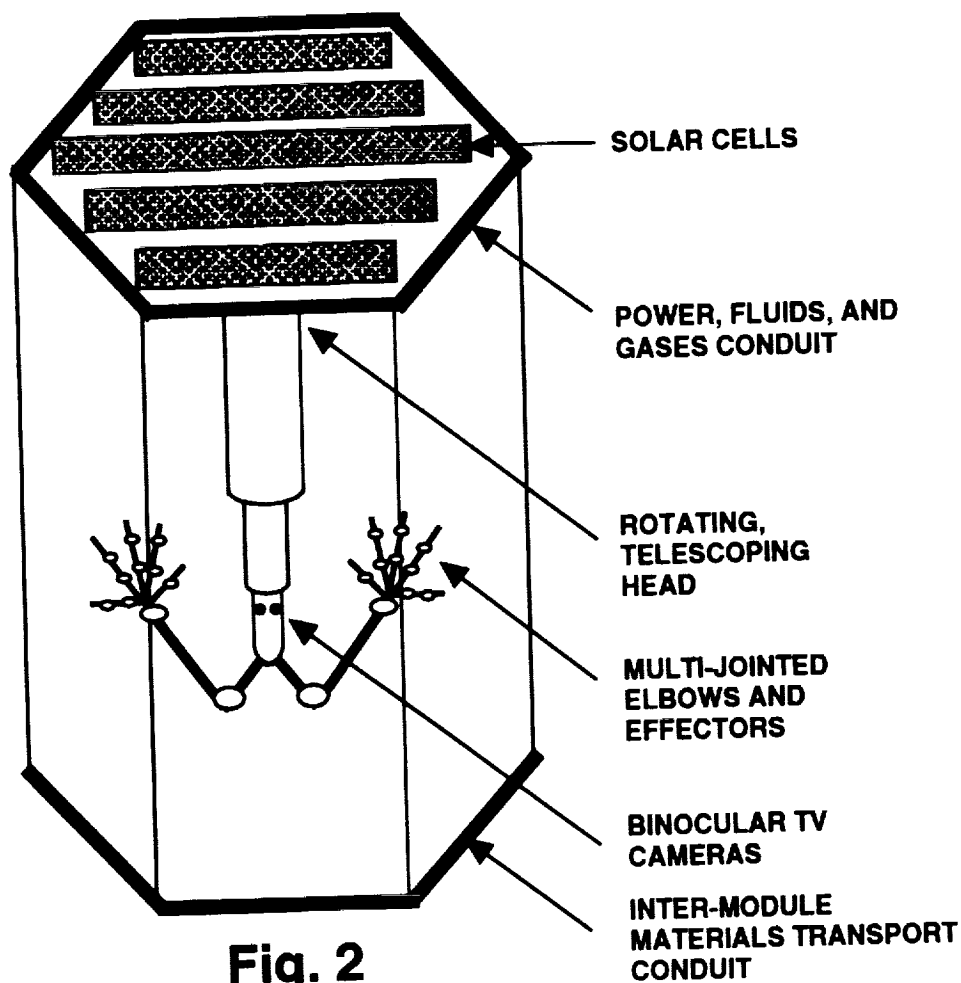
The main advantage of a complete shell is spinning the lab to set up a microgravity gradient. If a shell is not complete, the center of mass will not be at the center and it will be more difficult to stabilize the lab. A hexagonal shape was chosen for each lab to

facilitate incremental growth, i.e., the beehive pattern. This hexagonal shape allows easy locking of new modules and a quasi-circular shape as new shells are added. The quasi-circular, pancake shape makes it easier to spin the lab in a stable way.

Astronauts will bring new modules, link them together, enhance capabilities by replacing old equipment, perform maintenance, bring supplies, and return finished products, e.g. crystals, materials, and medical drugs, back to earth or to the space station. All modules are prewired and designed to quickly snap together. Special purpose modules may be designed for human life support.

## ROBOLAB INTERNAL ARCHITECTURE

RoboLab is a facility in which operations are performed by the telepresence robots. Fig. 2 illustrates an individual module showing the robot. The goal is to provide a user-friendly telepresence system that anyone can use after minimal instruction.



**Fig. 2**  
**ROBOLAB MODULE**

The RoboLab walls are attached to a frame consisting of hollow girders containing utility conduits for power, fluids, and gases, e.g., air and water. Utilities are routed by power, fluid, and gas switches from one module to another through these ceiling utility conduits. Special modules may serve as supply depots for utilities such as fluids and gases.

