Haptic devices

Control and Robotics in Medicine

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Introduction

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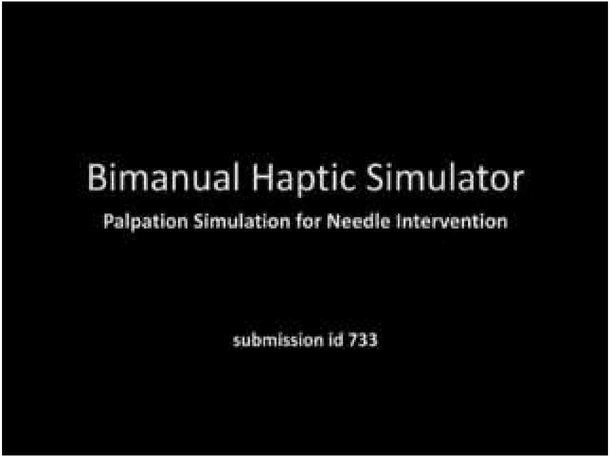


Introduction

Definition

- **Haptics**, from Greek, “haptikos”: grasp, touch
- Adj: Relative to the touch

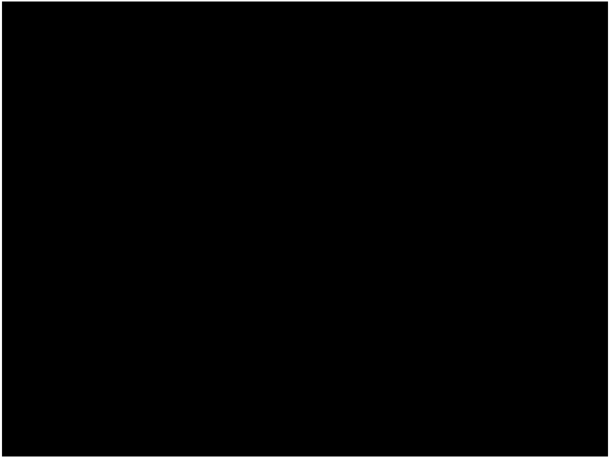





Senses

- touch
- sight
- hearing
- smell
- taste

Cutaneos sensibility lost



https://www.youtube.com/watch?v=0LfJ3M3Kn80

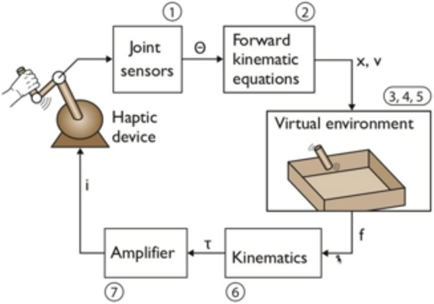
Haptics

- **Cutaneous**: Temperature, vibrations, texture,...
- **Kinesthesia**: Force, movement, location,...

Force feedback

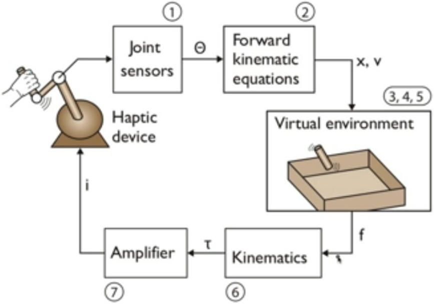
- An infinitely rigid “stick” used as a tool to work remotely.
- Because the “stick” is massless, the operator will feel the object to push.

