A Networked VR-Based Telerobotic System

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Why Japan did not send in robots for rescue in the initial stage of Fukujima nuclear accident on March 11, 2011 ?

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Why there is no Doraemon in our home ?

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Introduction

- Sojourner, the first ever space robot on Mars
- Global remote control through internet teleoperation, IEEE Robtotics and Automatin Magazine, March 2000
- New research directions in internet tele-robotics, Workshop, IEEE International Conference on Robotics and Automation, 2003
- The robot in the garden, MIT Press, 2000
- Education, Medicine, Industry, Entertainment, Training, VR dynamic simulation system, etc.

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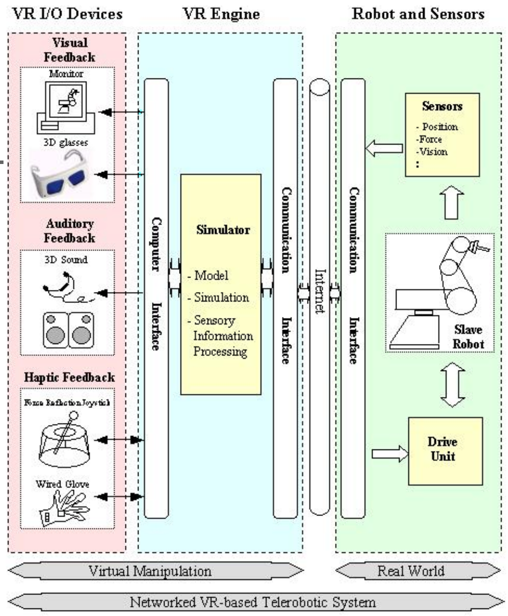

A typical networked VR-based telerobotic system

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THE CHALLENGES

- Telepresence of remote environments, including visual, auditory, and haptic senses
- Design of VR I/O devices, such as head mount display, 3D glasses, force-reflection joystick, data glove, etc.
- Incompatibility between the manipulative device and the remote manipulator
- Time delay due to network transmission

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THE CHALLENGES (Cont.)

- Supporting tools helpful for human operators in manipulation
- Remote intelligence controller dealing with interaction between the manipulator and the environment
- Cooperation between the human operator and remote intelligence controller

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A Multi-Functional Virtual Manipulation System

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Manipulative Device

Haptic Devices

- Data glove, force-reflection joystick, pen-based and robot-based haptic interfaces, etc.

Force-Reflection Joystick

- Simple in structure and popular in use.

Virtual Mechanism

- Force-reflection joystick + Virtual motion constraint
- To constraint the joystick to move within limited workspaces corresponding to requirements of various simulation tasks.

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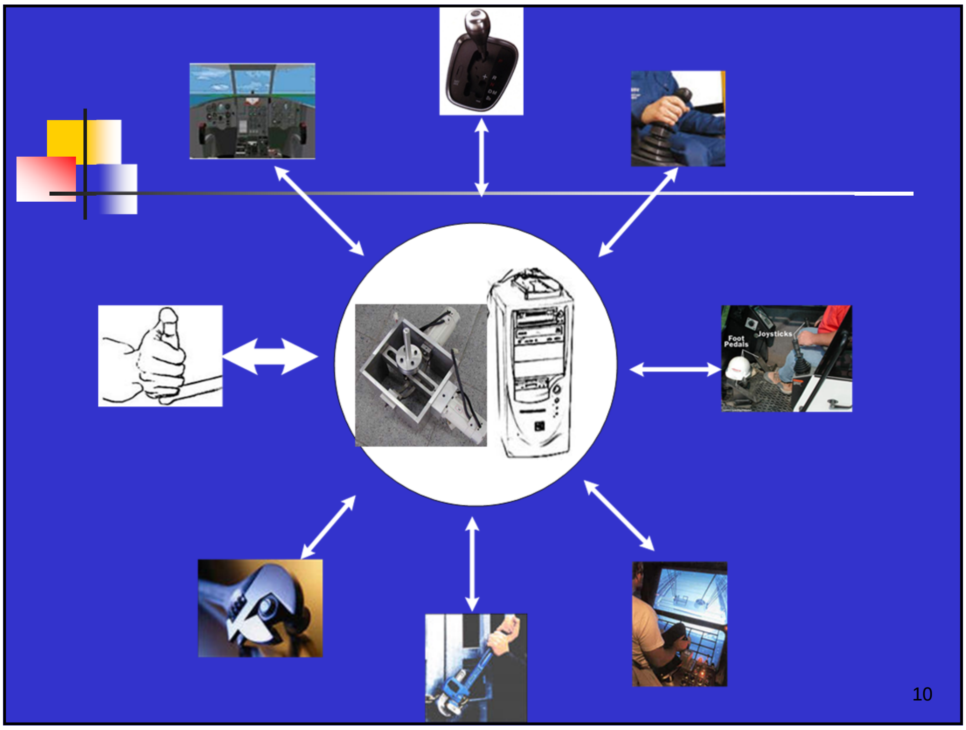

