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Robotics


Surgical robotics


Wearable robotics


Autonomous robotics

Virtual and Interactive Simulations of Reality, Lab
Department of Computing, Faculty of Science
Macquarie University | Sydney, NSW, Australia

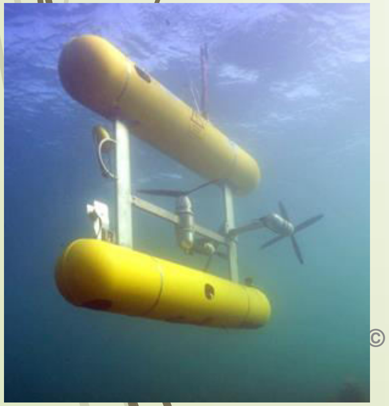
Smart Medical Devices Lab. (106-E) Office of
Research and Graduate Studies College of
Engineering, Qatar University,
Doha, Qatar

Dr. Tauseef Gulrez received a Ph.D. in Robotics and Computer Science from Macquarie University, Sydney, Australia in 2008. He also minored in Neuro-Engineering as a pre-doctoral research fellow from Rehabilitation Institute of Chicago, Northwestern University, IL, USA, in 2006. Previously, he received a Masters by research degree in Computer Systems Engineering from University of Technology, Sydney, Australia in 2005. He was a research fellow at Mechatronics and Haptic Interface Lab, School of Engineering, Rice University, TX, USA and Learning and Affect Technologies, The University of Sydney, Australia. Currently, he is a Postdoctoral researcher, in Smart Medical Devices Lab, College of Engineering, Qatar University, Doha. His main research interests include robotics, adaptive interfaces, virtual reality systems and signal processing.

Dr. Tauseef Gulrez

Robotic Systems

1. **Sensing System**
2. **Mechanical System**
3. **Artificial Intelligence**



Robotics Control Mode

Autonomous Control

Shared Controlled (Semi-autonomous)

Manual Mode

- **the machine is only used to transmit and adapt data from the user and the mobility task.**

Automatic Mode

- **the machine has complete control of the system, once a goal is selected.**

Semi-autonomous Mode

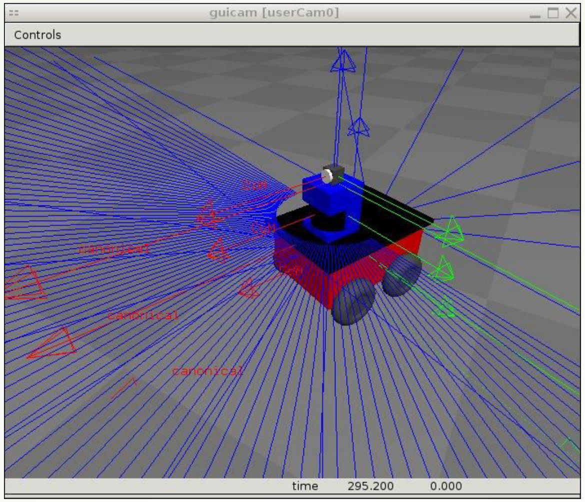
- **control is divided between the user and the machine.**
- **sharing degrees of liberty.**

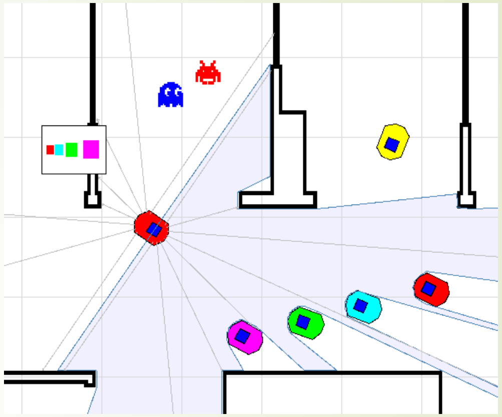
e.g.) the user: choose way to go, the machine: obstacle avoidance

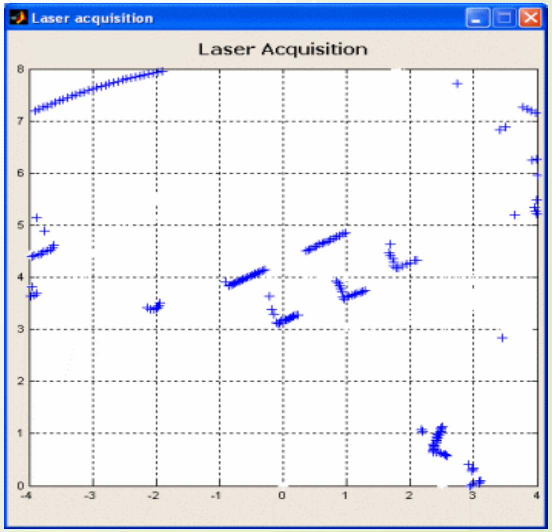
Purpose of Robotic Control

- Direct control of forces or displacements of a manipulator
- Path planning and navigation (mobile robots)
- Compensate for robot's dynamic properties (inertia, damping, etc.)
- Avoid internal/external obstacles