Haptic loop



- 1. Sense movement ($\boldsymbol{q}$)
- 2. Forward kinematics ($\boldsymbol{x}, \dot{\boldsymbol{x}}$)
- 3. Contact points
- 5. Calculate forces ($\boldsymbol{f}$)
- 6. Calculate torques ($\boldsymbol{\tau}$)
- 7. Send to actuators

Haptic loop



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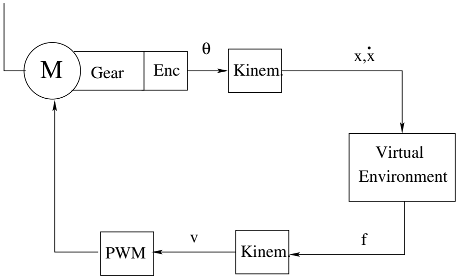
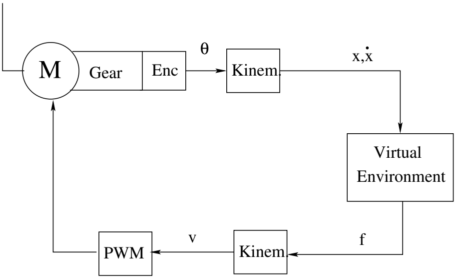
$$\boldsymbol{x} = f(\boldsymbol{q})$$
$$\dot{\boldsymbol{x}} = \boldsymbol{J}\dot{\boldsymbol{q}}$$
$$\boldsymbol{f} = \boldsymbol{J}\boldsymbol{\tau}$$
$$\boldsymbol{\tau} = \boldsymbol{J}^T\boldsymbol{f}$$

1 DOF



- 1. Sense movement (θ)
- 2. Forward kinematics ($\boldsymbol{x}, \dot{\boldsymbol{x}}$)
- 3. Contact point
- 5. Calculate force (f)
- 6. Calculate voltage (v)
- 7. Send to actuator

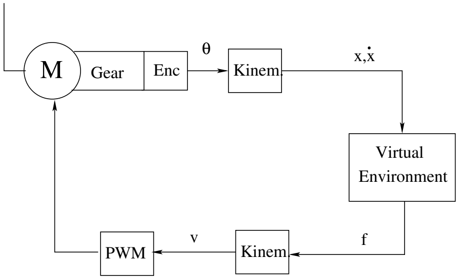
1 DOF



$$x = f(\theta)$$
$$\dot{x} = J\dot{\theta}$$
$$f = J\tau$$
$$\tau = J^T f$$
$$v = g(\tau)$$

- 1. Sense movement (θ)
- 2. Forward kinematics ($x, \dot{x}$)
- 3. Contact point
- 5. Calculate force (f)
- 6. Calculate voltage (v)
- 7. Send to actuator

1 DOF



- 1. Sense movement (θ)
- 2. Forward kinematics ($\boldsymbol{x}, \dot{\boldsymbol{x}}$)
- 3. Contact point
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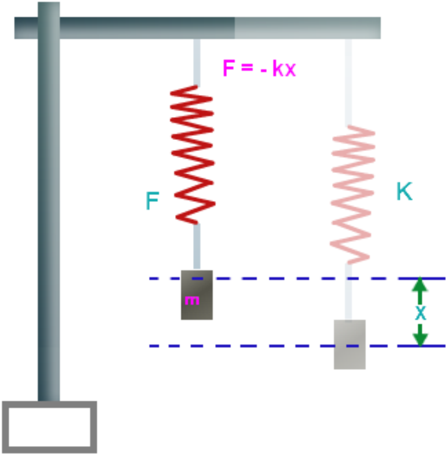
$$
\begin{aligned}
\boldsymbol{x} &= f(\theta) \\
\dot{\boldsymbol{x}} &= \boldsymbol{J}\dot{\theta} \\
f &= \boldsymbol{J}\tau \\
\tau &= J^T\boldsymbol{f} \\
v &= g(\tau)
\end{aligned}
$$

500-1000Hz!!!

Spring



$$F = -kx$$

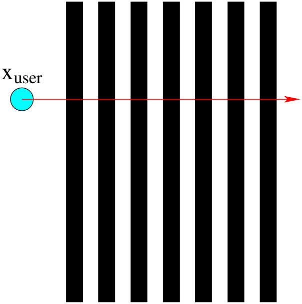
- F, force to be sensed by the user
- k, elastic constant
- x, position of the haptic device end
- $x = 0$, equilibrium position

