3.2 Human Machine Cooperative Telerobotics

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ABSTRACT

A promising way to achieve increased D&D remote worksystem efficiency (which will reduce costs) is to layer telerobotic technologies onto teleoperated remote systems. The research being reported here enables the teleoperation baseline to be supplemented with operator-selective telerobotic modes of operation that allow computer-assist functions, or subtask automation, to be interspersed within the remote operations. Computer-assist functions are augmentative control functions that allow the manipulator operator to more skillfully track lines, planar surfaces, curved surfaces and virtually any surface geometry in presence of force disturbances. Automatic performance of subtasks that are either repetitive, require high precision, or involve extreme patience will decrease task time and enhance work quality. The final stage of this project is focused on integrating these capabilities into a practical telerobot that can be used in actual D&D operations. A major subsystem is the Robot Task Space Analyzer (RSTA), a tool that combines infrared laser and visible stereo imaging, human-interactive modeling and computer-based object recognition to build 3-D models of the immediate work zone in which a robot system is operating. Ultimately, this model will be used by the telerobot control system in automatic collision checking and motion planning routines so that some aspects of the remote tasks can be performed robotically. This paper presents the hardware and software design of the human-machine cooperative telerobot system. Plans for full-scale testing in DOE facilities are summarized.

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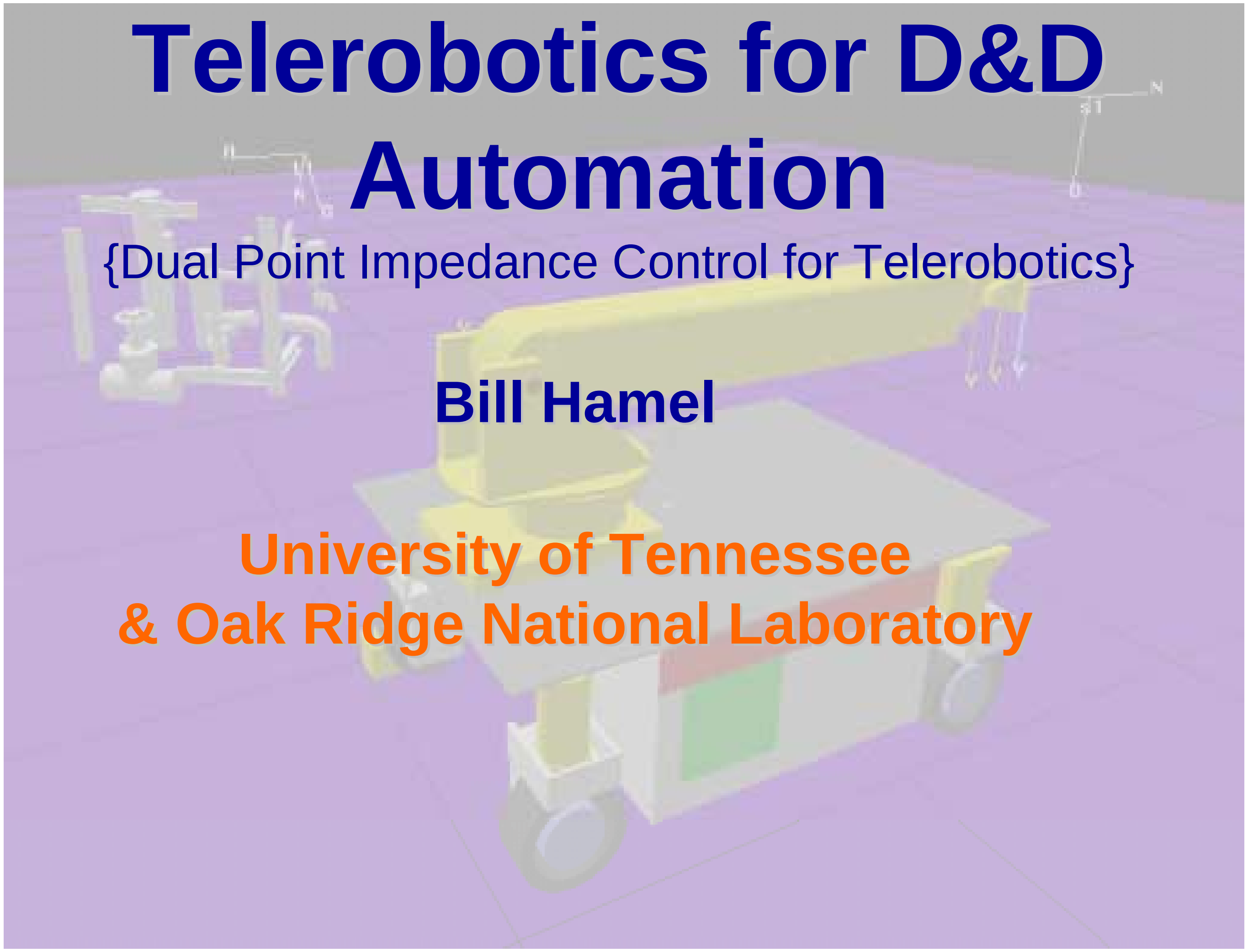
Telerobotics for D&D Automation

{Dual Point Impedance Control for Telerobotics}



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D&D Telerobotics Team

University of Tennessee	**Bill Hamel** Reid Kress	**Sewoong Kim** **Ge Zhang** **Pamela Murray**
Unversity of South Florida	**Rajiv Dubey**	**2 new students**

NETC COR	**Vijay Kothari**
DDFA	**Bob Bedick, Dr. Paul Hart**
ORNL	**Mark Noakes** **Dennis Haley**

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Better Remote Operations are Needed

- **Context**
  - **Facility deactivation & decommissioning: (D&D); decontamination, dismantlement**
  - **Tanks; remote operational enhancement of riser pits**
- **Baseline = remote operations via teleoperation.**
- **Remote operations are slow and costly.**
- **Improvements needed to increase remote work efficiency and reduce costs.**

Better = Increased remote work efficiency…

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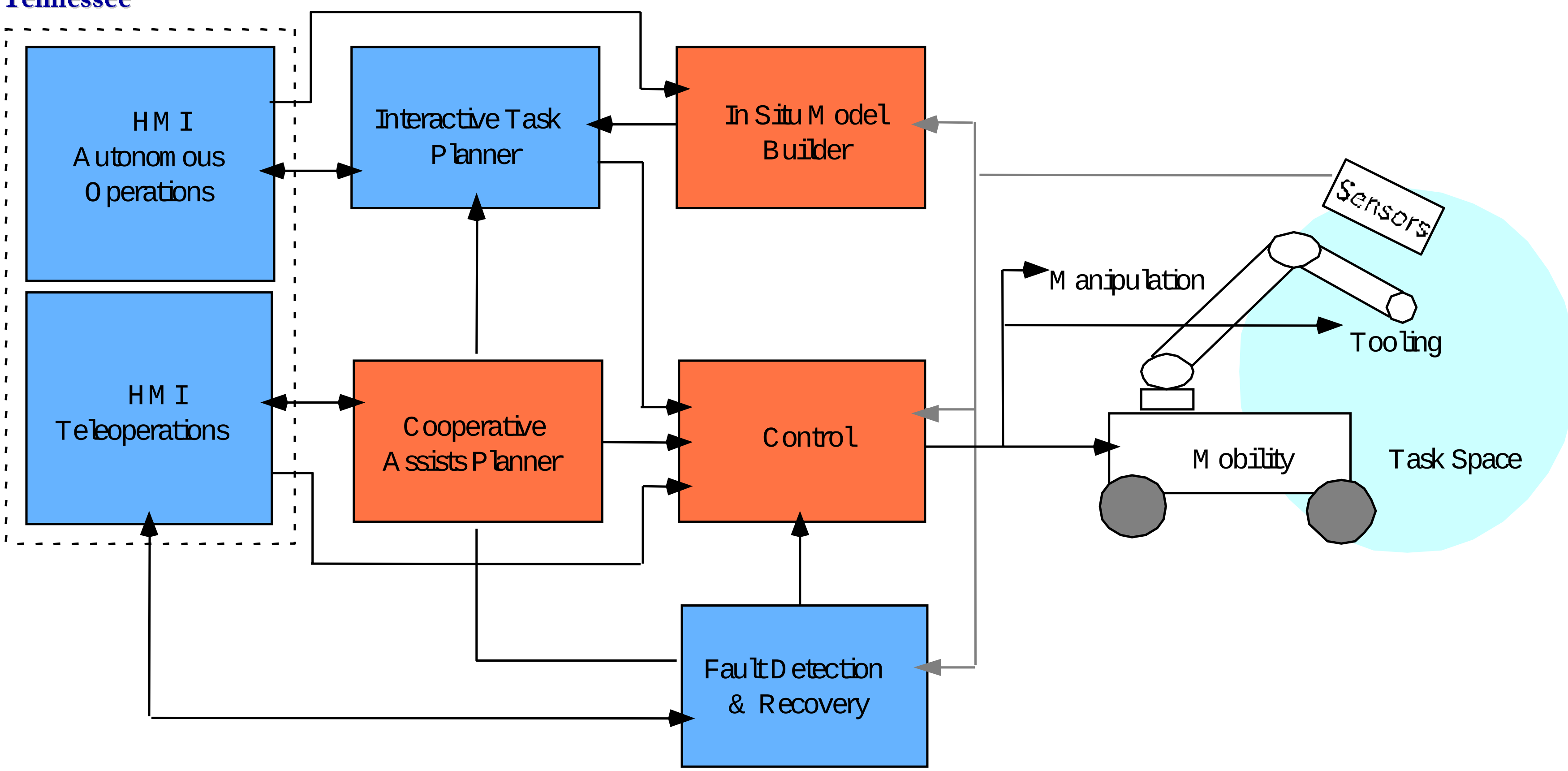
- **Enhanced teleoperations.**
  - **more effective human-machine interfaces.**
  - ***computer-based operator assists.* better teleoperators.**
- **"Integrated" subtask automation.**
  - **faster execution with fewer errors for some subtasks.**
  - **requires *in-situ programming* and/or sensor-based control of the telerobot.**