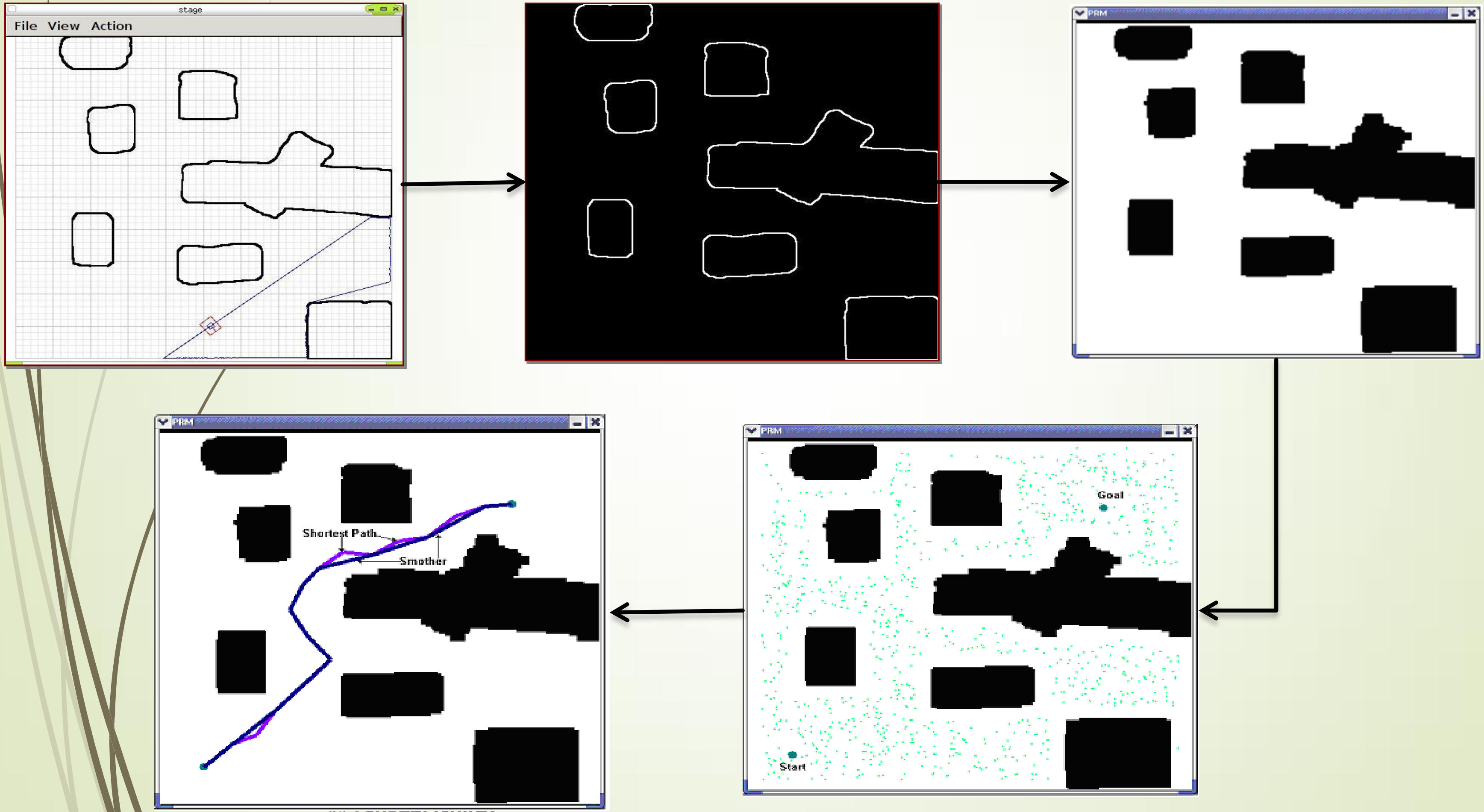
Laser Map Building (Sonar, Vision, etc.)





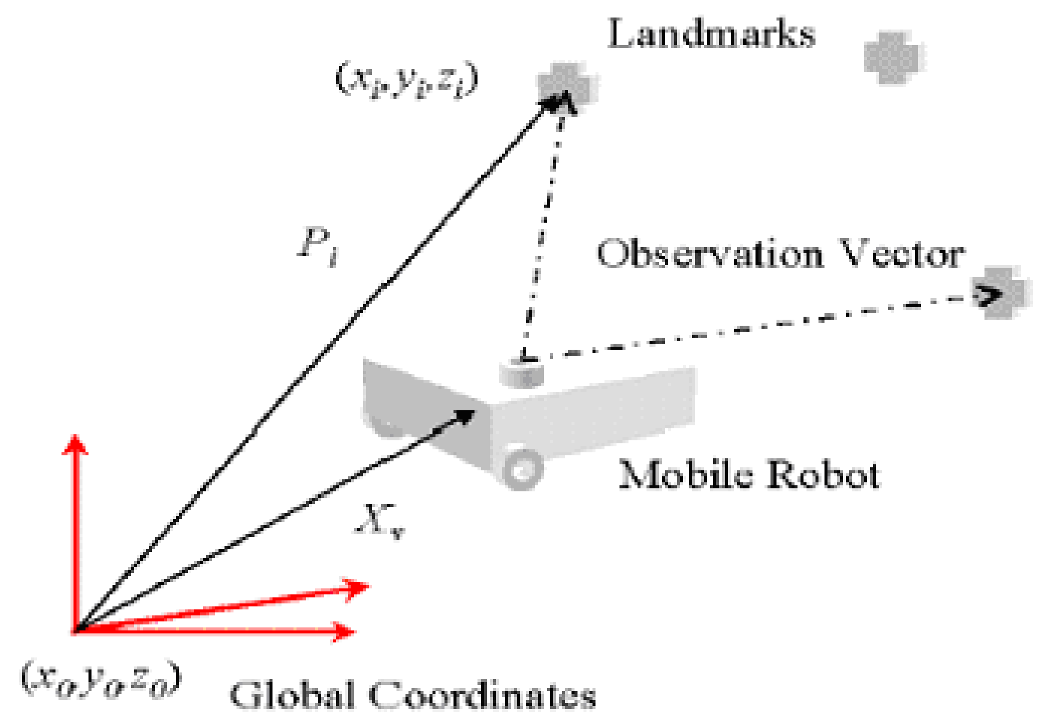


Map Building & Path-Planning Process



State-Space Model of Robotic Wheelchair

Robot Relative Measurements



Autonomous Robotics – State Space Model

Continuous Time Space

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} V\cos\varphi \\ V\sin\varphi \\ \omega \end{bmatrix}$$

Discrete Time Space

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ \varphi(k+1) \end{bmatrix} = \begin{bmatrix} x(k) + \Delta T V\cos(\varphi(k)) \\ y(k) + \Delta T V\sin(\varphi(k)) \\ \varphi(k) + \Delta T\omega \end{bmatrix}$$