Viscosity

$$F = -b\dot{x}$$

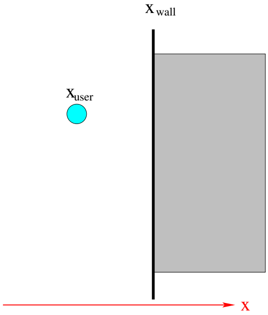
- F, force to be sensed by the user
- b, viscous constant
- $\dot{x}$, speed of the haptic device end

Textures

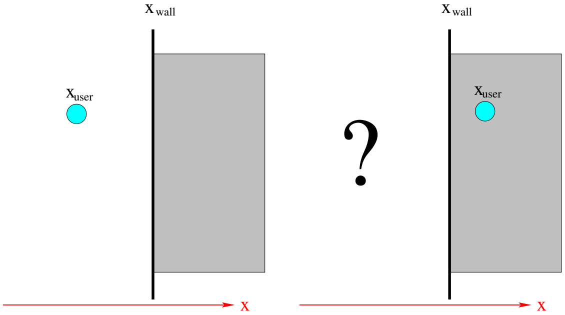


$$\begin{cases} F = 0 & x \in free \\ F = -b\dot{x} & x \in stick \end{cases}$$

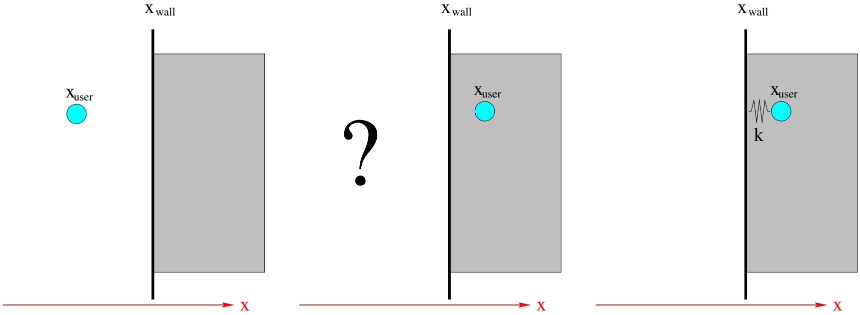
Virtual wall



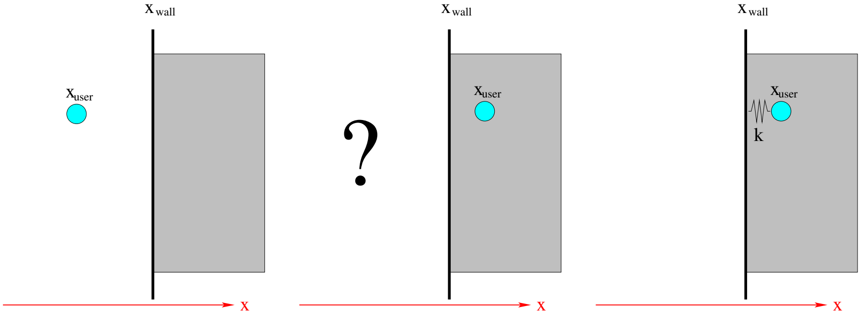
Virtual wall



Virtual wall



Virtual wall



$$\begin{cases} F = 0 & x_{user} \leq x_{wall} \\ F = k(x_{wall} - x_{user}) & x_{user} > x_{wall} \end{cases}$$

Equations

$$u_m(t) = R_m i(t) + L_m \frac{di(t)}{dt} + e_b(t)$$

$$\tau_m(t) = J_m \ddot{\theta}_m(t) + B_m \dot{\theta}_m(t) + \tau_l(t)$$

Equations

$$u_m(t) = R_m i(t) + L_m \frac{di(t)}{dt} + e_b(t)$$

$$\tau_m(t) = J_m \ddot{\theta}_m(t) + B_m \dot{\theta}_m(t) + \tau_l(t)$$

$$e_b(t) = k_b \dot{\theta}_m(t)$$

$$\tau_m(t) = k_m i(t)$$

$$t_e = \frac{L_m}{R_m}$$

$$t_m = \frac{R_m J_m}{R_m B_m + k_b k_m}$$

Equations

$$u_m(t) = R_m i(t) + L_m \frac{di(t)}{dt} + e_b(t)$$

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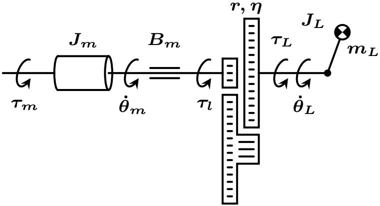
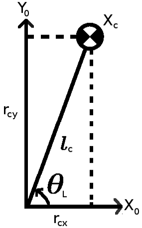
$$t_e = \frac{L_m}{R_m}$$