Virtual Manipulation System

Force-reflection joystick system

- High bandwidth, precision, and output torque
- Workspace analysis, system identification, and system modeling

Virtual Constraint

- Generation of virtual wall
- Transition rules for movement between wall to wall
- Generation of virtual motion constraint

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Multi-Functional Manipulation System

- Simulation system has been applied to various tasks
  - To emulate the practical system
  - To assist in mechanical design
  - To serve as the interface for teleoperation
- To make a single manipulative device applicable for various tasks is demanded

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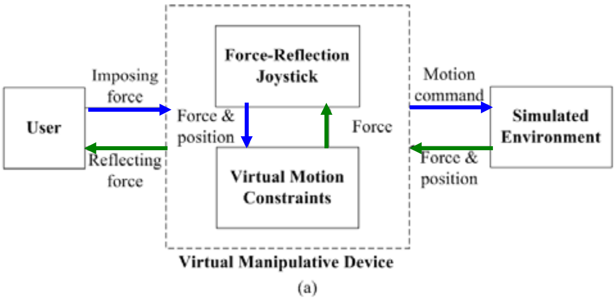
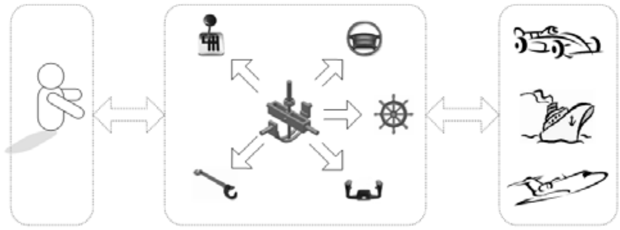
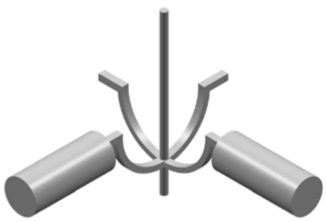
Proposed Virtual Manipulation System

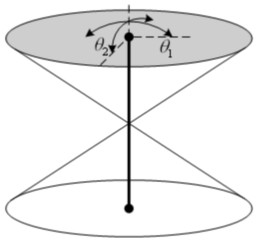




(b)

2D Single-Yoke Transmission Mechanism

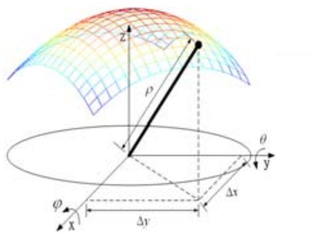




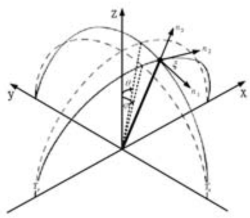
(a) Mechanism **(b) Action space and workspace**