Bearing $\theta_i(k) = \arctan\left(\frac{y_i - y_r(k)}{x_i - x_r(k)}\right) - \varphi(k) + \omega_\theta(k)$

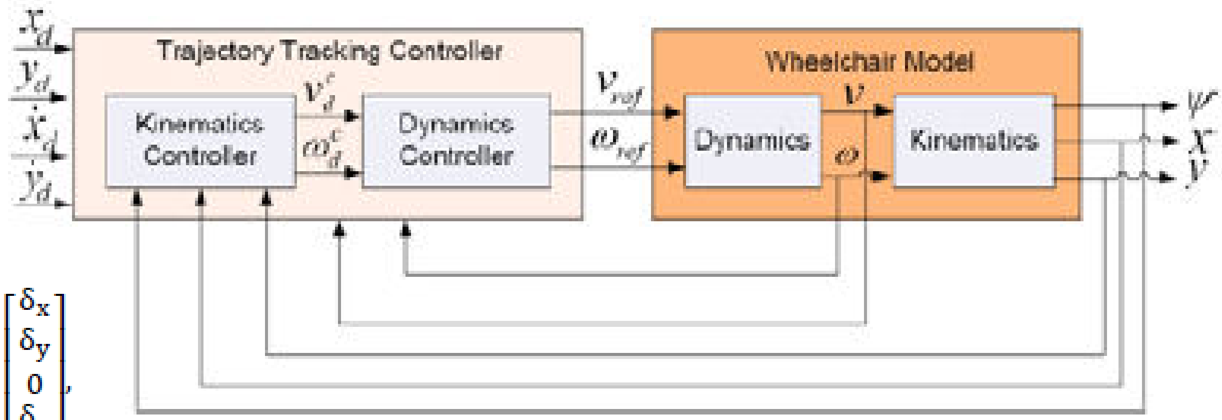
Landmarks

$$\begin{bmatrix} x_i(k+1) \\ y_i(k+1) \end{bmatrix} = \begin{bmatrix} x_i(k) \\ y_i(k) \end{bmatrix}$$

Range

$$r_i(k) = \sqrt{(x_i - x_r(k))^2 + (y_i - y_r(k))^2} + \omega_r(k)$$

Wheelchair Kinematics Model



$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\psi}\\ \dot{v}\\ \dot{\omega}\end{bmatrix}=\begin{bmatrix}v\cos\psi - a\omega\sin\psi\\ v\sin\psi + a\omega\cos\psi\\ \omega\\ \frac{\theta_3}{\theta_1}\omega^2-\frac{\theta_4}{\theta_1}v\\ -\frac{\theta_5}{\theta_2}v\omega-\frac{\theta_6}{\theta_2}\omega\end{bmatrix}+\begin{bmatrix}0&0\\0&0\\0&0\\ \frac{1}{\theta_1}&0\\ 0&\frac{1}{\theta_2}\end{bmatrix}\begin{bmatrix}v_{ref}\\ \omega_{ref}\end{bmatrix}+\begin{bmatrix}\delta_x\\ \delta_y\\ 0\\ \delta_v\\ \delta_\omega\end{bmatrix},$$

Input Vector:

$$\boldsymbol{h}=[x \quad y]^t$$

Time derivative of

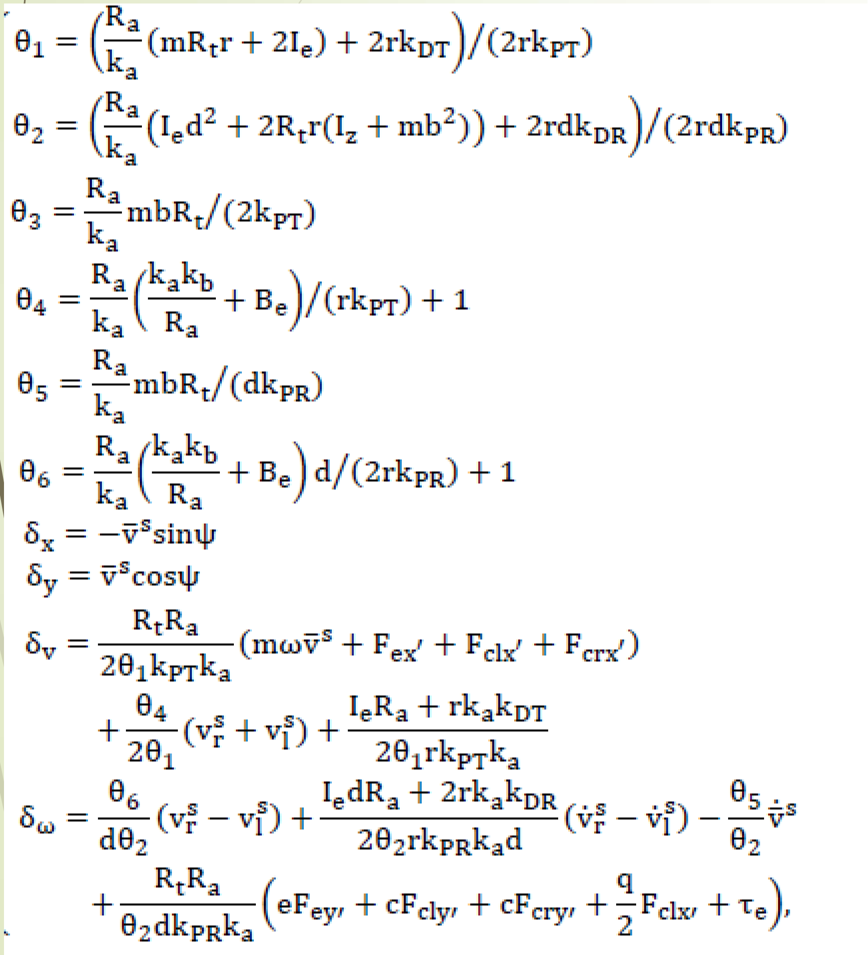
$$\dot{\boldsymbol{h}}=\begin{bmatrix}\dot{x}\\ \dot{y}\end{bmatrix}=\begin{bmatrix}cos\psi & -asin\psi\\ sin\psi & acos\psi\end{bmatrix}\begin{bmatrix}v\\ \omega\end{bmatrix},$$