$$t_m = \frac{R_m J_m}{R_m B_m + k_b k_m}$$

$$\boxed{\frac{k_m}{R_m} u_m(t) = J_m \ddot{\theta}_m(t) + \left(B_m + \frac{k_b k_m}{R_m}\right) \dot{\theta}_m(t) + \tau_l(t)} \tag{1}$$

Modelling

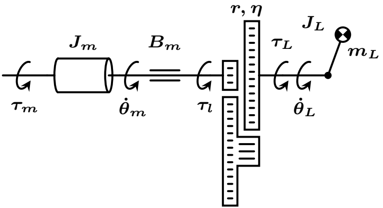


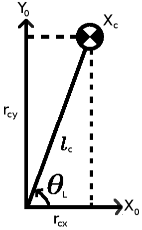


$$\theta_L(t) = r\theta_m(t)$$

$$\tau_L(t) = \frac{\eta}{r}\tau_l(t)$$

Modelling





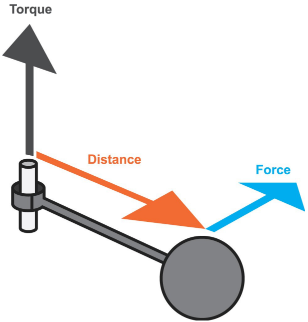
$$\theta_L(t) = r\theta_m(t)$$

$$\tau_L(t) = \frac{\eta}{r}\tau_l(t)$$

$$\frac{k_m}{R_m}u_m(t) = J_m\ddot{\theta}_m(t) + \left(B_m + \frac{k_b k_m}{R_m}\right)\dot{\theta}_m(t) + \tau_l(t)$$

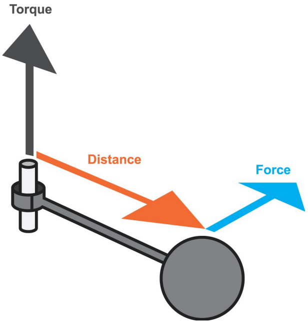
$$\boxed{\frac{k_m}{R_m}u_m(t) = J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(t)} \qquad (2)$$

External force



Torque = Distance x Force

External force



Torque = Distance x Force

$$\tau_e(t) = J^T(\theta_L(t))F_e(t) \tag{3}$$

$$J(\theta_L(t)) = \begin{bmatrix} -l\sin(\theta_L(t)+\alpha_c) \\ l\cos(\theta_L(t)+\alpha_c) \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{4}$$

$$F_e(t) = \begin{bmatrix} f_{ex}(t) \\ f_{ey}(t) \\ f_{ez}(t) \\ n_{ex}(t) \\ n_{ey}(t) \\ n_{ez}(t) \end{bmatrix} \tag{5}$$

$$\frac{k_m}{R_m}u_m(t) = J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(t) - \frac{r}{\eta}\left(lf'_{eT}(t) - n_{ez}(t)\right) \tag{6}$$

Direct torque control

$$u(t) = J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) \quad (7)$$

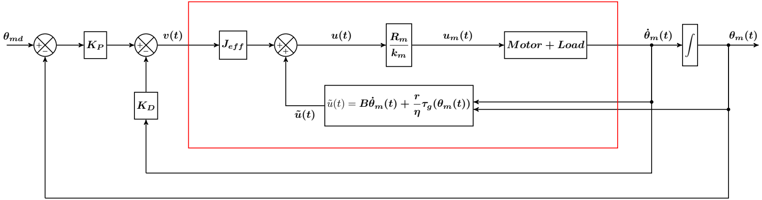
$$\boxed{u(t) = J_{eff}v(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t))} \quad (8)$$