Mechanism Analysis

(a) Modified mechanism



(b) Workspace



(c) Axis movement

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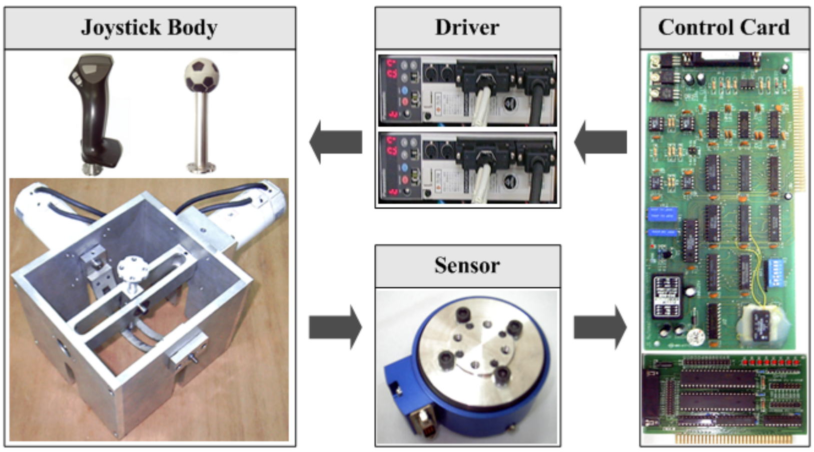
2-DOF Force-Reflection Joystick System



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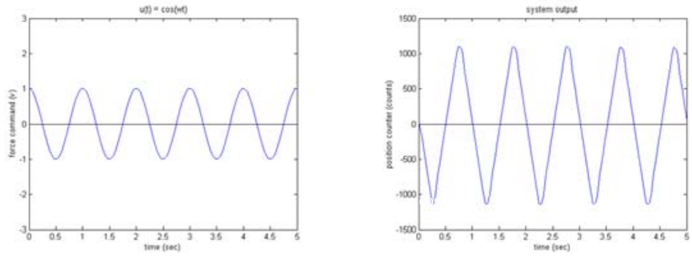
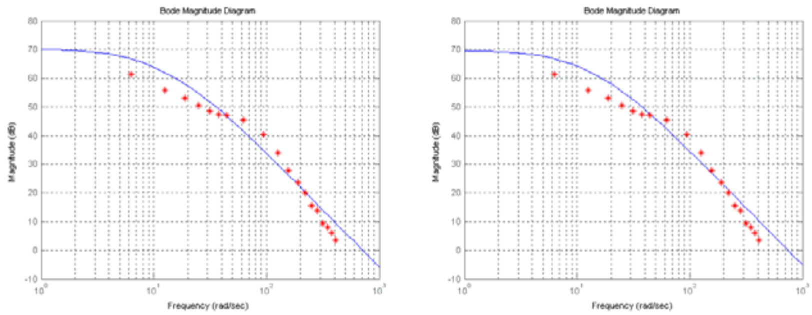
System Identification



$$F(j\omega) \longrightarrow \boxed{G(j\omega)} \longrightarrow X(j\omega)$$

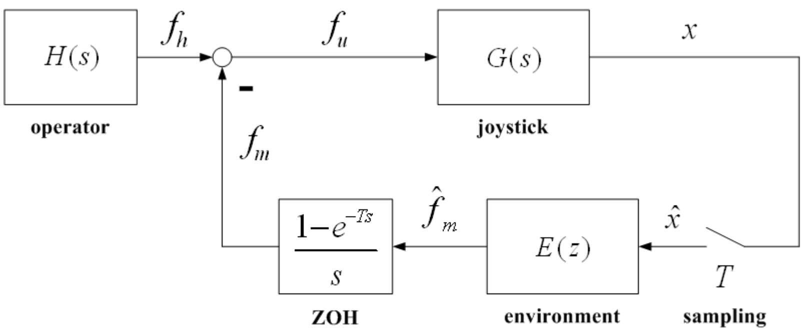
Frequency-Response Analysis

System Identification



(a) X axis **(b) Y axis**

Simulation System



Stability Analysis

Passivity Criterion

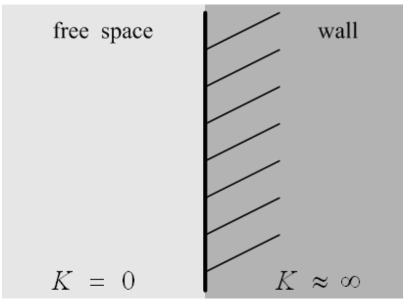
$$b > \frac{T}{2}\frac{1}{1-\cos\omega T}\mathrm{Re}\{(1-e^{-j\omega T})E(e^{j\omega T})\}$$

$$0 \le \omega \le \omega_N$$

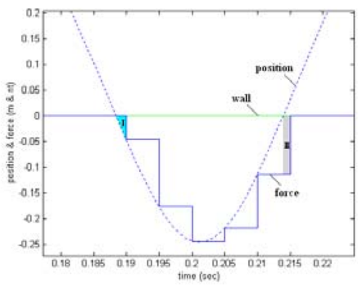
Realistic Virtual Wall

- Stiffness: 2000 ~ 8000 N/m
- Sampling rate
- Output torque
- Movement speed

Virtual Wall



(a) A virtual wall



(b) Deferred force generation

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Motion Constraint Design

- Different shapes of motion constraints may be placed in different orientations
- Objects may be made of different materials
- The shapes, orientations, and physical properties of motion constraints may vary along with the task execution

