Haptic Systems
530-655

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Lecture 2
9/1/06

Generating Force-Feedback with a Manipulator

- Tip of a kinesthetic Haptic display and degrees of freedom
- Relation between the tip position and joint angles
- Encoders and measuring joint angles
- Relation between joint torques and forces at the tip
- Jacobean
- Actuator equations
- Nonidealities of a haptic device
- Discussion
- References

Tip of a Kinesthetic haptic display

- A point of haptic display whose position and orientation are used for haptic simulation
- Through this point human user interacts with haptic systems
- Haptic simulator defines the force and torques should be generated at this point by the manipulator

Degrees of freedom of a haptic display:

The number of directions that a haptic display can pivot or move its tip

DOF of motion

DOF of sensing

DOF of actuation

Tip Location and Degrees of Freedom

SensAble Phantom Omni

Tip

DOF of motion: 4

DOF of sensing: 4

DOF of actuation: 3

Tip Location and Degrees of Freedom

MPB 6S

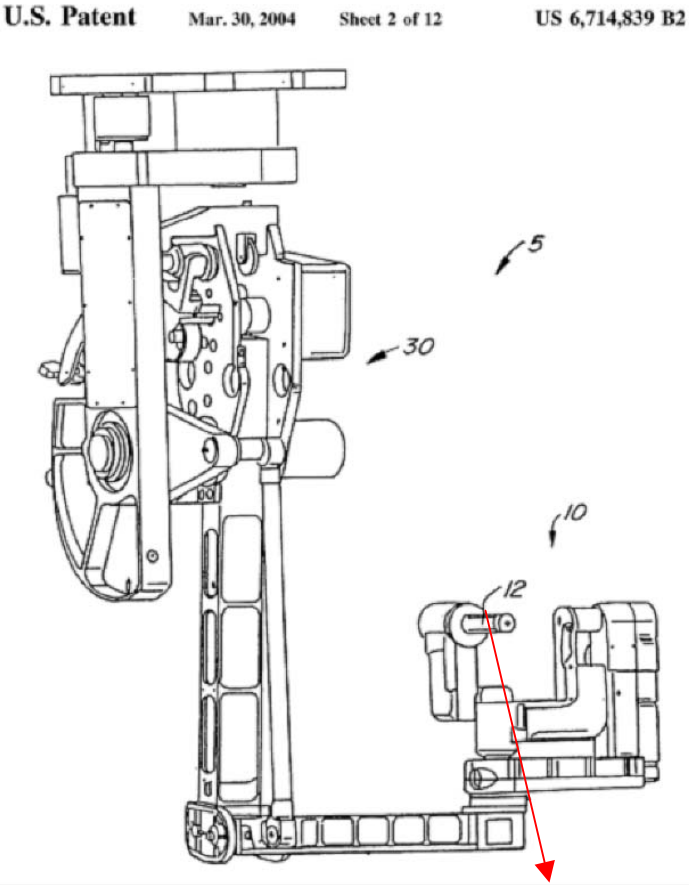
DOF of motion: 7

DOF of sensing: 7

DOF of actuation: 6

Tip Location and Degrees of Freedom

da Vinci Master (From US Patent **06714839)**



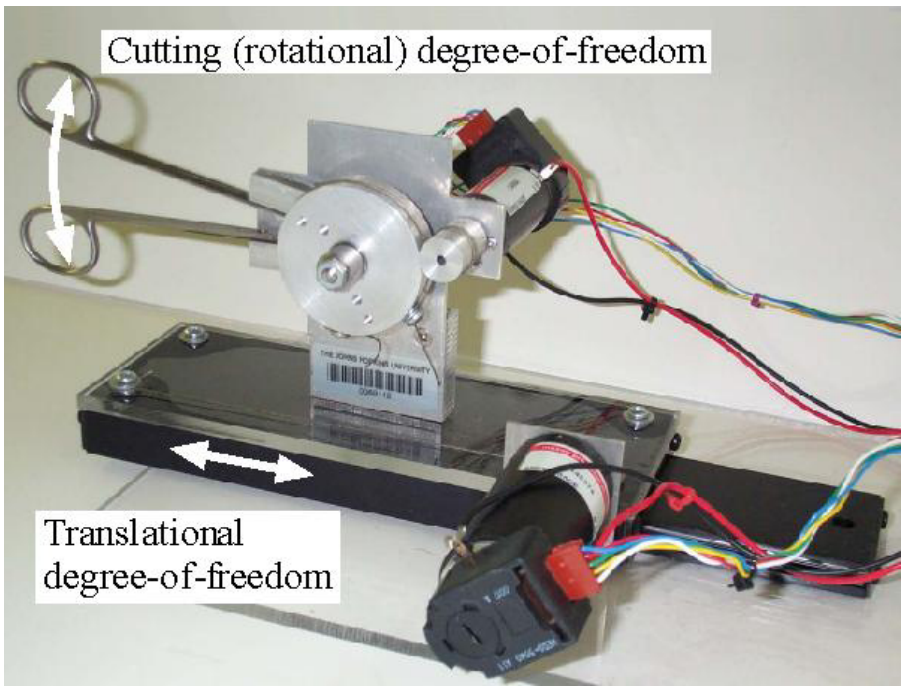
DOF of motion: 7

DOF of sensing: 7

DOF of actuation: 7

Tip Location and Degrees of Freedom

Haptic scissors



DOF of motion: 2

DOF of sensing: 2

DOF of actuation: 2

Tip?

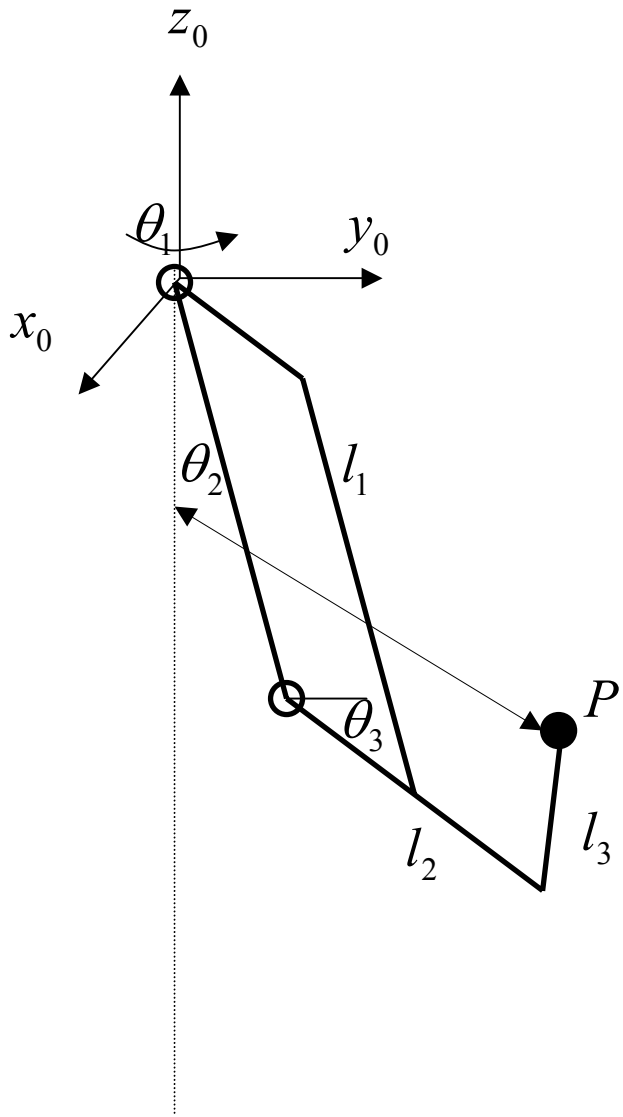
Relation Between Tip Position and Joint Angles (Forward Kinematics)