Closed Loop input equation with velocity

$$\dot{\tilde{\boldsymbol{h}}}=-\left[l_x tanh\left(\frac{k_x}{l_x}\tilde{x}\right) \quad l_y tanh\left(\frac{k_y}{l_y}\tilde{y}\right)\right]^t$$

Kinematics Control

$$\begin{bmatrix}v_d\\ \omega_d\end{bmatrix}=\begin{bmatrix}cos\psi & sin\psi\\ -\frac{1}{a}sin\psi & \frac{1}{a}cos\psi\end{bmatrix}\begin{bmatrix}\dot{x}_d+l_x tanh\left(\frac{k_x}{l_x}\tilde{x}\right)\\ \dot{y}_d+l_y tanh\left(\frac{k_y}{l_y}\tilde{y}\right)\end{bmatrix}.$$



$$\theta_1 = \left(\frac{R_a}{k_a}(mR_t r + 2I_e) + 2rk_{DT}\right)/(2rk_{PT})$$

$$\theta_2 = \left(\frac{R_a}{k_a}(I_e d^2 + 2R_t r(I_z + mb^2)) + 2rdk_{DR}\right)/(2rdk_{PR})$$

$$\theta_3 = \frac{R_a}{k_a} mbR_t/(2k_{PT})$$

$$\theta_4 = \frac{R_a}{k_a}\left(\frac{k_a k_b}{R_a} + B_e\right)/(rk_{PT}) + 1$$

$$\theta_5 = \frac{R_a}{k_a} mbR_t/(dk_{PR})$$

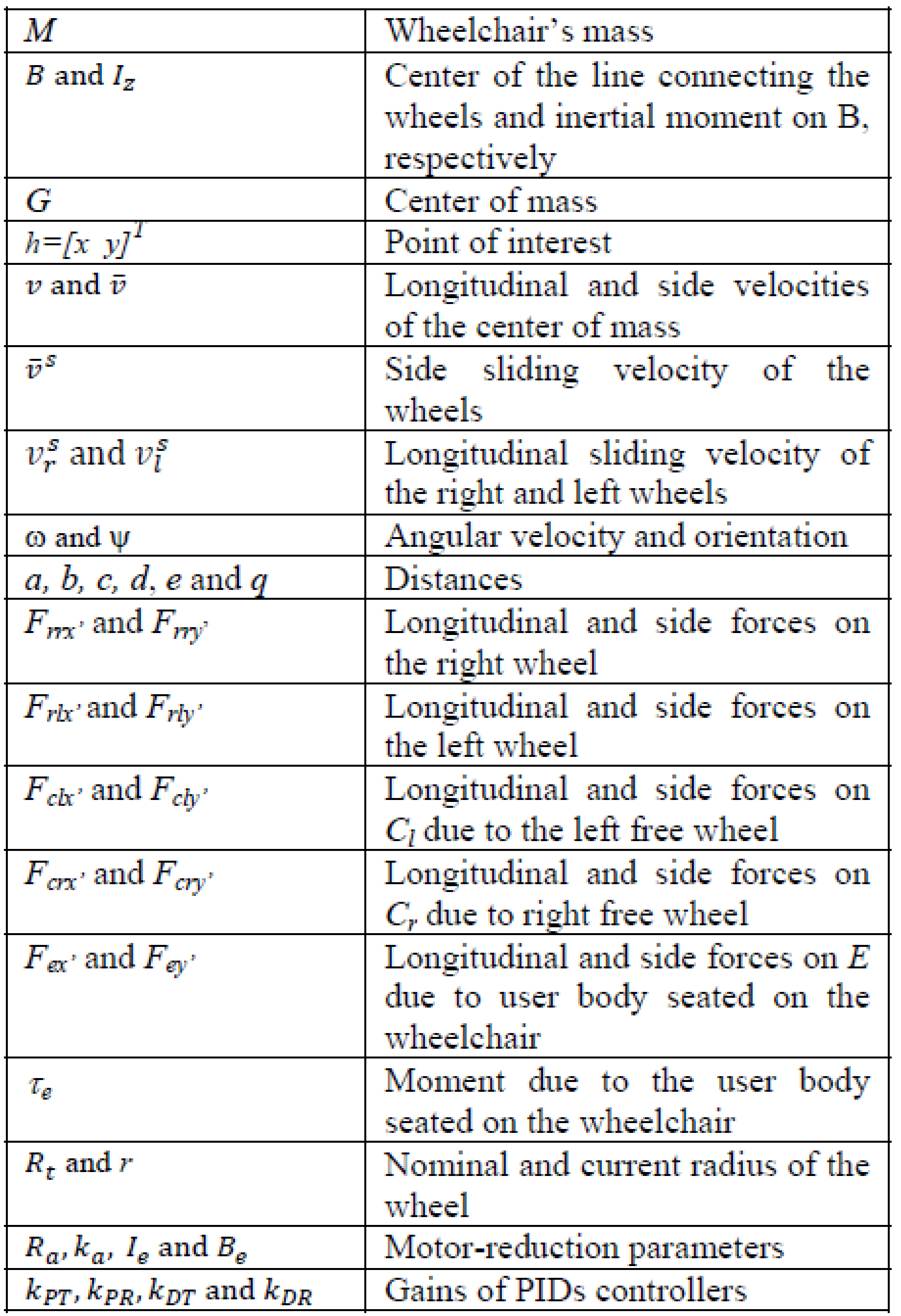
$$\theta_6 = \frac{R_a}{k_a}\left(\frac{k_a k_b}{R_a} + B_e\right) d/(2rk_{PR}) + 1$$

$$\delta_x = -\bar{v}^s \sin\psi$$

$$\delta_y = \bar{v}^s \cos\psi$$

$$\delta_v = \frac{R_t R_a}{2\theta_1 k_{PT} k_a}(m\omega\bar{v}^s + F_{ex'} + F_{clx'} + F_{crx'}) + \frac{\theta_4}{2\theta_1}(v_r^s + v_l^s) + \frac{I_e R_a + rk_a k_{DT}}{2\theta_1 rk_{PT} k_a}$$