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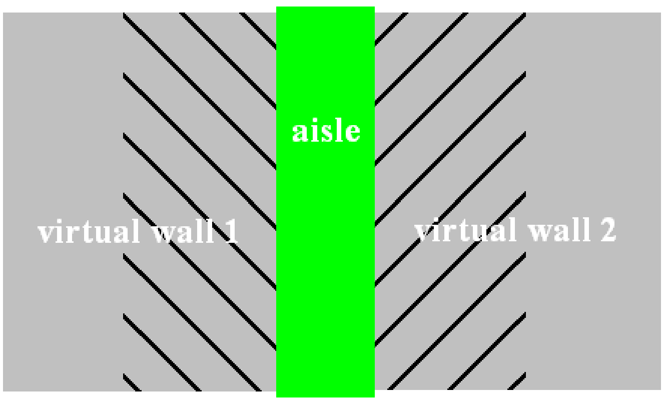
Virtual Wall Design

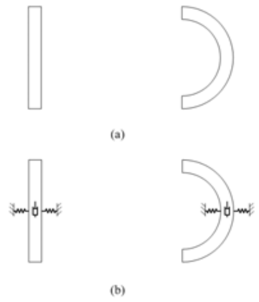
- Issues in digital implementation of virtual walls
  - Low sampling rate, high pushing force, fast-moving joystick
- Our strategies
  - Upgrade the hardware of the joystick
  - Pair the virtual walls to form the virtual aisles
  - Motion constraint serves as the guidance

Aisle



Virtual Wall Design (cont.)

- Shapes
  - Rectangular aisle
  - Circular aisle
- Physical properties
  - Stiffness
  - Damping



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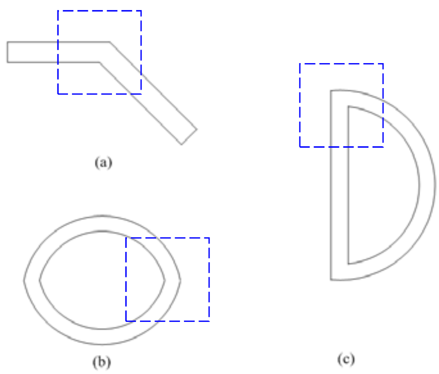
Motion constraint construction

- Connection between walls



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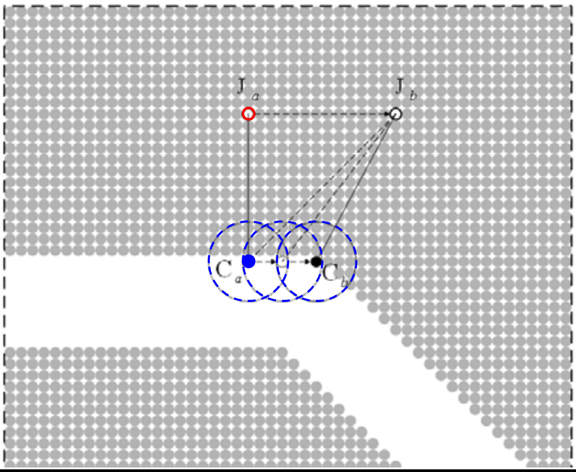
Force Rendering

- To find the NSP (nearest surface point)



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Procedure for motion constraint construction

- Step 1: Perform analysis and specify the task requirements
- Step 2: Select virtual walls of suitable shapes and physical properties
- Step 3: Assemble the walls into aisles. Perform force rendering using the graphics-based method
- Step 4: Update the virtual constraints timely via proper adjustment