Direct torque control

$$u(t) = J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) \quad (7)$$

$$u(t) = J_{eff}v(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) \quad (8)$$

- Example:



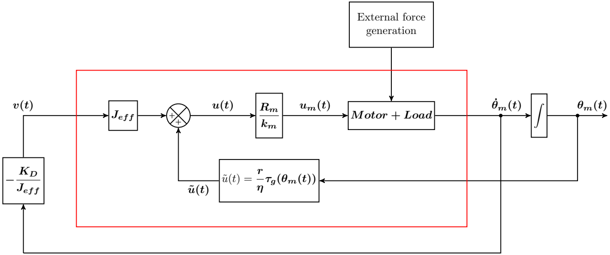
$$v(t) = K_P(\theta_{md} - \theta_m(t)) - K_D\dot{\theta}_m(t) \quad (9)$$

Gravity torque compensation

$$u(t) = \begin{cases} J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) - \frac{r}{\eta}\left(lf_{eT}(t) - n_{ez}(t)\right) & t \in [t_0, t_f] \quad (10) \\ J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) & t > t_f^- \quad (11) \end{cases}$$

Gravity torque compensation

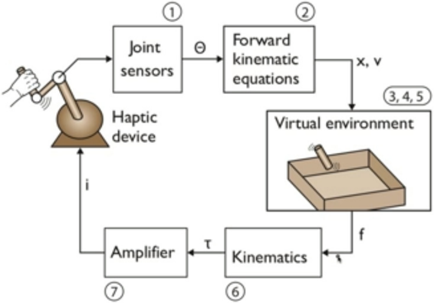
$$u(t) = \begin{cases} J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) - \frac{r}{\eta}(lf_{eT}(t) - n_{ez}(t)) & t \in [t_0, t_f] \quad (10) \\ J_{eff}\ddot{\theta}_m(t) + B\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) & t > t_f^- \quad (11) \end{cases}$$



$$u(t) = -K_D\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) \quad (12)$$

$$u_m(t) = \frac{R_m}{k_m}u(t)$$

Haptic loop



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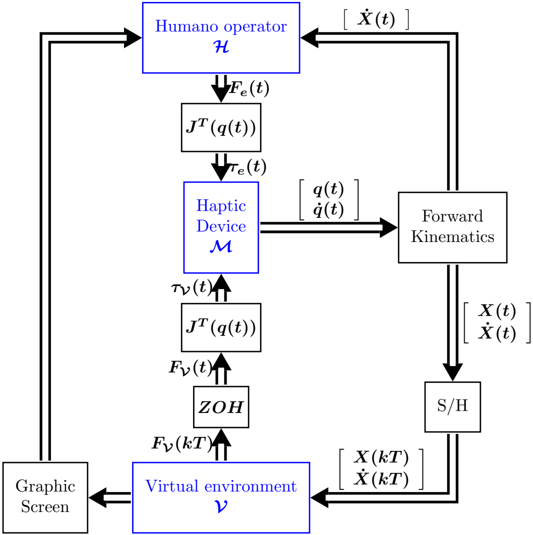
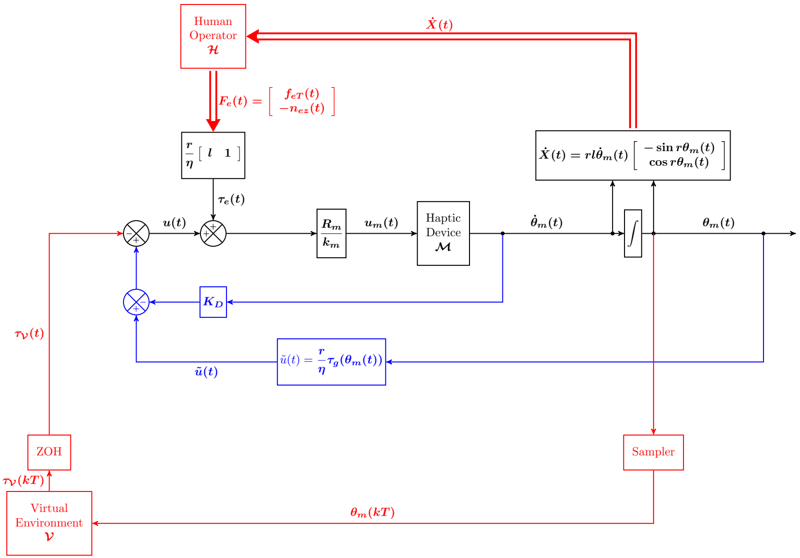
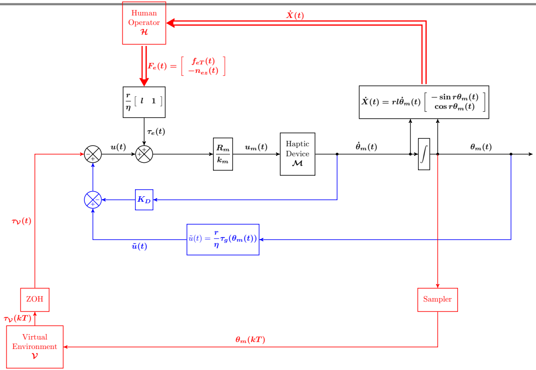
Haptic system definition