Telerobotics = Teleoperations ≈ Robotics

- **Human interaction**
- **Unstructured task environment**
- **Hazardous conditions**
- **Remote locations**
- **System:**
  - **Mobility**
  - **Manipulation**
  - **Tools**
  - **Useful work**

The "Ultimate" Telerobot



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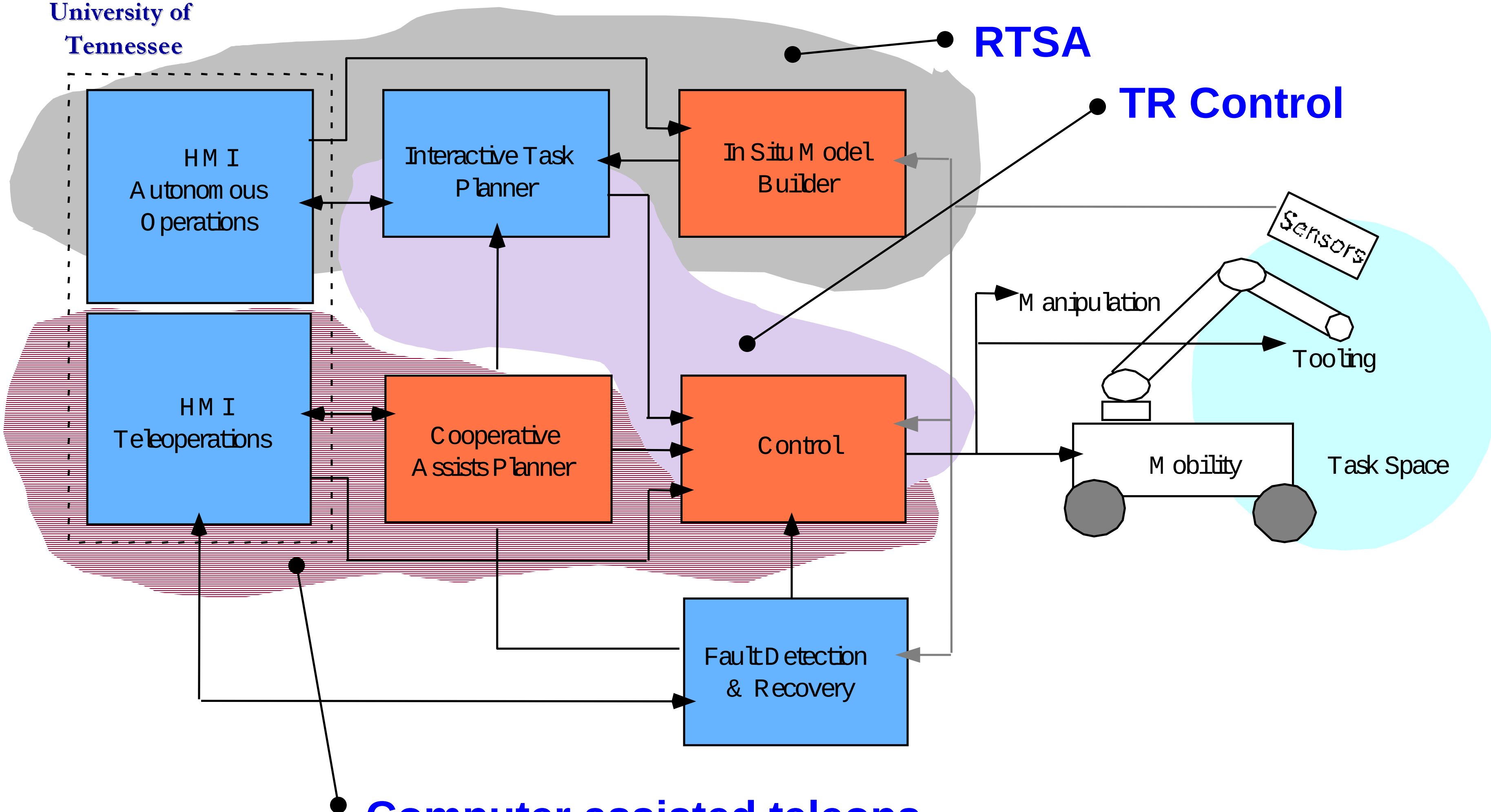
The "Ultimate" Telerobot



Telerobotic modes must be fast and simple...

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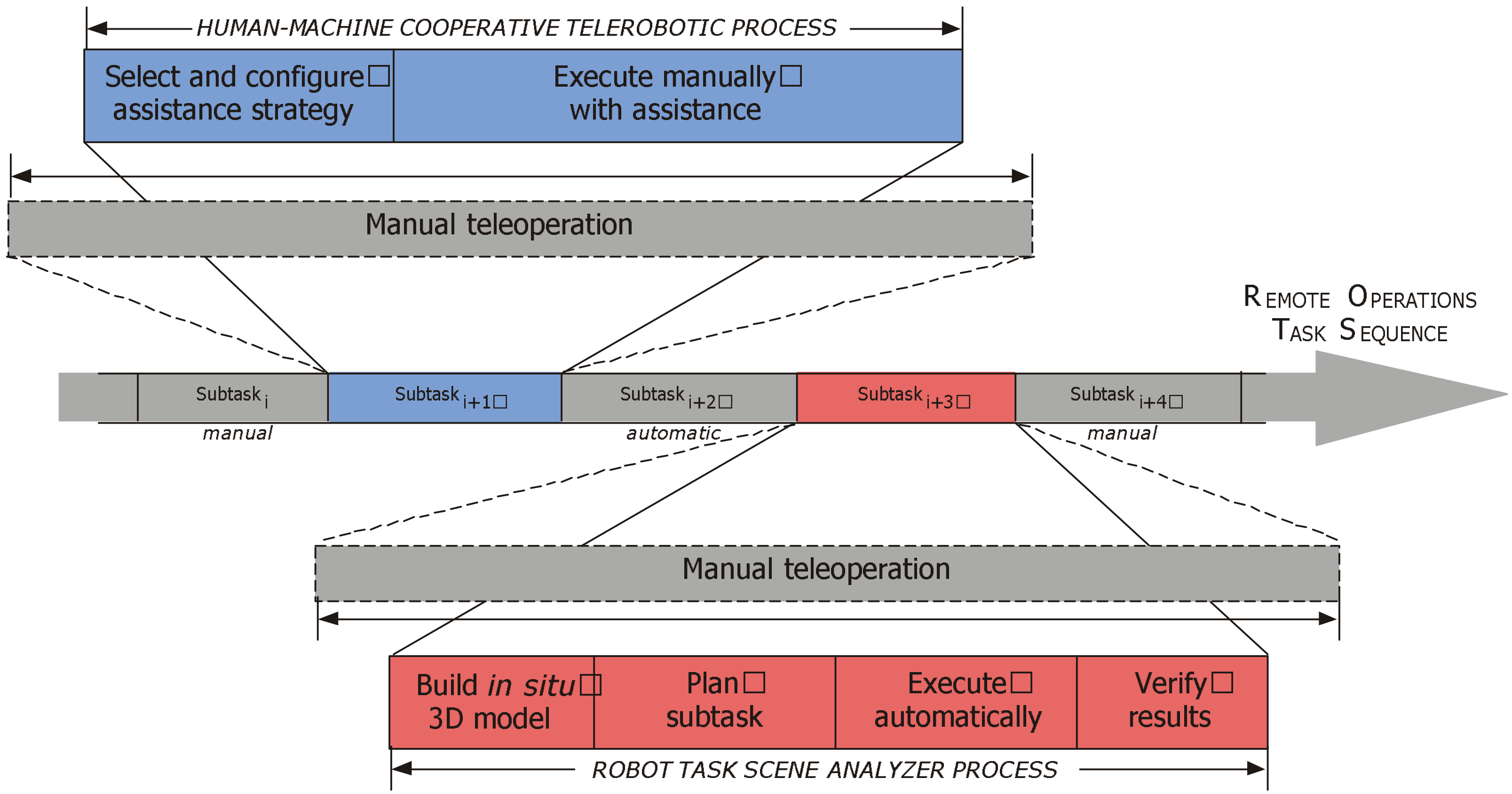

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RTSA…enabling stepping stone to automation

- ***Subtask automation requires 3D geometrical representations of the work area.***