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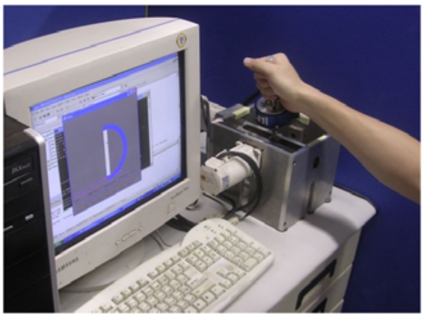
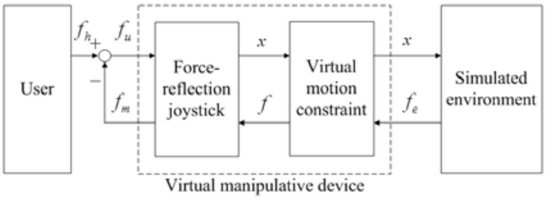
Experiments



(a)



(b)

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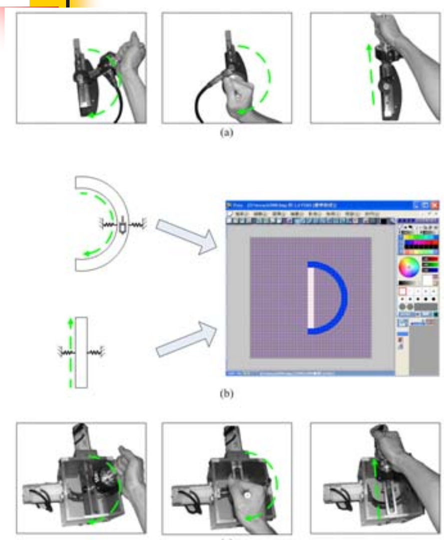
Virtual omni-directional wrench



(a)

(b)

(c)

Real wrench manipulation

Virtual motion constraint generation

- Damping coefficient

$$B_w = \begin{cases} c\alpha & if\ \alpha \geq 0 \\ 0 & if\ \alpha < 0 \end{cases}$$

α : screw turning angle

c : a ratio

Virtual wrench manipulation

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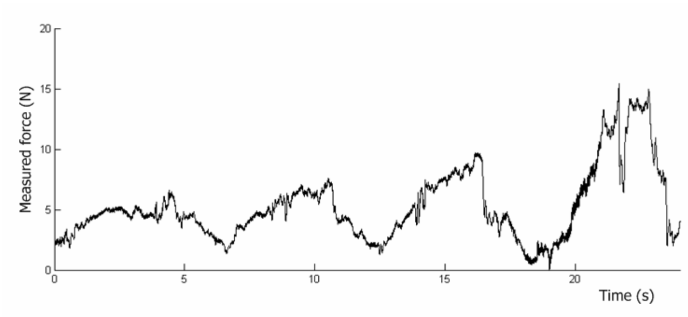
Screw Tightening Using a Real Wrench



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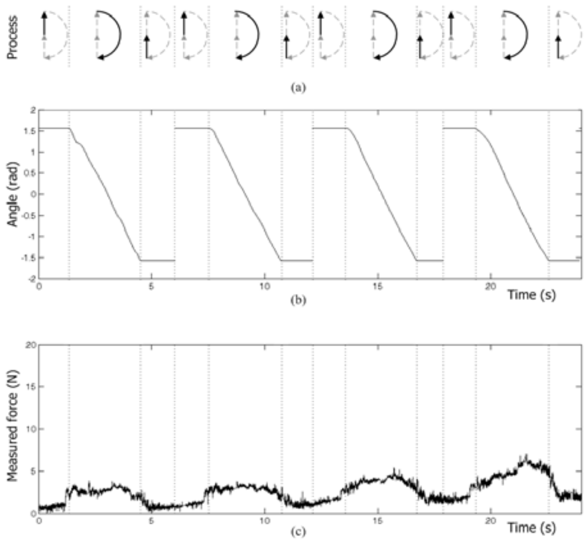
Experimental results (C = 5 N-s/m-rad)