As more modules are connected, the available solar power to RoboLab increases. The aggregation of this power comprises a solar power grid. Electricity from the grid may be routed on demand to those module which need more than their individual panels can provide. An active power switching system routes power from modules which need less to those which need more via the power conduits. The active power switch resides in the ceiling of each module to siphon off the required power.

The hollow girders of the floor contain an electric powered "subway" transfer system to shuttle materials from one module to another. Coffee-can sized containers can be transported on the subway train to any other module. Semi-processed materials can be transferred to other modules for finishing. Finished products can be transported to a special linear accelerator module for launch to Earth or the space station.

## **TELEPRESENCE ROBOT**

The telepresence robot has two TV cameras that provide 3D binocular vision to the remote operator. The robot arms and end-effectors are designed to emulate operation of the normal human arms and hands. Tactile feedback will be provided so that the remote human operator will feel pressure, vibration, texture, and temperature. This means that the users will be more comfortable, require less training, and be less likely to make mistakes. This is particularly important since if someone makes a mistake, it may be very difficult to correct since the lab is in space.

Modules may be designed to work independently or in cooperation. As an example of cooperative work would be a series of module designed to produce high quality crystals or integrated circuit chips. In the zero-g and ultra low contamination environment of the RoboLab, it would be routine to produce chips with zero defects. This is particularly important as demand for larger size computer memory grows, especially for chips of gigabyte capacities which are currently not available on earth.

One module may be a stockroom that supplies selected chemicals to a chemical lab module where the chemicals are mixed in correct proportions. This module transfers the mixtures or single elements to a crystal growth module with a furnace. After the crystal is grown it is transferred to a processing module for additional doping. The finished crystal is then transferred to a module which slices and dices the wafer. Next a module packages each die into a chip for testing. Finally a module acts as a storeroom for the completed chips until pickup by astronauts.

## **VIRTUAL REALITY SIMULATION**

The RoboLab virtual reality simulation was developed using special purpose hardware and software. The system I/O components include a Spatial Tracking System and the Data Acquisition and Transmission Unit. The Data Acquisition and

Transmission Unit includes the VPL EyePhone Model 2 head mounted display and the DataGlove Model 2 hand input device.

The DataGlove is an input device that converts hand motions and flexation into computer readable form. The EyePhone is a stereo color computer display system. Left and right liquid crystal screens show each eye a video image from a slightly different point of view so that the user sees objects in three dimensions.

The EyePhone's headphones provide audio feedback from the virtual reality and the optional AudioSphere System provides three-dimensional real-time sound rendering. The Convolvotron spatializes sounds generated by a MIDI synthesizer.

The image rendering components consists of two Silicon Graphics PowerSeries workstations which run an in-house developed (NASA/JSC Software Technology Branch Lab) real-time rendering package. This is a C program to read data from the Spatial Tracking System, the DataGlove, and simulate the virtual environment in real time by rendering the image and displaying it in the EyePhone head-mounted display.

The software consists of the Solid Surface Modeler for solid-shaded and wireframe 3D geometric modeling. It is used to develop the objects that comprise the virtual environment. The Tree Display Manager is a graphics visualization tool which uses a hierarchical representation of the 3D models created with the Solid Surface Modeler to give structure to the virtual environment.

At runtime, the data acquisition components collect real world information about the user's position and actions. For instance, the DataGlove measures movements in the finger joints while the Spatial Tracking System monitors the head and hands positions and orientation in the real world 3D space.

## **LONG DURATION LIFE SCIENCE STUDY**

One question that has been investigated since the beginning of the space program is — What are the long-term effects of space on living organisms? This question is particularly important as we plan for long duration space flights such as the Mars mission, in-orbit missions such as the space station, and a lunar settlement.

The RoboLab Life Sciences (LS) module is designed to provide some answers to this question. LS is a complete closed ecosystem having plants and animals. The plants are grown using hydroponics gardening and are the food source of the animals. *In-vivo* testing of the animals is performed by the robot which also functions as the gardener of the plants. Through telepresence, the robot plants seeds, fertilizes, and harvests the plants. The produce is fed to the animals. Through blood tests, cell cultures, and a variety of other tests, the health of the animals is determined. The animals will be allowed to breed and most of their progeny will be returned to earth for further testing and studies. However, offspring from each generation will also be kept in LS to observe the long-term effects of space on successive generations.