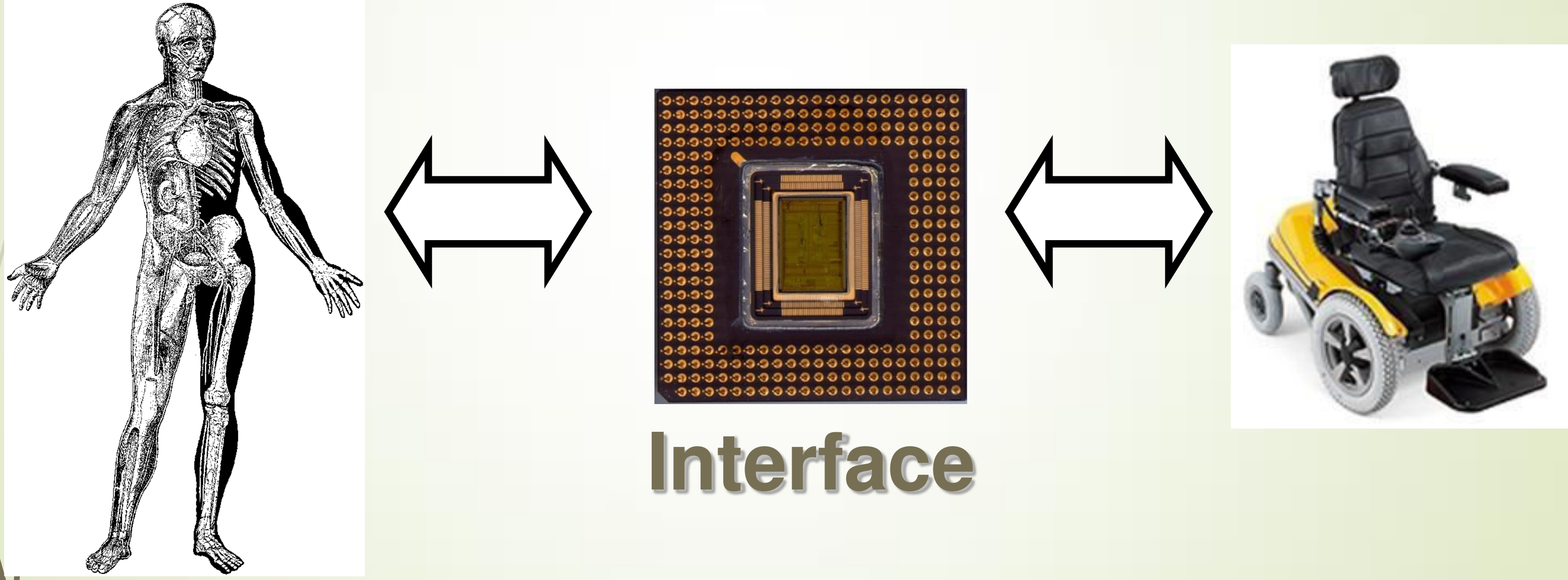
$$\delta_\omega = \frac{\theta_6}{d\theta_2}(v_r^s - v_l^s) + \frac{I_e dR_a + 2rk_a k_{DR}}{2\theta_2 rk_{PR} k_a d}(\dot{v}_r^s - \dot{v}_l^s) - \frac{\theta_5}{\theta_2}\dot{\bar{v}}^s + \frac{R_t R_a}{\theta_2 dk_{PR} k_a}\left(eF_{ey'} + cF_{cly'} + cF_{cry'} + \frac{q}{2}F_{clx'} + \tau_e\right),$$



M	Wheelchair's mass
B and I_z	Center of the line connecting the wheels and inertial moment on B, respectively
G	Center of mass
$h=[x\ \ y]^T$	Point of interest
v and $\bar{v}$	Longitudinal and side velocities of the center of mass
$\bar{v}^s$	Side sliding velocity of the wheels
v_r^s and v_l^s	Longitudinal sliding velocity of the right and left wheels
ω and ψ	Angular velocity and orientation
a, b, c, d, e and q	Distances
$F_{rrx'}$ and $F_{rry'}$	Longitudinal and side forces on the right wheel
$F_{rlx'}$ and $F_{rly'}$	Longitudinal and side forces on the left wheel
$F_{clx'}$ and $F_{cly'}$	Longitudinal and side forces on C_l due to the left free wheel
$F_{crx'}$ and $F_{cry'}$	Longitudinal and side forces on C_r due to right free wheel
$F_{ex'}$ and $F_{ey'}$	Longitudinal and side forces on E due to user body seated on the wheelchair
τ_e	Moment due to the user body seated on the wheelchair
R_t and r	Nominal and current radius of the wheel
R_a, k_a, I_e and B_e	Motor-reduction parameters
k_{PT}, k_{PR}, k_{DT} and k_{DR}	Gains of PIDs controllers