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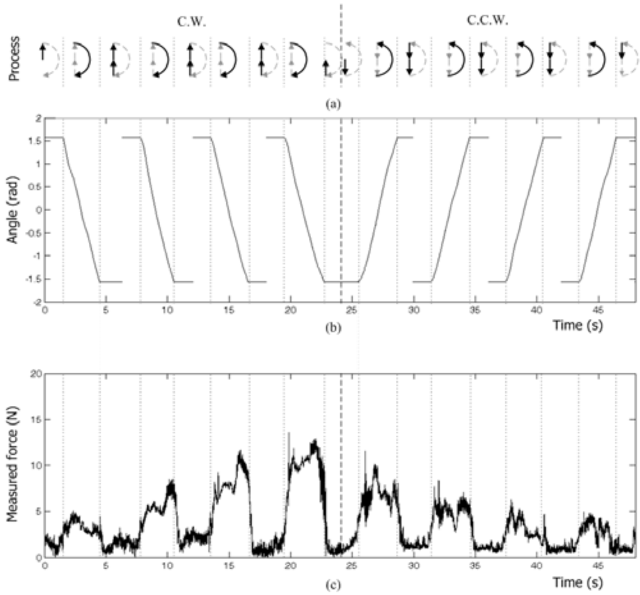
Experimental results (c = 15 N-s/m-rad)



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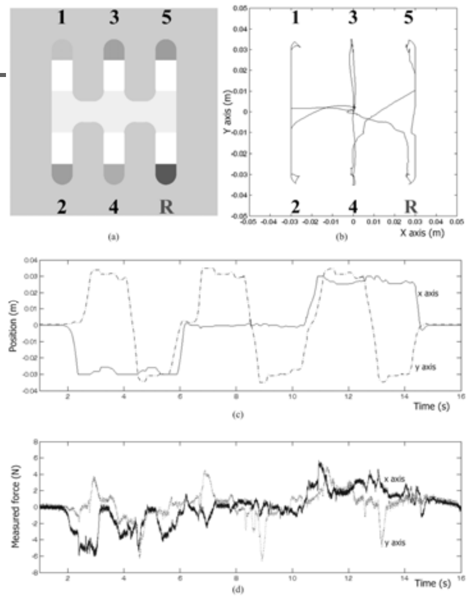
Virtual Manual Gearshift System



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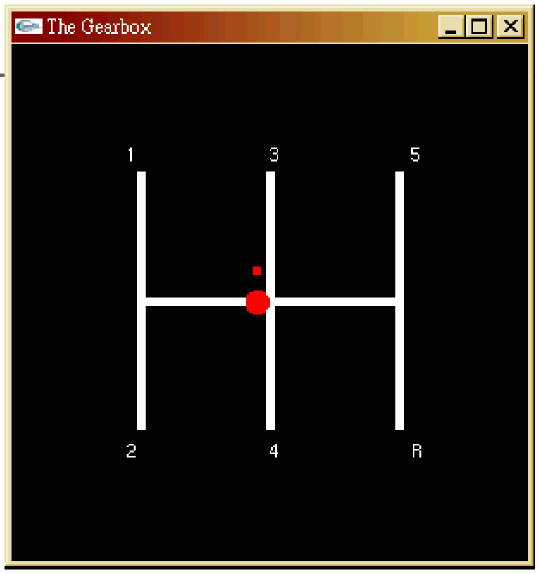
Virtual Gearshift Emulation



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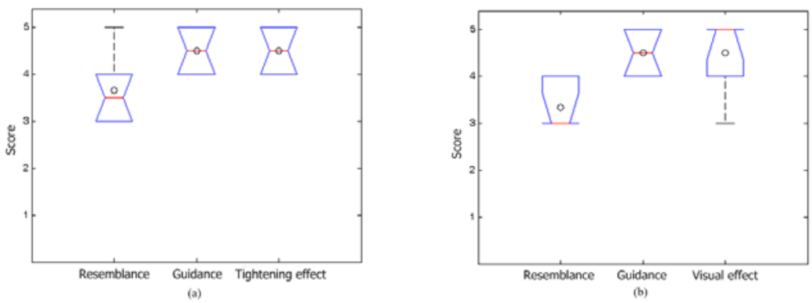
User Response Evaluation

- Omni-directional wrench
- Manual gearshift system



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Conclusion

- We have proposed a systematic approach to design and implement motion constraints for a multi-functional virtual manipulation system
  - Pixel-based method for force rendering
  - Virtual omni-directional wrench and manual gearshift system implementation
- Future works
  - Various kinds of compliance tasks
  - Tasks with multiple users
  - Tasks with 3D motion constraints

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