- **RTSA generates 3D model of the *"task space"***
  - **software analyzes data from imaging sensors**
  - **automatic modules & interactive modules work in parallel**
  - **human interactivity mitigates geometric complexity**
  - **simple operator interface promotes speed**

- **RTSA results passed to robot controllers**
  - **facilitates automation of selected subtasks**
  - **incorporates telerobotic operational layer**
  - **decreases subtask execution time…time is $.**
  - **may improve safety and quality**

Task Space Concept

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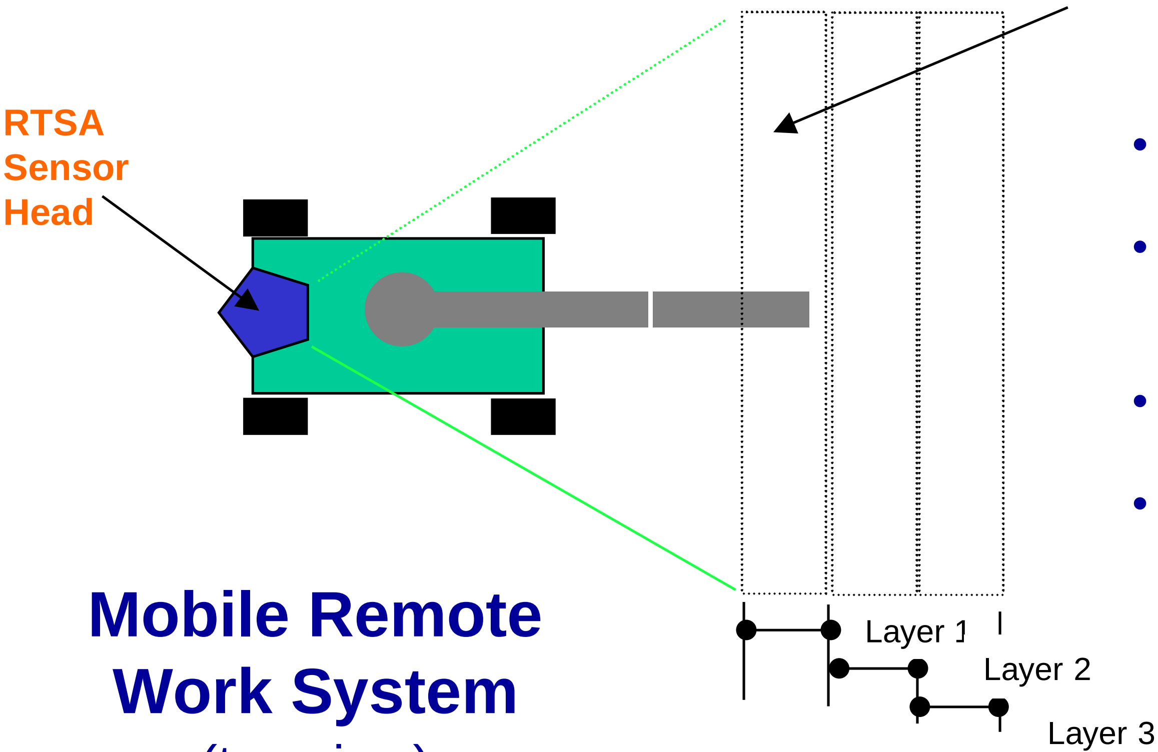

Mobile Remote Work System

(top view)

***Each task space region*:**

- **Layer size defined by work system reach and tools.**
- **Layers are like "onion" layers**
- **Layers "worked" without major mobile robot repositioning**
- **Active task models in one layer only**
- **Task space modeling results in robot coordinates**

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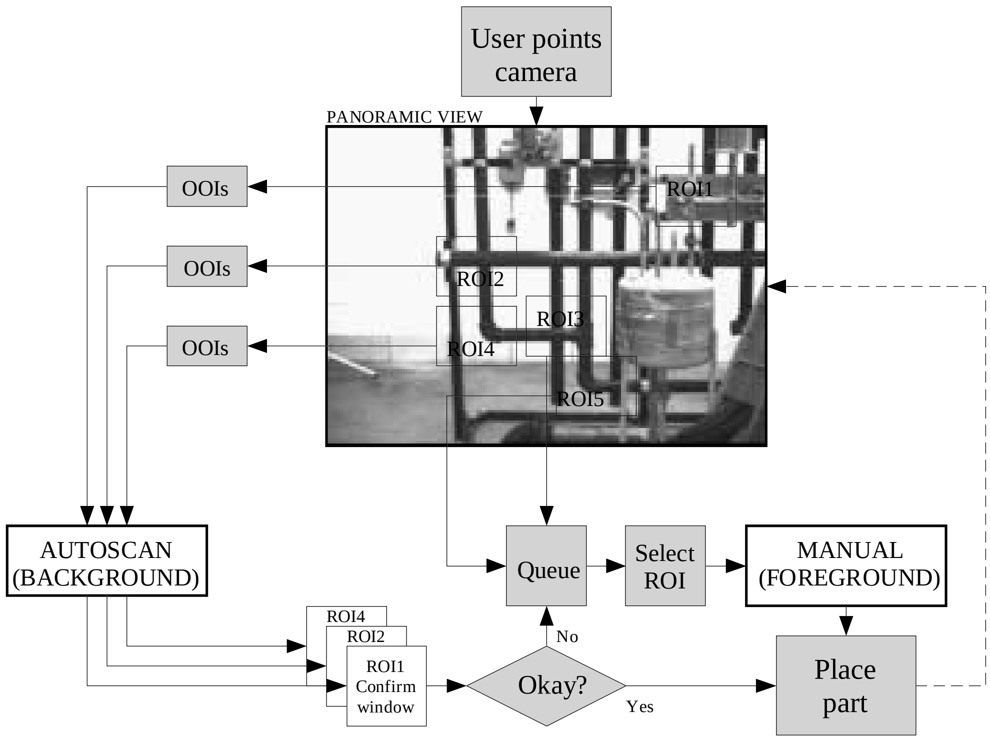
Operator interactivity assures robustness…

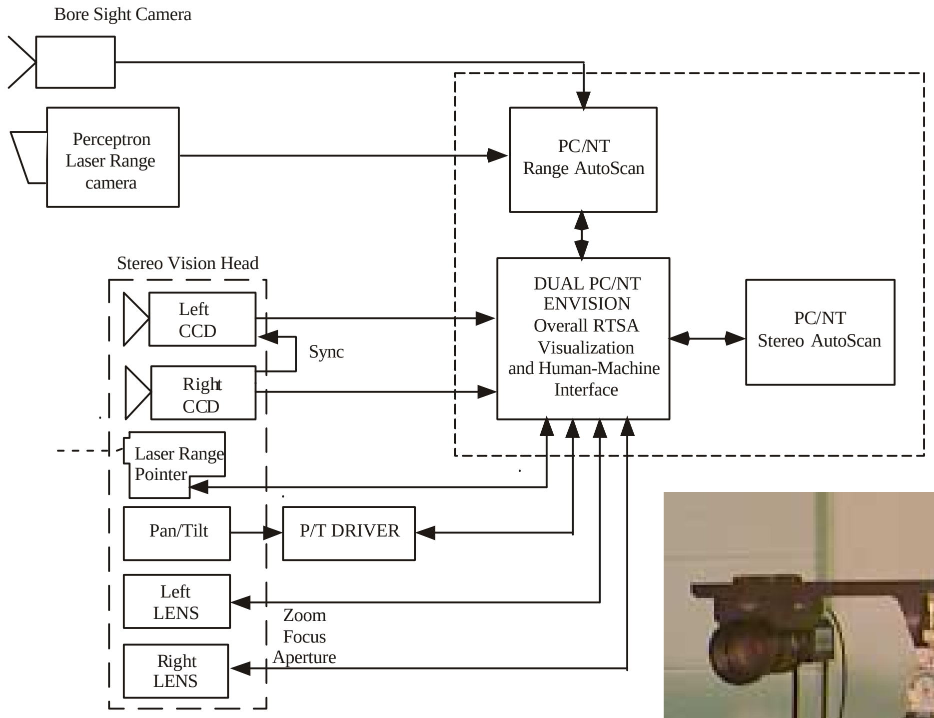
- Use a priori scene knowledge.
  - standard process, equipment component, structural materials models.
  - standard sizes and shapes.
  - expandable libraries.
- Human-based object “specification.”
- Human-based RTSA FG/BG delegation.
- Human-based fine tuning (position & orientation).
- “Peel onion layers” ⇨ “small” area of interest.