$$r = l_1 \sin(\theta_2) + l_2 \cos(\theta_3) - l_3 \sin(\theta_3)$$

$$p_x = r \cos(\theta_1)$$

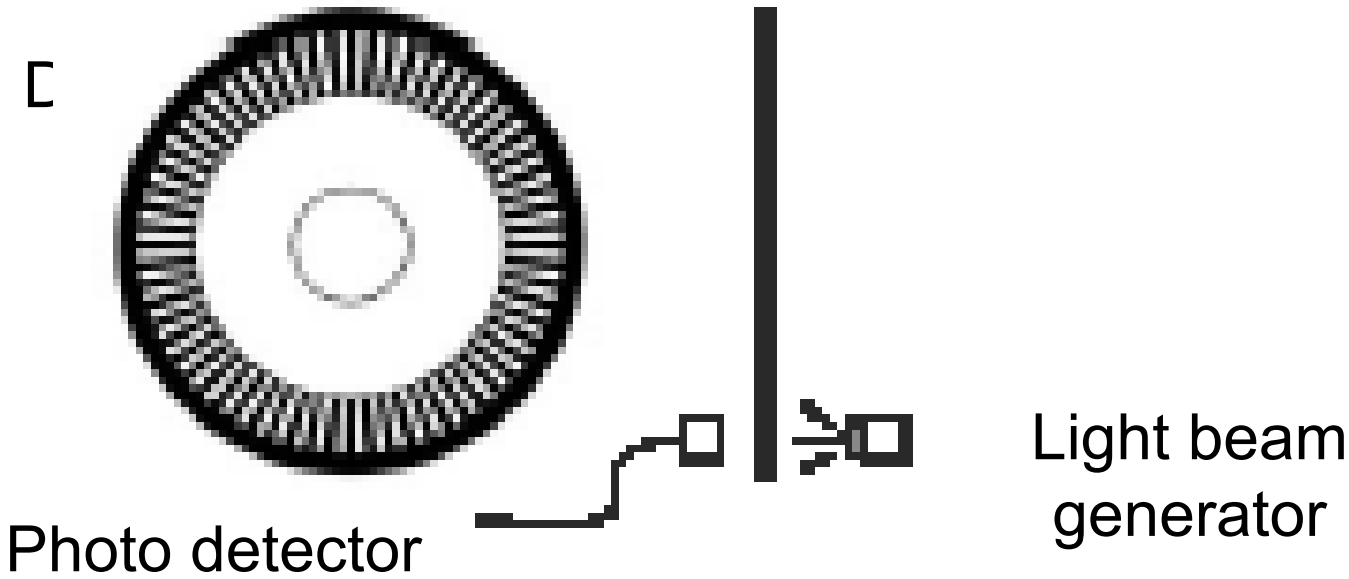
$$p_y = r \sin(\theta_1)$$

$$p_z = -l_1 \cos(\theta_2) + l_2 \sin(\theta_3) - l_3 \cos(\theta_3)$$



Encoders

Small discs that have holes in them that can be read by photo sensors. The photo sensors record the number of transitions between light and dark.



Initializations:Potentiometers and fixed setting points

Relation between Joint Torques and Forces at the tip

- Principal of virtual work

$$F.\Delta X = \tau.\Delta\theta$$

- Jacobian

$$\Delta X = J\Delta\theta$$

$$F^T J\Delta\theta = \tau^T\Delta\theta$$

$$F^T J = \tau^T$$

$$\tau = J^T F$$

Jacobian

Taking partial derivatives

$$r = l_1 \sin(\theta_2) + l_2 \cos(\theta_3) - l_3 \sin(\theta_3)$$

$$p_x = r\cos(\theta_1)$$

$$p_y = r\sin(\theta_1)$$

$$p_z = -l_1 \cos(\theta_2) + l_2 \sin(\theta_3) - l_3 \cos(\theta_3)$$

$$\Delta X = J \Delta \theta$$

$$J_{11} = \partial p_x / \partial \theta_1$$

$$J_{21} = \partial p_y / \partial \theta_1$$

$$J_{21} = \partial p_y / \partial \theta_1$$

$$\tau_x = -r\sin(\theta_1) f_x + r\cos(\theta_1) f_y$$

$$\tau_y = l_1 \cos(\theta_1)\cos(\theta 2) f_x + l_1 \sin(\theta_1)\cos(\theta 2) f_y - l_1 \sin(\theta_2) f_z$$

$$\tau_z = -(l_2 \sin(\theta_3) + l_3 \cos(\theta_3)) * \cos(\theta_1) f_x - (l_2 \sin(\theta_3) + l_3 \cos(\theta_3)) * \sin(\theta_1) f_y$$

$$+ (l_2 \cos(\theta_3) - l_3 \sin(\theta_3)) f_z$$

Actuators Equations

- Torque

$$\tau = k_t I$$

- Voltage

$$V = L \frac{dI}{dt} + RI + E$$

$$E = K \omega$$

- Input

  Current amplifier: I as an input

  Voltage amplifier: V as an input

Nonidealities of a haptic device

Ideal haptic devices

- No friction
- No Inertia
- High bandwidth

$$F_{hand} = KI$$

Actual haptic devices

$$M\ddot{X} + C\dot{X} + G + H(I) + F_{friction} = F_{hand}$$

Discussion

- High fidelity haptic devices
- Friction
- Inertia
- gravity
- Device bandwidth
- Sensors
- Actuators

References

Introduction to Robotics Mechanics and Control, 2nd Ed., John J. Craig, Addison- Wesley (Chapter 3 and 5.7 to 5.11)

Tomorrow

Introduction to haptic rendering