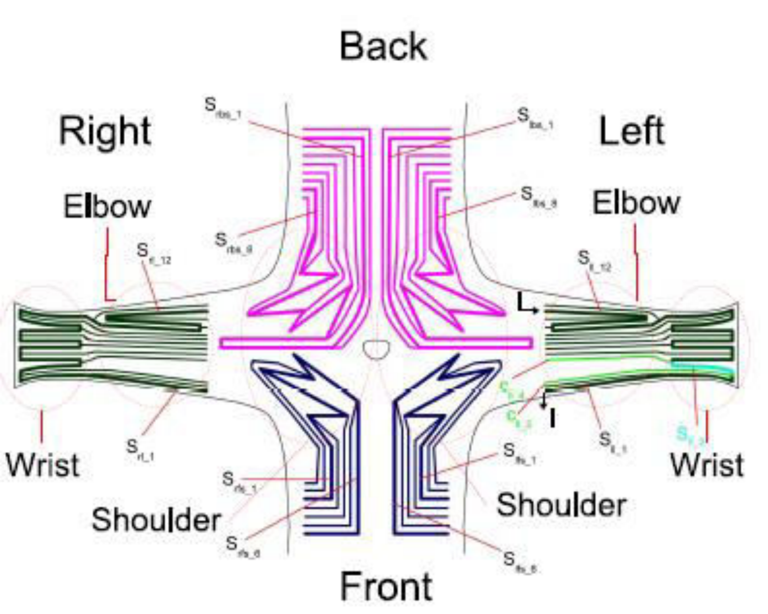
Shared Control Robotics

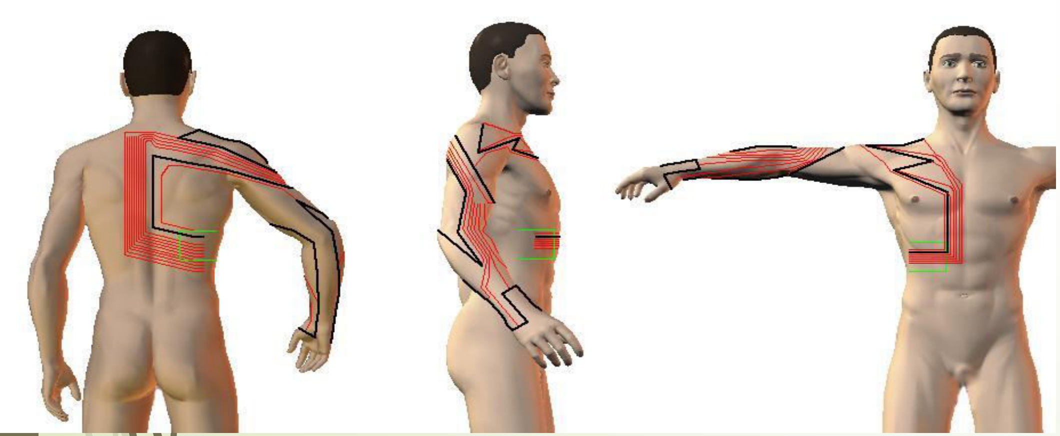
Learning Interfaces



Interface

Wearable Sensors – For body signals

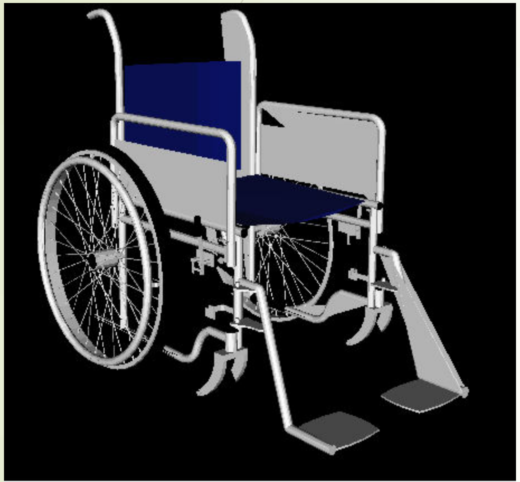


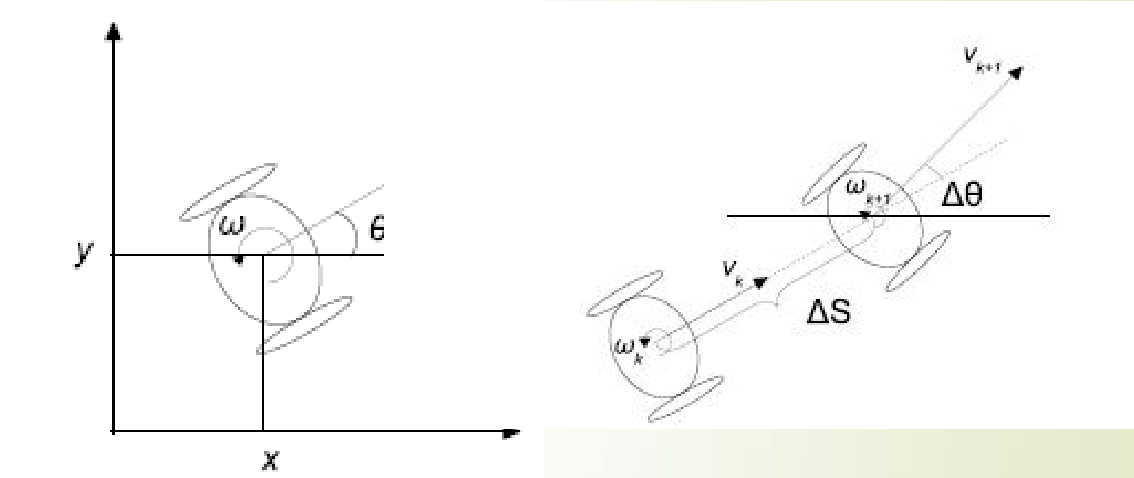


52 - sensors

Change in current due to deformations caused by body movement.