RTSA Functional Architecture

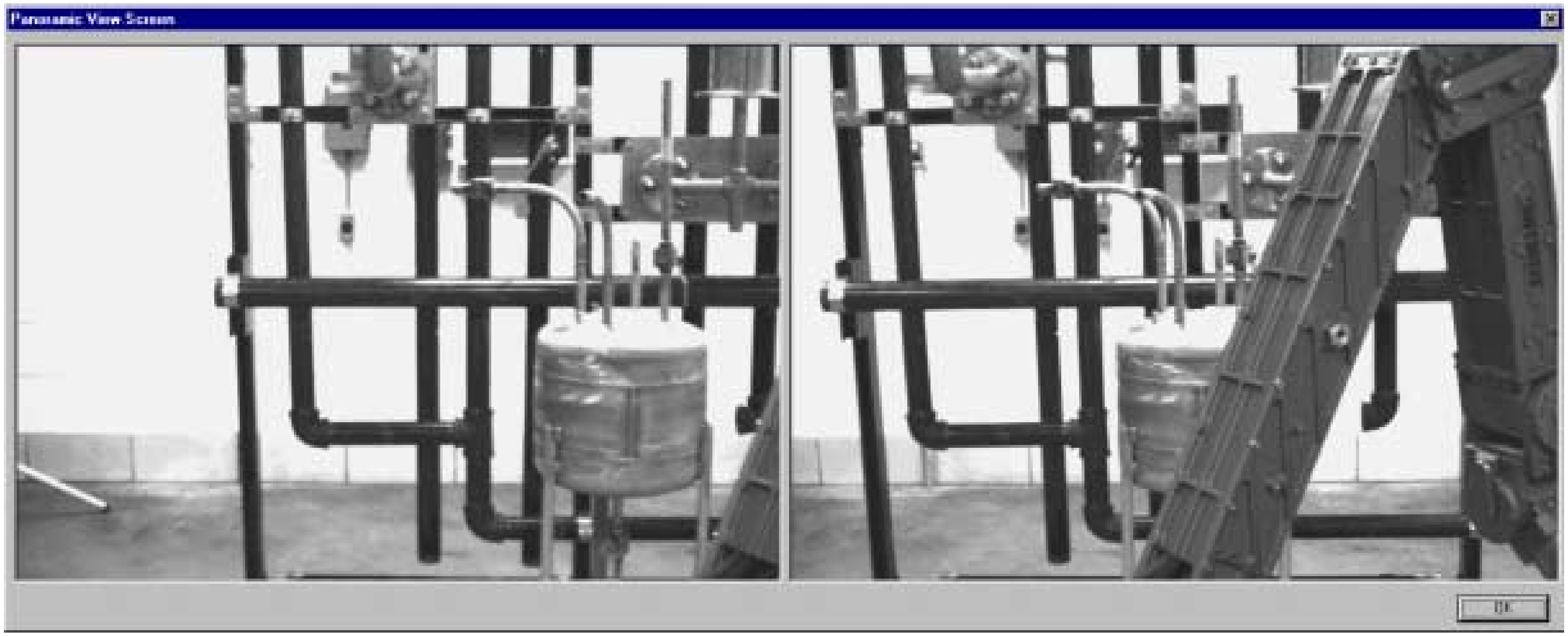
- **Parallel Execution**
  - Manual Foreground.
  - Autonomous Background.
- **Operator Control**
  - Where, what, and how.
  - Acceptance of results.
- **Simplified GUI**
  - 5 pop-up window menus
  - Color overlays



RTSA Hardware



Stereo panoramic view screen



Operator chooses region of scene to be modeled

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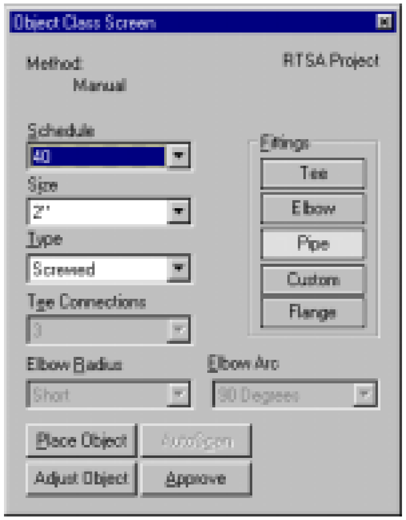
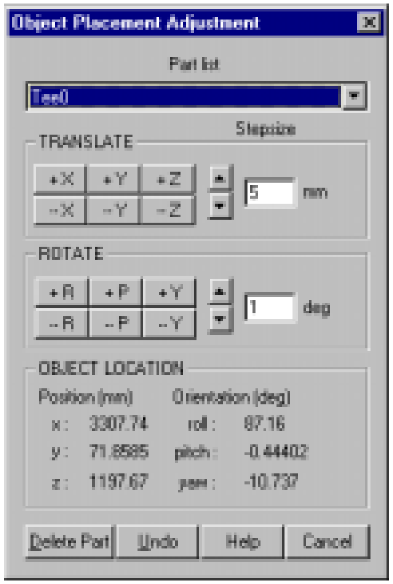
Manual part selection and placement windows



Operator defines object and aims laser range pointer to define X, Θ

Object adjustment windows



Operator accepts and adjusts

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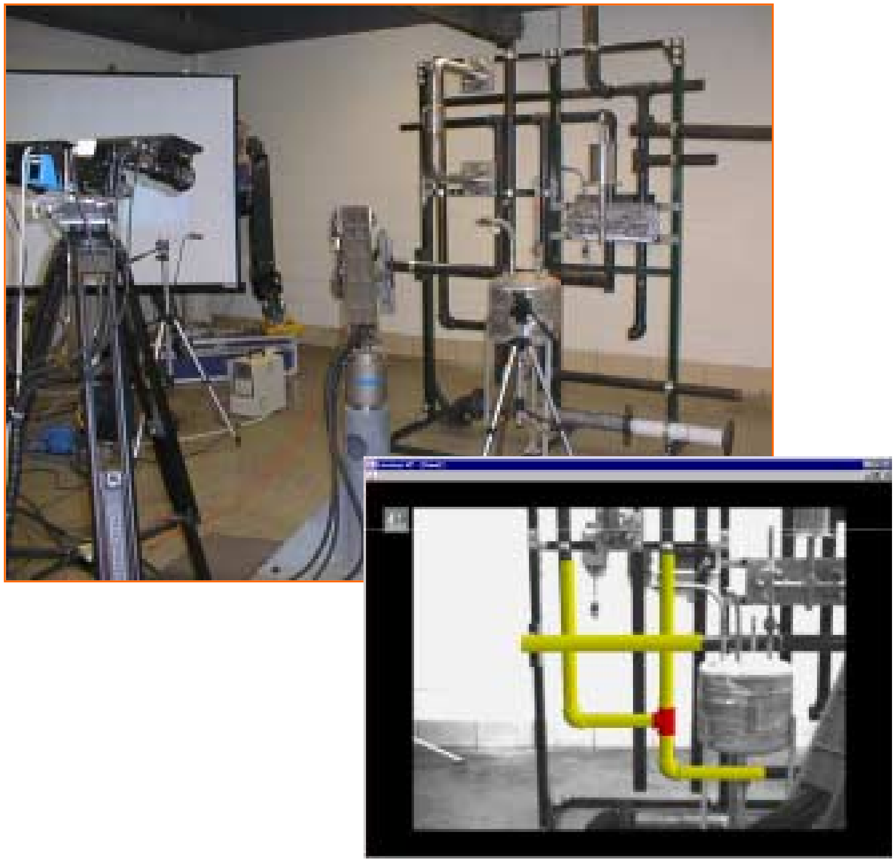
In Situ Modeling Piece…Looks Good!

- **Independent Foreground and Background processing demonstrated**
- **“Inside Teleoperation’s-Cycle” performance achieved…**



- **Manual modeling position error ~ <1% of range (±0.5-1 inches) to object; depends on piping object class (tees<elbows<pipe sections)**
- **Manual model building time is about 4 minutes for study scene.**
- **Position adjustments ok. Orientation adjustments not ok.**
- **Automatic background schemes not as robust or accurate; on the order of 1-10% of range with image analysis times on the order of 2-5 minutes.**

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Point & Click Interactive Task Planning

Cut plane/point

- Point to “action” point
- Swivel approach direction
- Sequence “actions”
- Computer generates script

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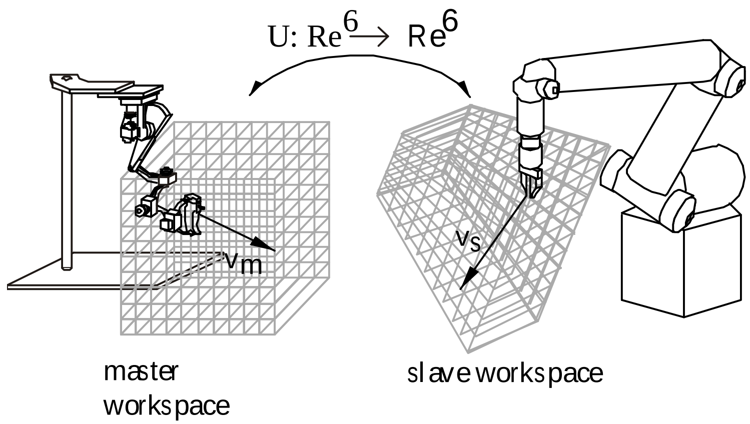
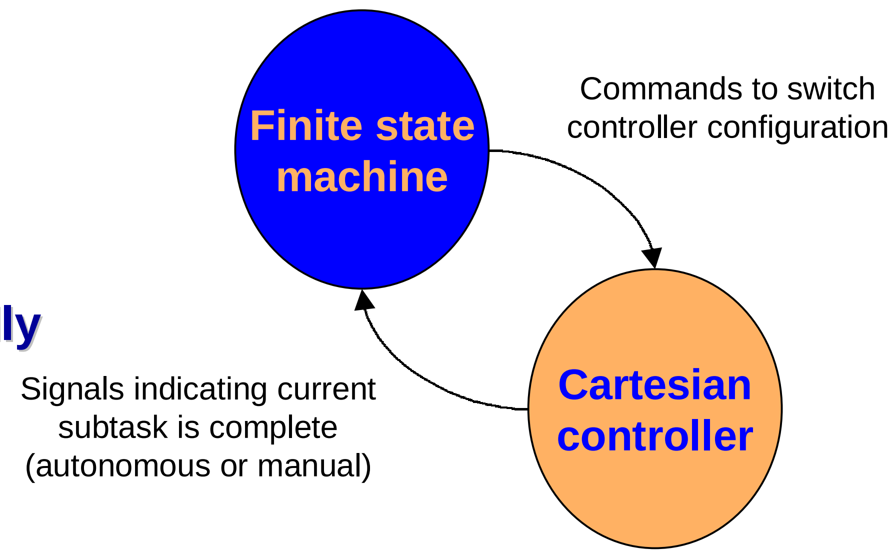
Human Machine Cooperative Telerobotics Concept