The plants are chosen for their ease of growth and harvesting. Also, they will provide a valuable source of fresh produce for astronauts in long duration space shuttle flights or on the space station. The initial plants will be lettuce, tomatoes, cucumbers, radishes, peppers, and a variety of herbs. This will allow astronauts to enjoy fresh salads in space. The animals will include rabbits, hamsters, and gerbils. The space-born animals and plant seeds will be returned to earth for testing and then given away by lottery to schoolchildren to raise.

This program imitates the immensely successful tomato seed program in which schoolchildren across the country learned science in an exciting way by raising tomato plants from seeds left up in space for years. The "Astrobunny" program will be even more popular among schoolchildren since these are living creatures. Fig. 3 shows a black and white image of a small RoboLab complex of several lab modules. The actual simulation is in color. The VR hand allows the user to "fly" around in the environment.

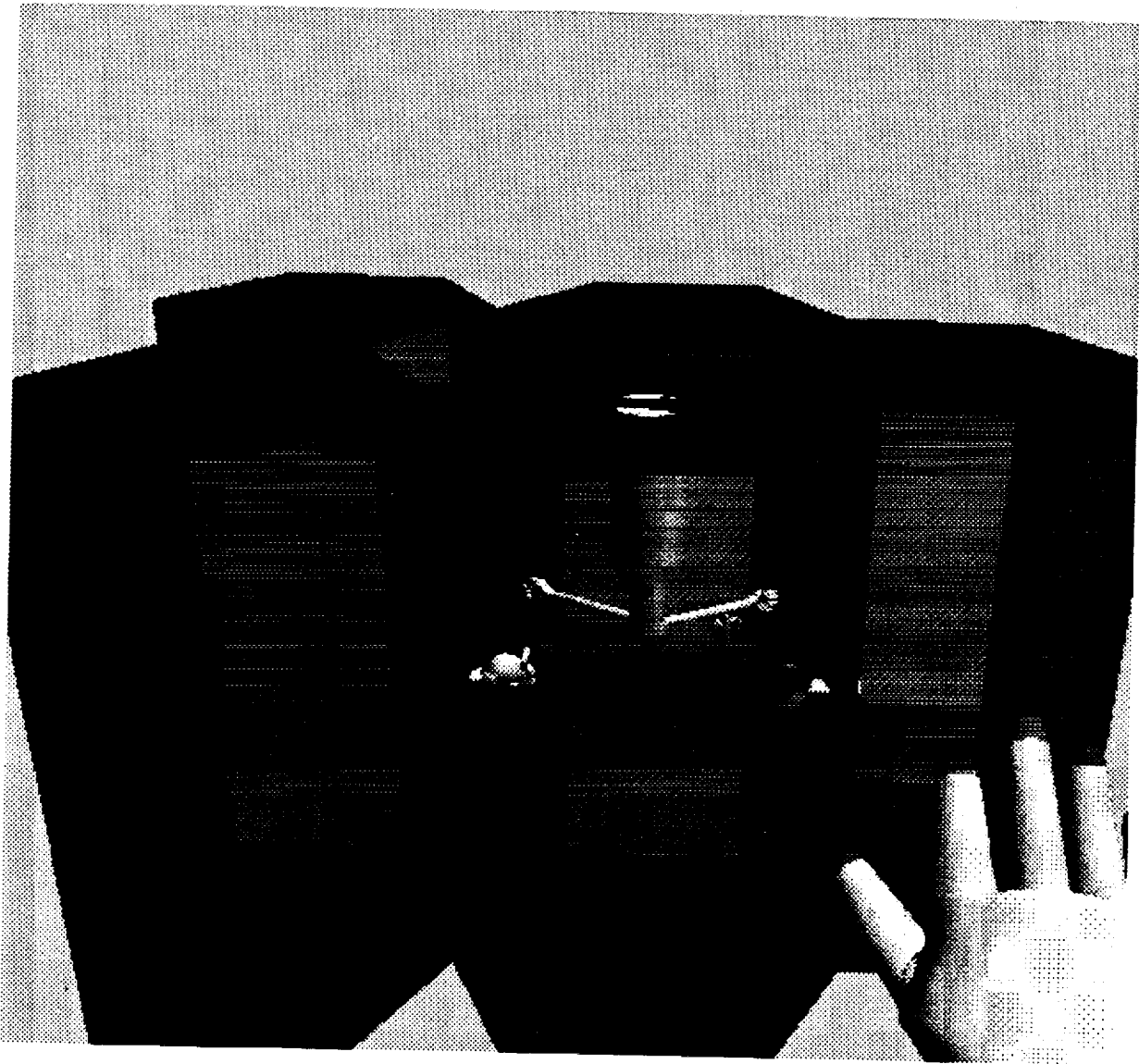


Fig. 3 External View of Several RoboLab Modules in Virtual Reality

Fig. 4 shows an internal view of the Long Duration Life Sciences module. Simulated plants include carrots, lettuce, and tomatoes. Astrobunny is also simulated.