Haptic device definition



Haptic device as spring

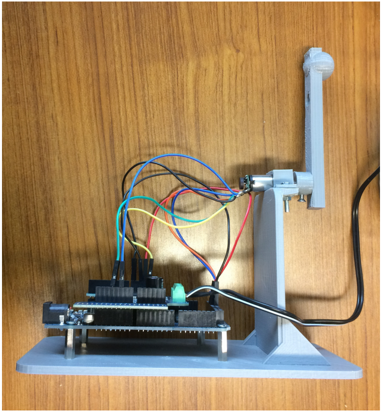


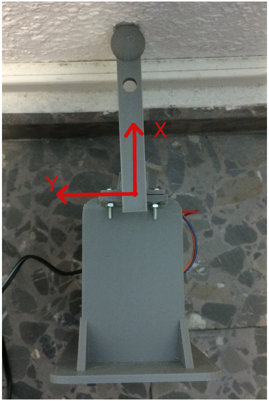
$$u(t) = -K_D\dot{\theta}_m(t) + \frac{r}{\eta}\tau_g(\theta_m(t)) - \tau_{\mathcal{V}}(t) \tag{13}$$

$$\tau_{\mathcal{V}}(t) = rk_{\mathcal{V}}\theta_m(t) - rk_{\mathcal{V}}\theta_{m0} + rB_{\mathcal{V}}\dot{\theta}_m(t)$$

$$\tau_{\mathcal{V}}(k) = ra(T)\theta_m(k) - ra(T)\theta_{m0} + r(k_{\mathcal{V}} - a(T))\theta_m(k-1)$$

Deliverable D3





Deliverable D3

1. **Gravity torque compensation (30%)**
   1.1 **Design a controller without including the linear control of speed (70%)**
   1.2 **Design a controller without including the linear control of speed and with errors in the mass calculation (30%)**
2. **Haptic system (60%)**
   2.1 **Design a haptic system with a torsion spring without including the viscous friction (30%)** Wall at $\theta \geq 2\pi/3$. Create a“soft”, “hard” and “very hard” wall.
   2.2 **Design a viscous environment (30%)** Create a viscous environment at position $\theta \in (-\infty, 2\pi/3)$. Create a “low”, “medium” and “high” viscousity environment.
   2.3 **Design a haptic system that attaches to a virtual object (40%)** Viscous environment at position $\theta \in (-\infty, 2\pi/3)$. An object at position $\theta = 2\pi/3$. Once the object has been touched, the system should emulate that it has been grasped.
3. **Conclusions (10%)**
4. **References**

THANKS FOR LISTENING!!