- **Assistance configured graphically during task planning and effected by mappings between master velocity and slave velocity**

- **Telerobotic system integrates manual, assisted, and automatically executed tasks**



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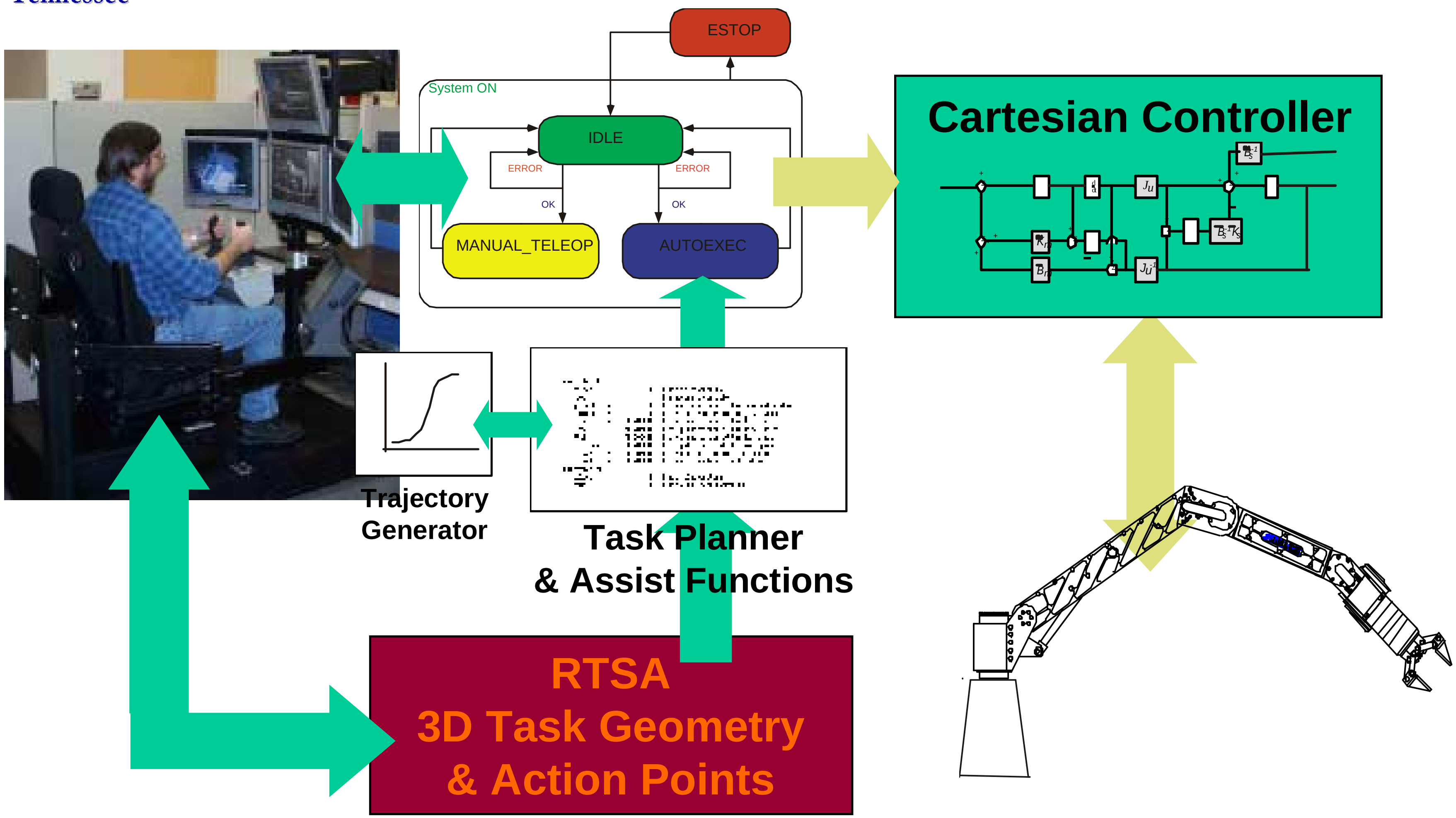
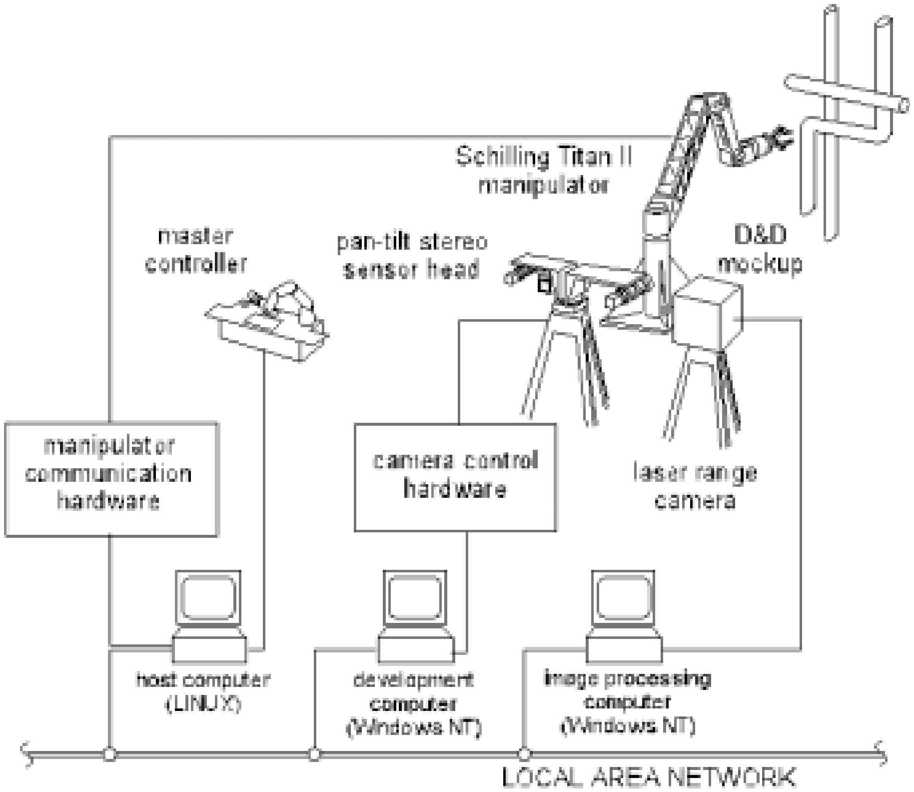
Telerobot Control Structure



δ{Ultimate} Telerobot (RTSA, HMCTR) Network Computer Control Architecture

- **Dedicated NT server for image processing routines**
- **Development NT computer for model builder and task planner**
- **Host LINUX computer for telerobotic controller, ControlShell software, FSM**
  - **Provides ability to interleave teleoperation and autonomous subtask execution**



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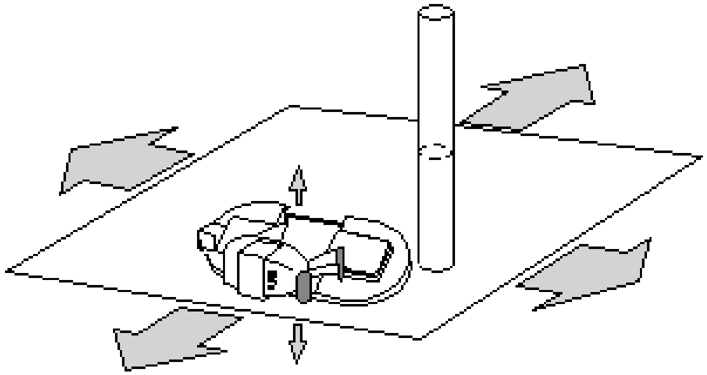
Computer Assistance Functions

- **Virtual fixtures - linear, planar, other**
  - *Application: drilling and sawing constraints*
- **Variable velocity mapping - avoidance, approach**
  - *Application: initial alignment with bolt heads*
- **Workspace warping (nonlinear position mapping)**
  - *Application: wall following for scarifying or inspection*
- **On-line impedance adjustment (in progress)**
  - *Application: reduction of unintended impact forces*
- **Force reduction or amplification**
  - *Application: reduction of operator fatigue*