Wheelchair Kinematics Model



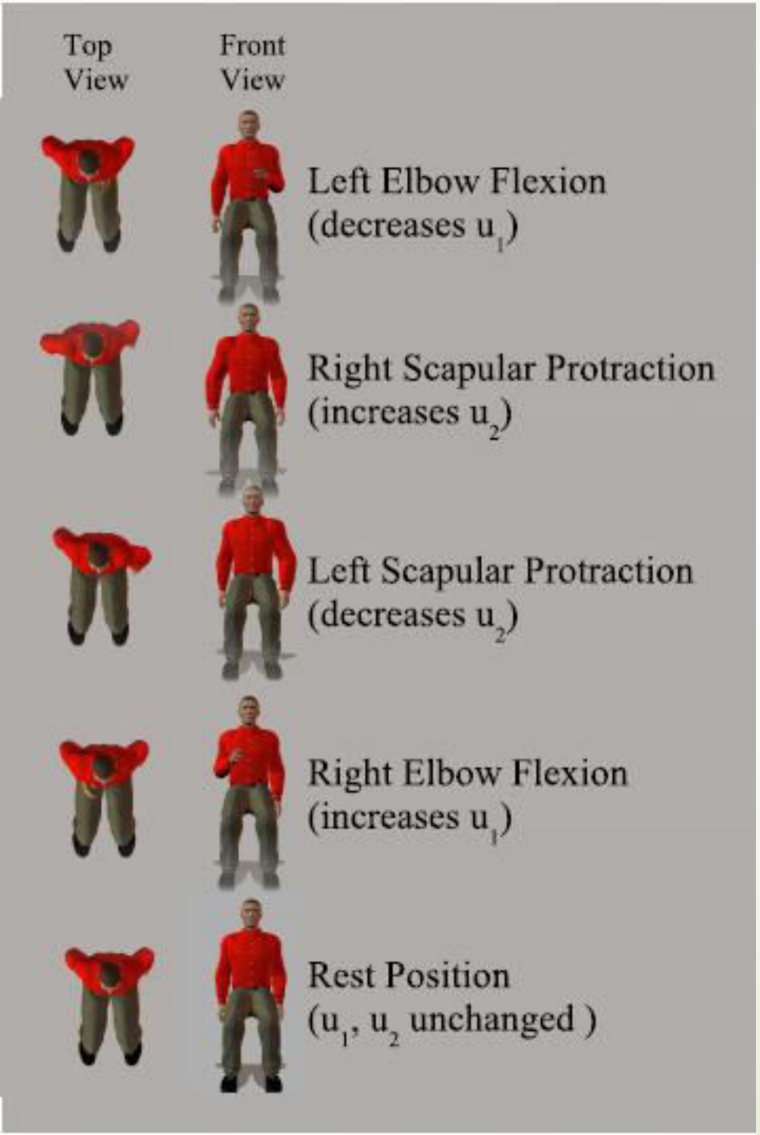


$$\begin{aligned}\dot{x}(t) &= v(t)cos(\theta(t))\\ \dot{y}(t) &= v(t)sin(\theta(t))\\ \dot{\theta}(t) &= \omega(t)\end{aligned}$$

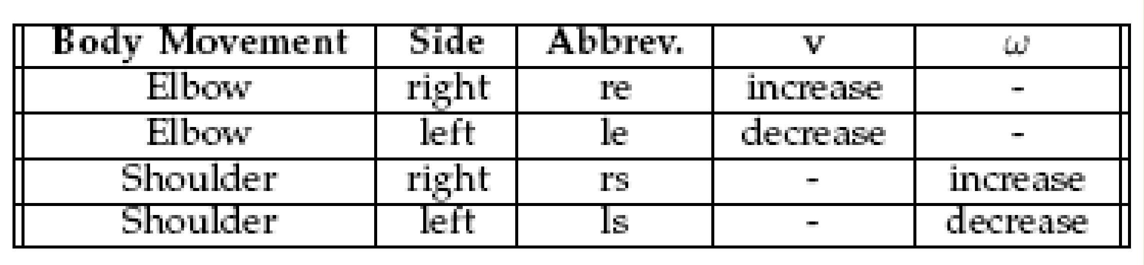
$$\begin{aligned}x_{k+1} &= x_k + v_k cos(\theta_k)\Delta t\\ y_{k+1} &= y_k + v_k sin(\theta_k)\Delta t\\ \theta_{k+1} &= \theta_k + \omega_k \Delta t\end{aligned}$$

$$\begin{aligned}\Delta S &= v_k \Delta t = k_1 V_{f\,k} \Delta t\\ \Delta\theta &= \omega_k \Delta t = k_2 V_{r\,k} \Delta t\end{aligned}$$