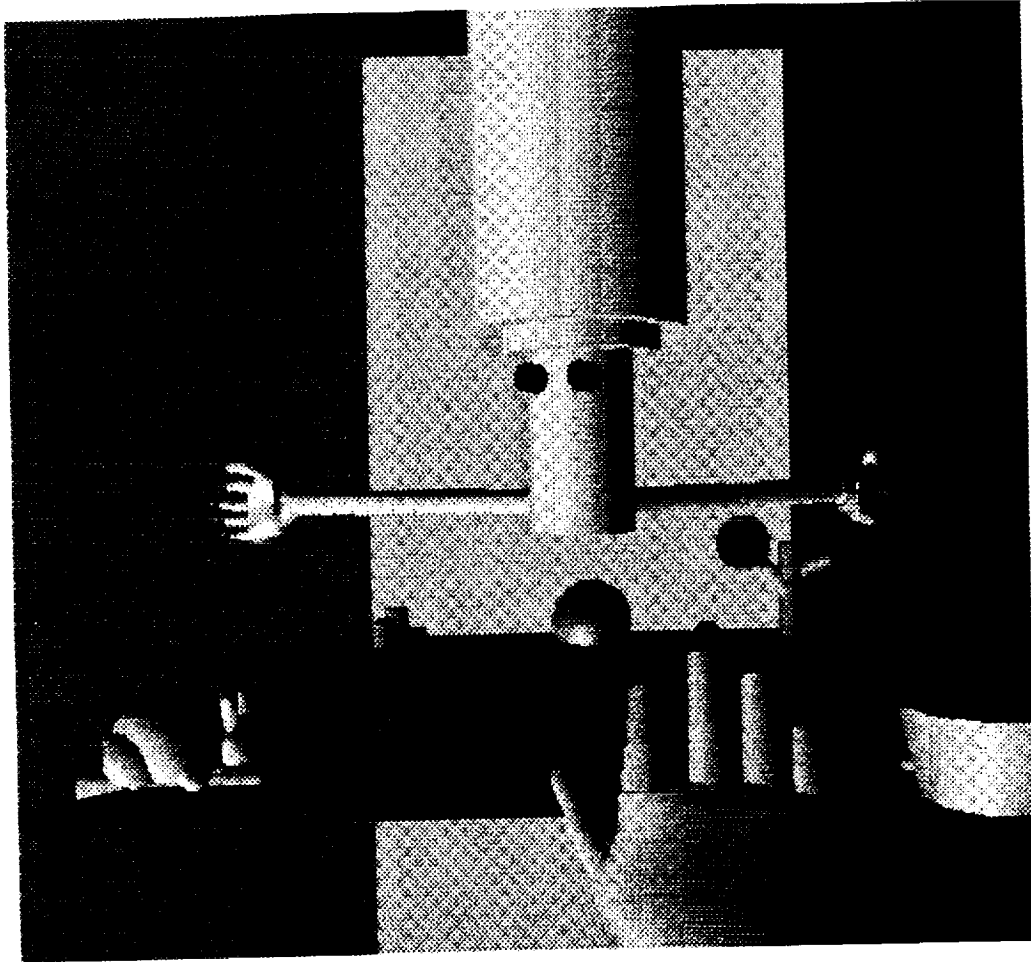


Fig. 4 Internal View of the Long Duration Life Sciences RoboLab

Future plans involve enhancing the RoboLab concept, and adding more modules. As more VR hardware becomes available, we will be able to simulate cooperative RoboLab modules working on joint projects such as semiconductor crystal growing and fabrication. We also plan to develop a RoboLab VR toolkit to facilitate simulation.



**Session R5: REMOTE INTERACTION WITH  
PHYSICAL SYSTEMS**

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**Session Chair: Mr. Joe Herndon**



# DEVELOPMENT AND DEMONSTRATION OF A TELEROBOTIC EXCAVATION SYSTEM\*

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