“Geometry” Constraints

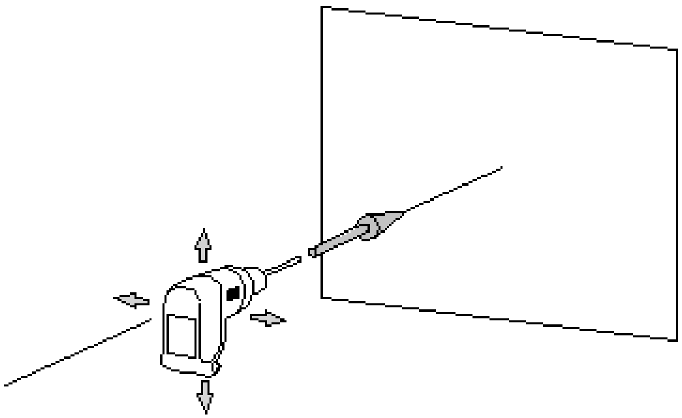


Planar Constraint

- Constrains band saw to desired plane
- Allows minimal movement out of plane

Linear Constraint

- Constrains drill to desired line
- Allows minimal movement in perpendicular directions



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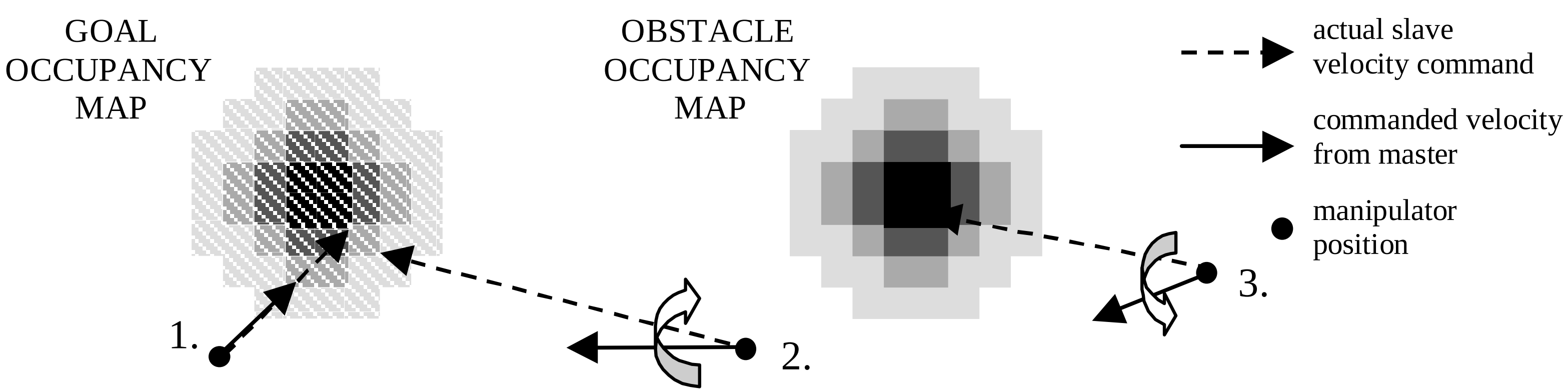
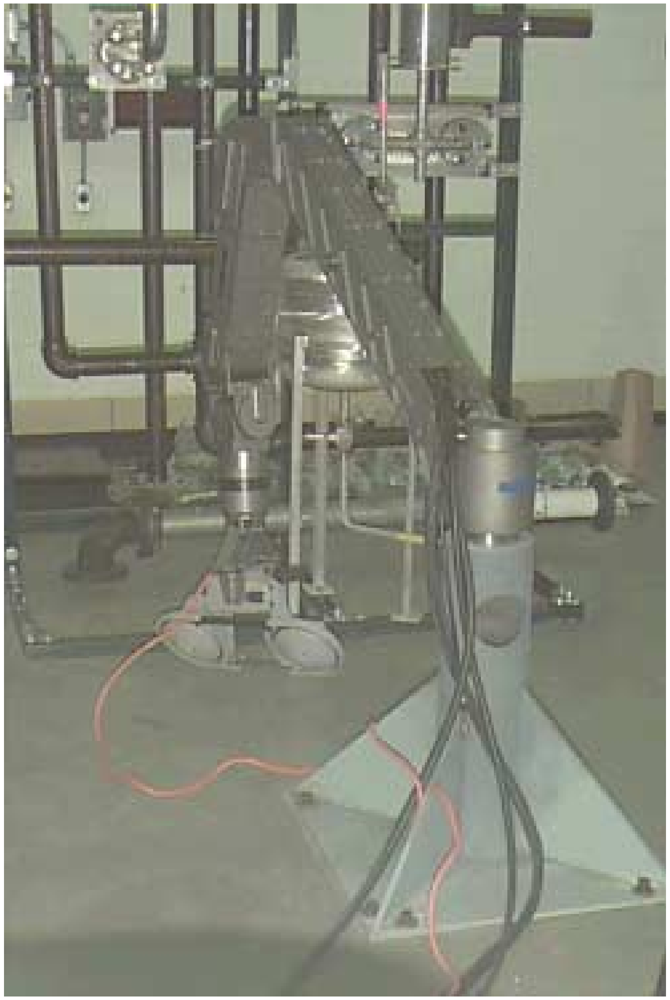
Variable Velocity Mapping - Approach/Avoidance of Task Objects



1. Close proximity to goal: reduce speed maintain commanded direction	2. Distant from goal: increase speed rotate direction toward goal	3. Close proximity to obstacle: reduce speed rotate direction away from obstacle

Uses RTSA results or other geometry data

Summary



- **General Telerobotic automation ~ (1/01-5/01) @ UTK.**
  - **RTSA, HMCTR, Titan II**
  - **Auto removal of pipe section**
- **Future Steps**
  - **Full-scale Testing at ORNL RTAF ~ (6/01)**
  - **Dual-Arm Telerobot**
    - Fully integrated (h/w & s/w) system
    - Prototypical HMI, Refine GUI
  - **Detailed performance evaluations**
  - **Commercialization**
  - **“Inform” Users**

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Back Up Slides

Technology Roadmap Progress

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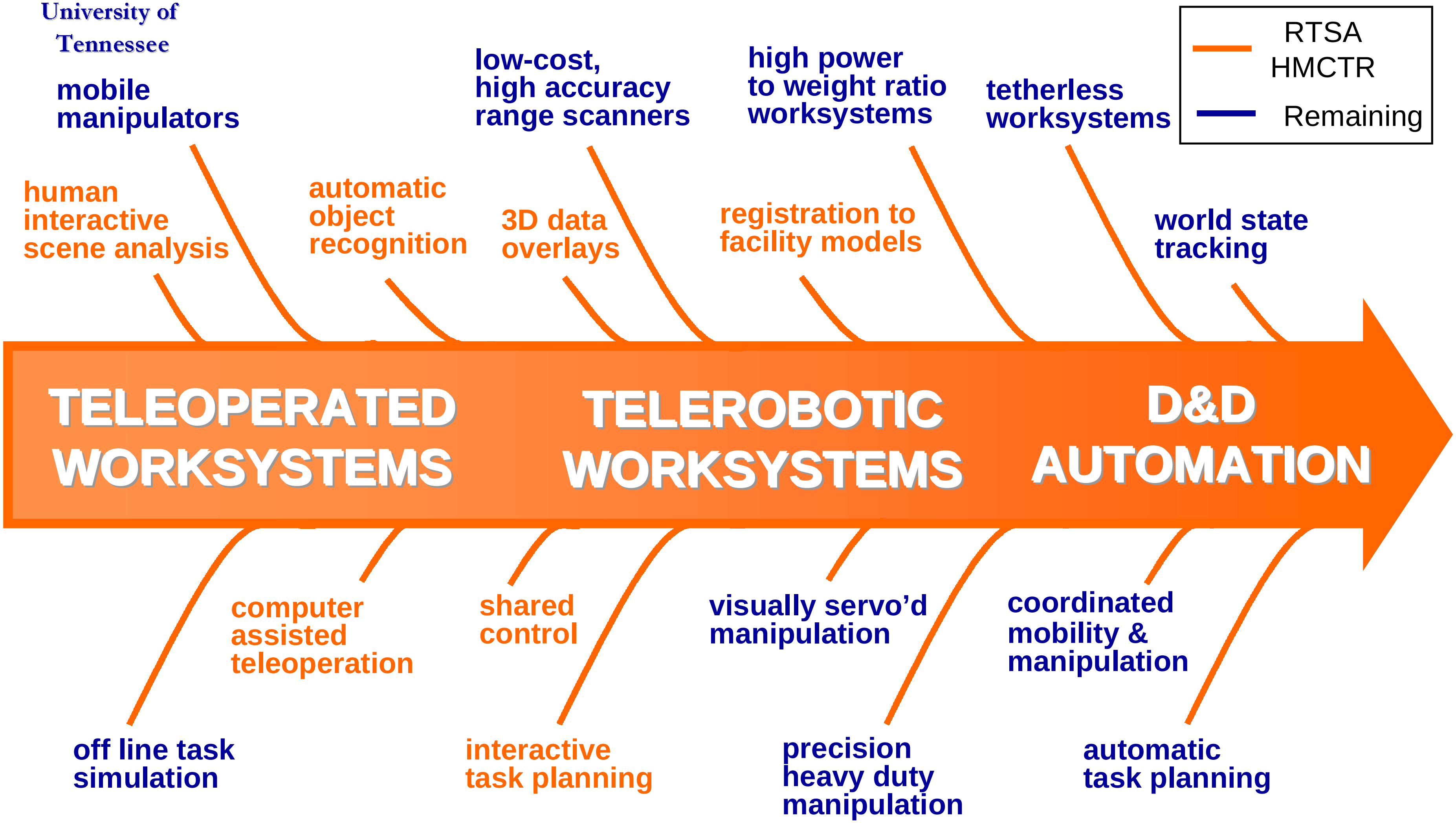