Wheelchair Control Strategy

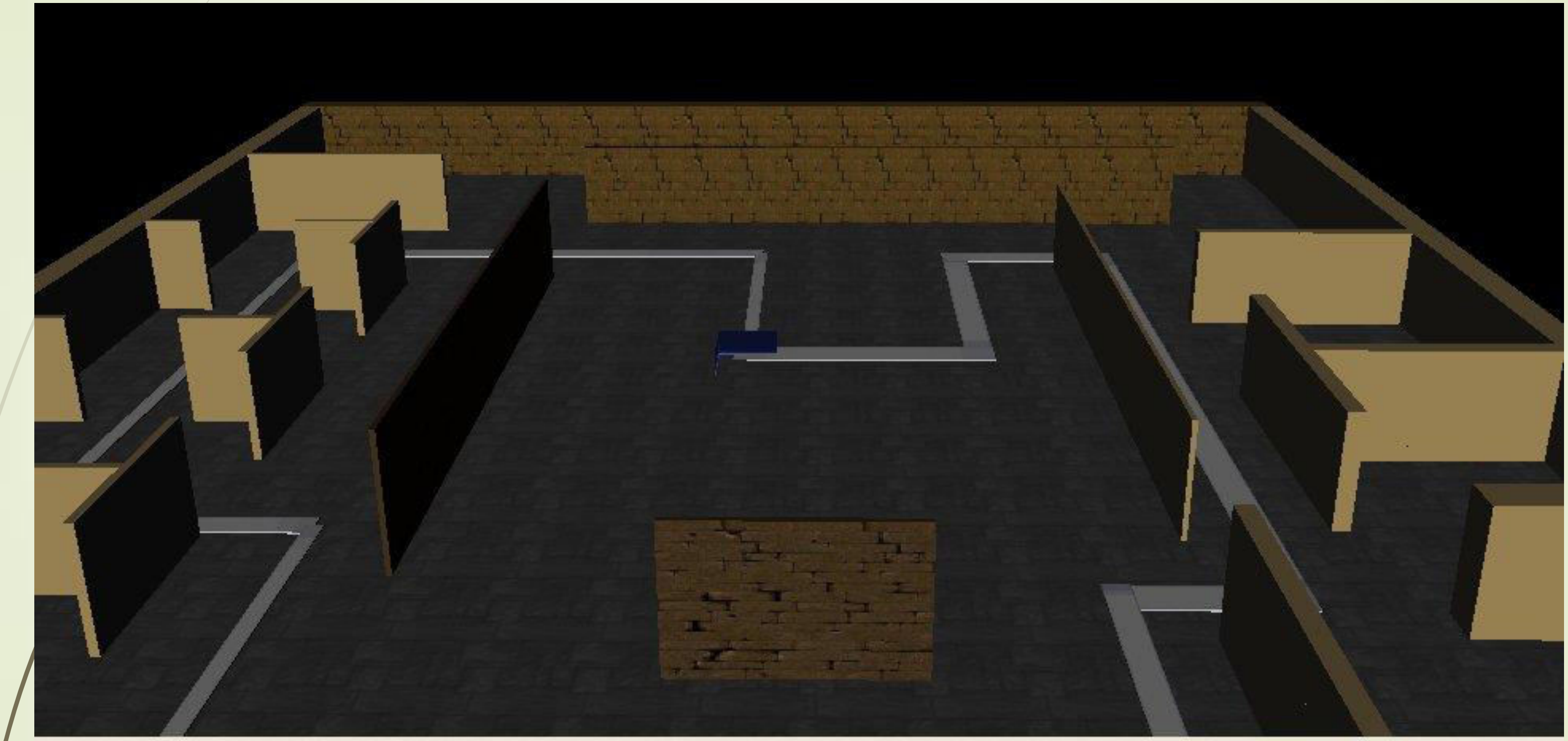


$$u = [v_k, \omega_k]^T$$

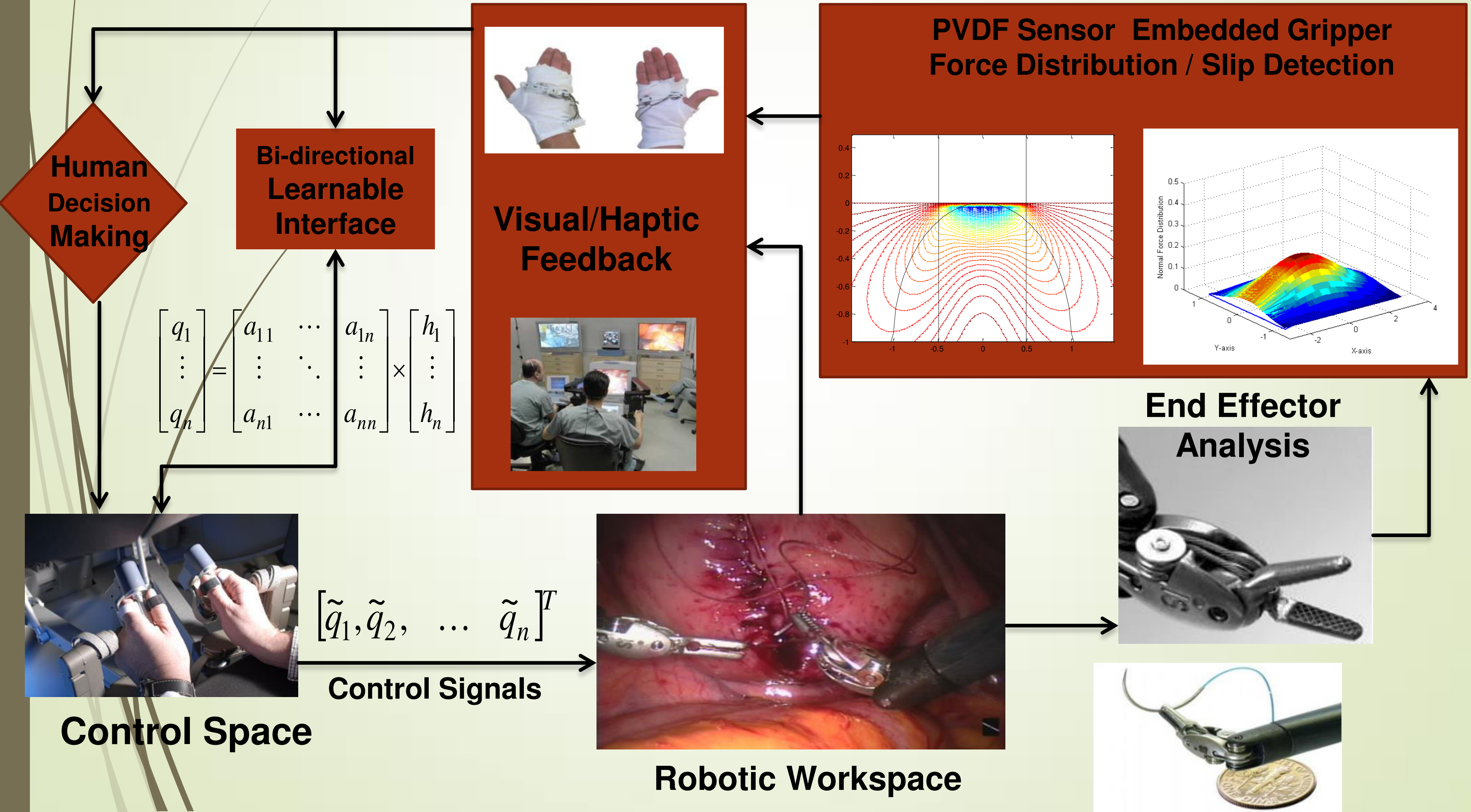


Body Movement	Side	Abbrev.	v	ω
Elbow	right	re	increase	-
Elbow	left	le	decrease	-
Shoulder	right	rs	-	increase
Shoulder	left	ls	-	decrease

Wheelchair Non-destructive Testbed (Virtual Reality)



Minimal Invasive Tele-Robotic Surgical System



PVDF Sensor Embedded Gripper
Force Distribution / Slip Detection

Human Decision Making

Bi-directional Learnable Interface

Visual/Haptic Feedback

$$\begin{bmatrix} q_1 \\ \vdots \\ q_n \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} h_1 \\ \vdots \\ h_n \end{bmatrix}$$

End Effector Analysis

$$[\tilde{q}_1, \tilde{q}_2, \quad \dots \quad \tilde{q}_n]^T$$

Control Signals

Control Space

Robotic Workspace

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