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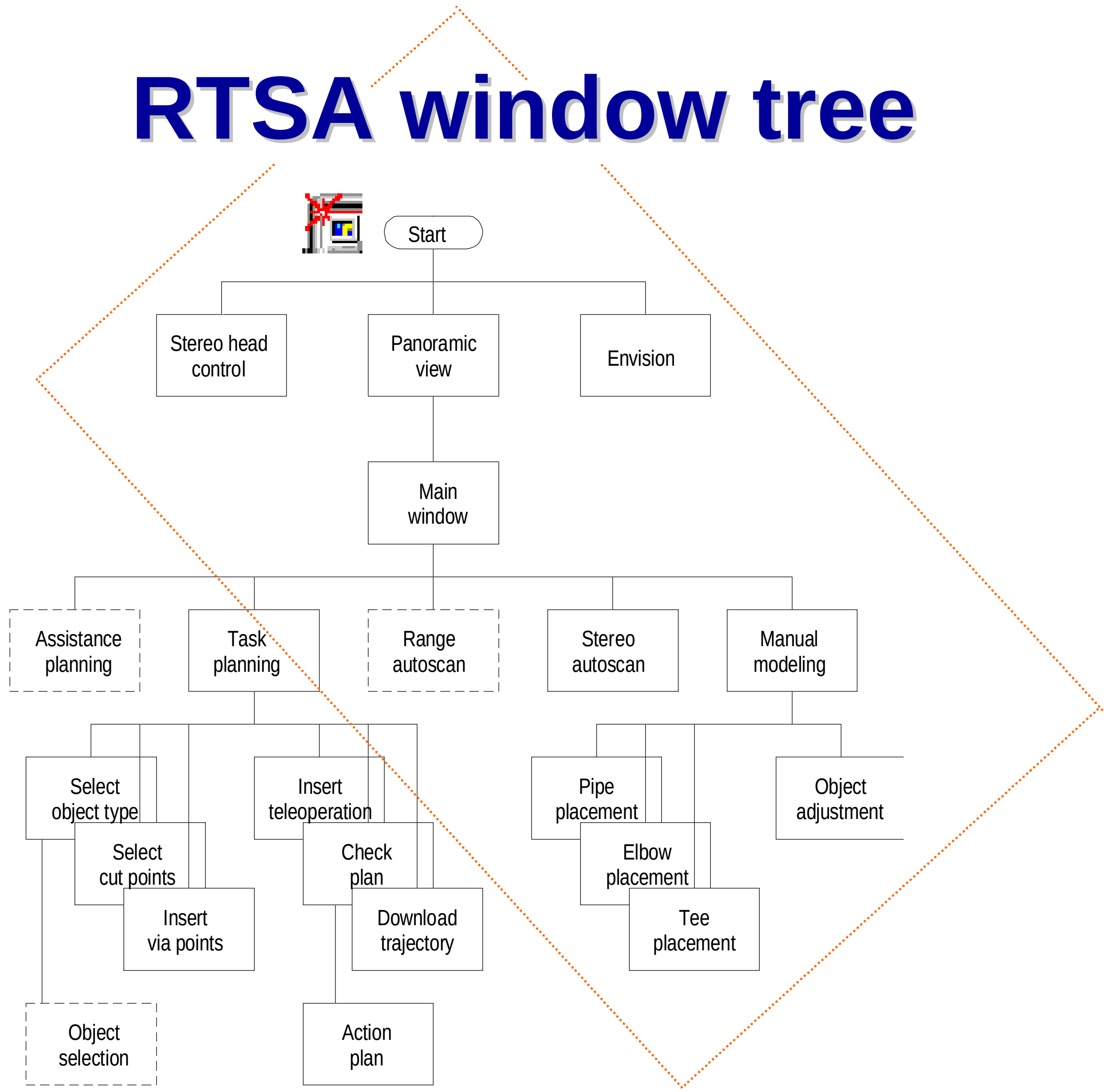
Finite State Machine

- Adding task-planned control to teleoperation improves the speed and accuracy of the telerobotic system.
- Discrete nature of the task planner requires the system to behave as a discrete event dynamic system.
- The planned tasks are characterized as discrete event system and modeled as a Finite System Machine.
- Finite State Machine is high lever discrete controller between the task planner and the lower level continuous controller of the manipulator.

RTSA window tree



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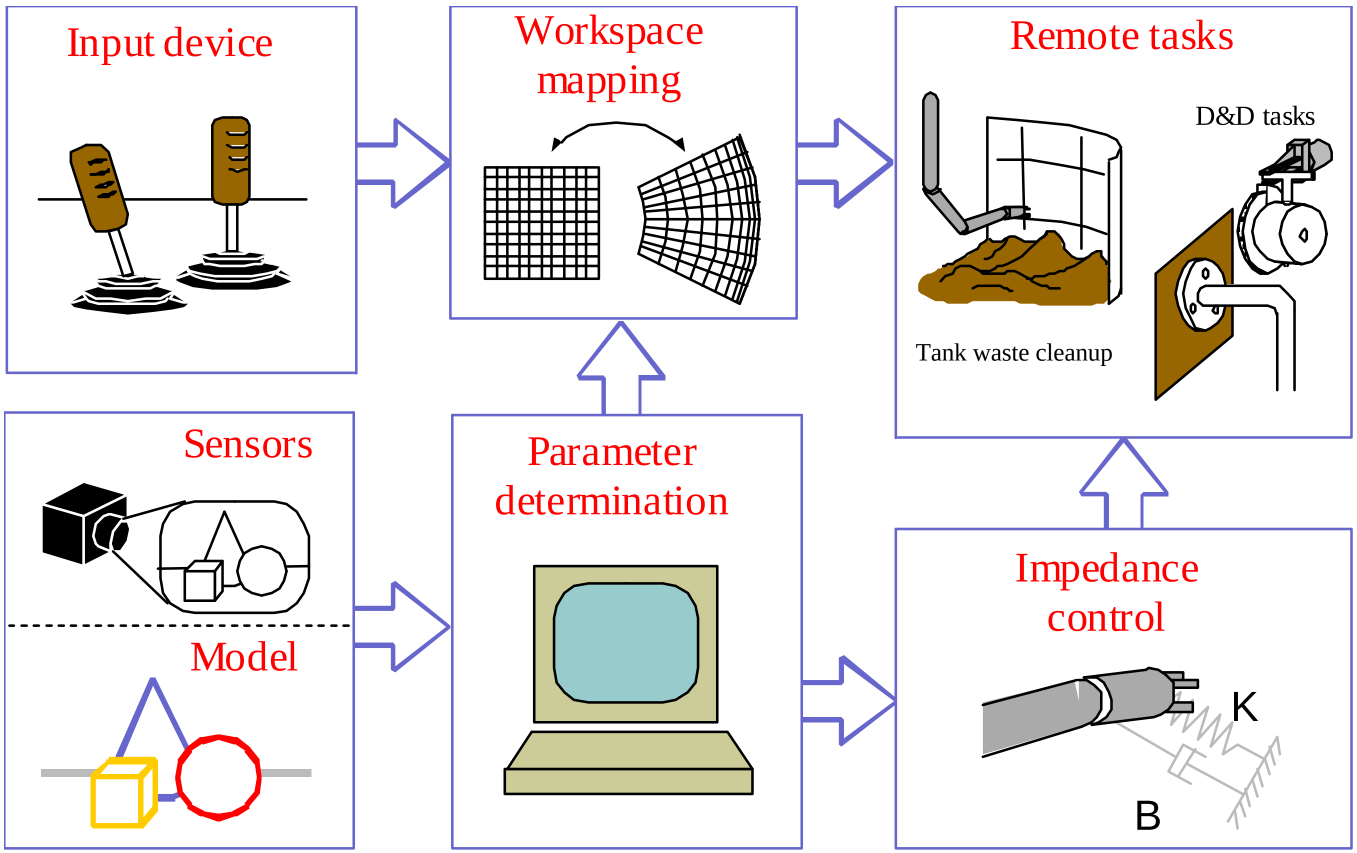
HMCTR Concept



RTSA parent windows

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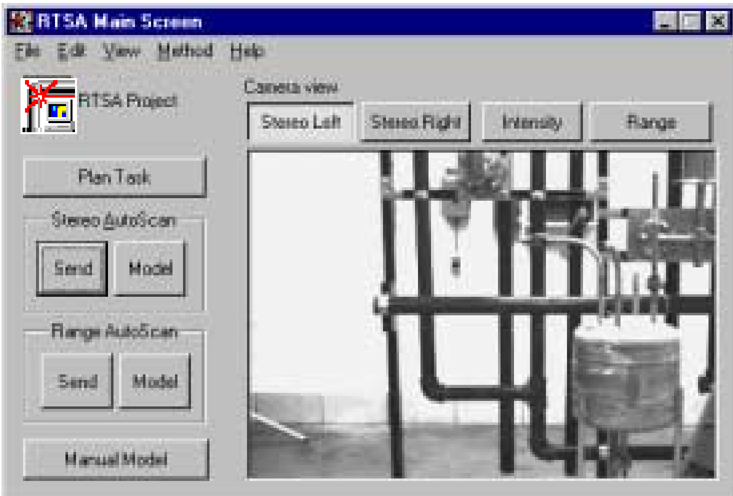
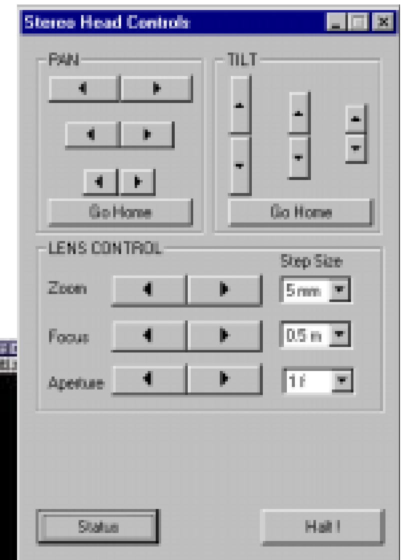


Mouse or joystick positions laser range pointer



Operator selects modeling process

Stereo autoscan part selection

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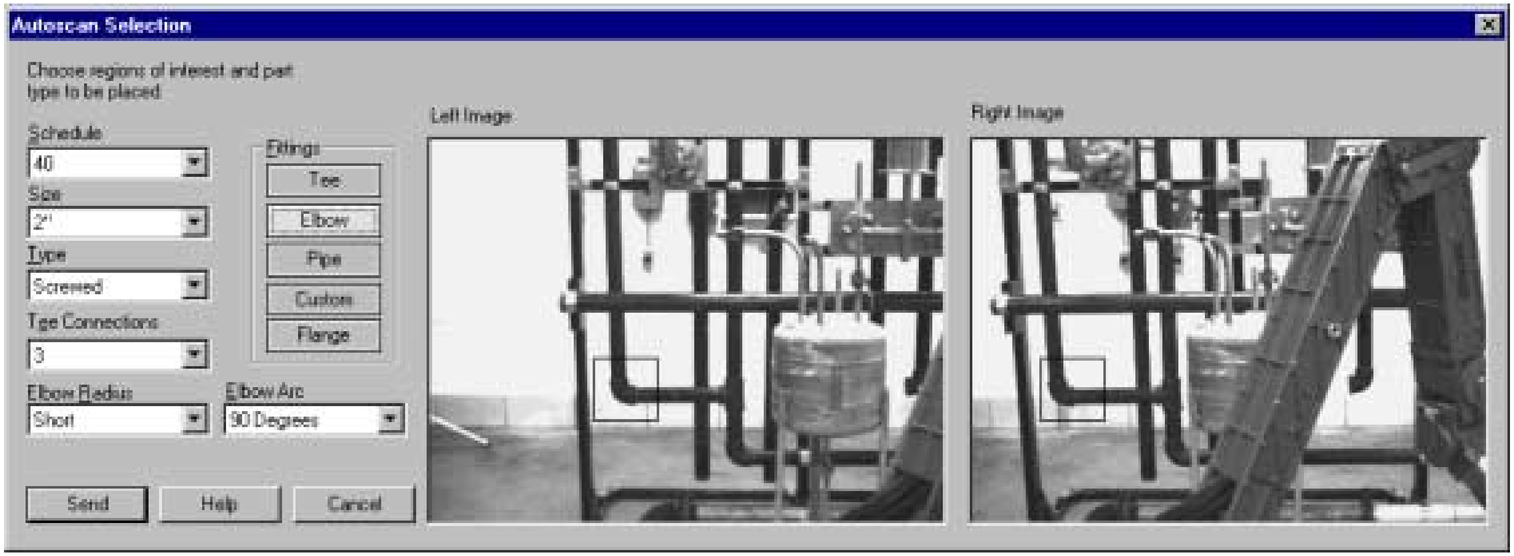
Operator defines what objects to auto scanned



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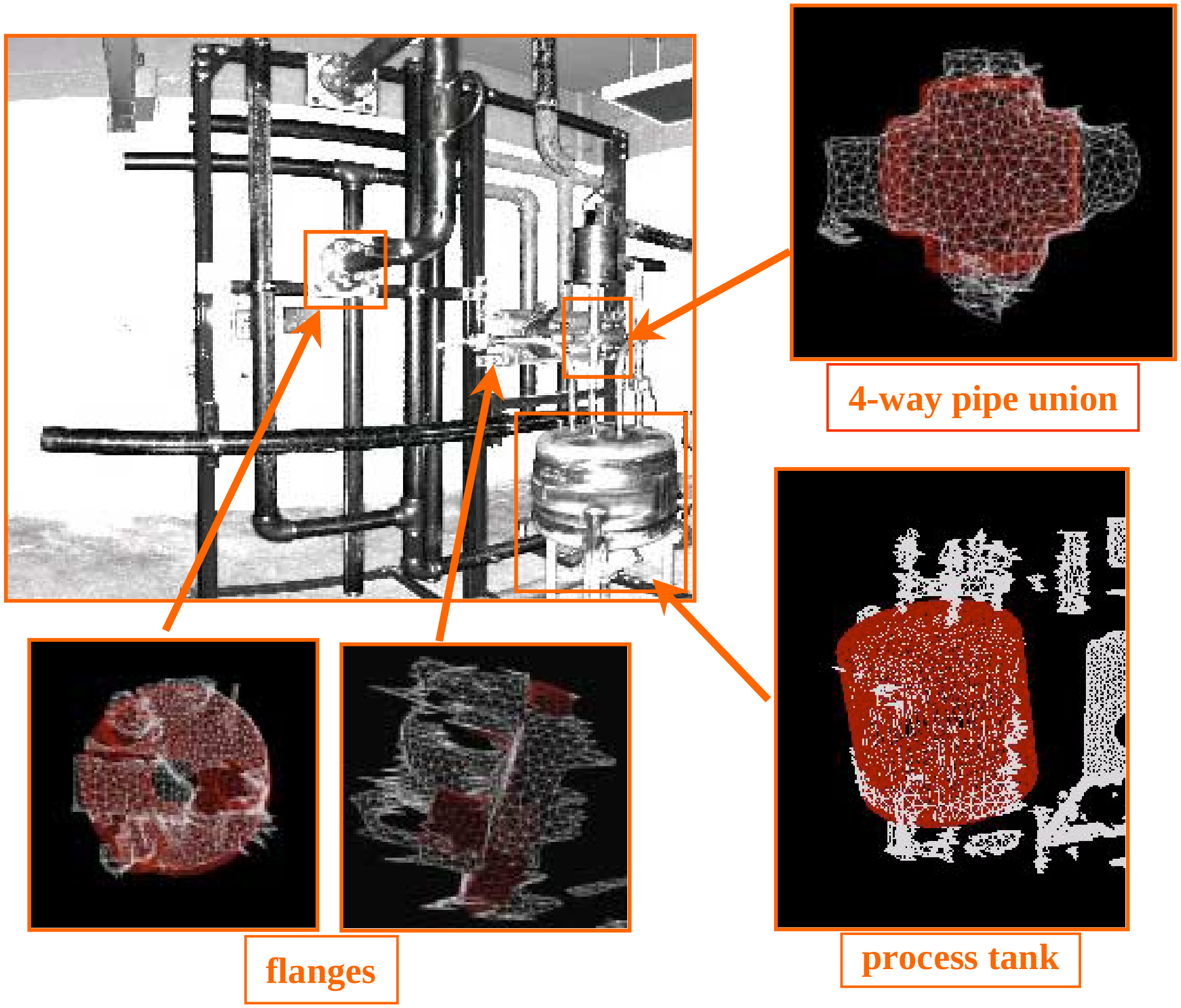
Range autoscan module



- **Uses scanning laser rangefinder data**
- **Recognizes complexly shaped objects in scene**
  - operator selects object types from online catalog
  - software determines number of occurences in scene & their precise locations

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Path Forward…Commercialization

- **Sensor Suppliers**
  - CCD 2D cameras
  - Structured light systems
  - Laser Range Cameras
  - P/T drives

- **Remote System Integrators**
  - RedZone
  - AEA
  - Etc.

- **Remote Handling Equipment Suppliers**
  - PaR
  - Schilling Development
  - RedZone
  - HMW
  - GEC
  - Etc.

- **Remote System Suppliers**
  - PaR
  - HMW
  - Etc.

RTSA HMCTr

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RTSA Summary

- Projects focused on improving remote D&D operations.
- Pervasive utilization opportunities exist.
- Technology is at Gate 3
  - Performance results are positive…RTSA can enable automation
- Commercialization
  - Strategy established; embedded technology
  - Dependent on full-scale testing results and user interest
- Full-scale test and evaluation in conjunction with DDFA/Rbx is planned…after 20 years, first "working" telerobot…major increase in remote work efficiency.