IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

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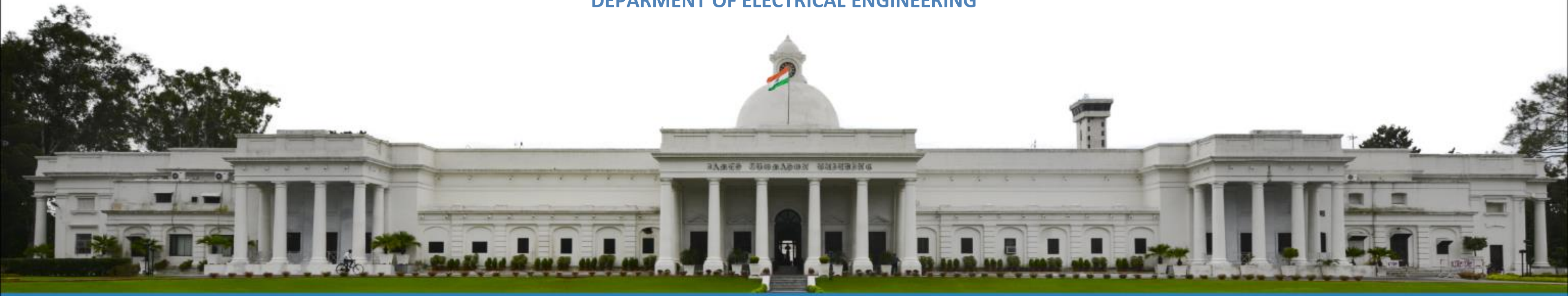
DEPARMENT OF ELECTRICAL ENGINEERING



Force Control of an Index Finger Exoskeleton

Outline

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3. Force Control Strategy
4. Stability Analysis
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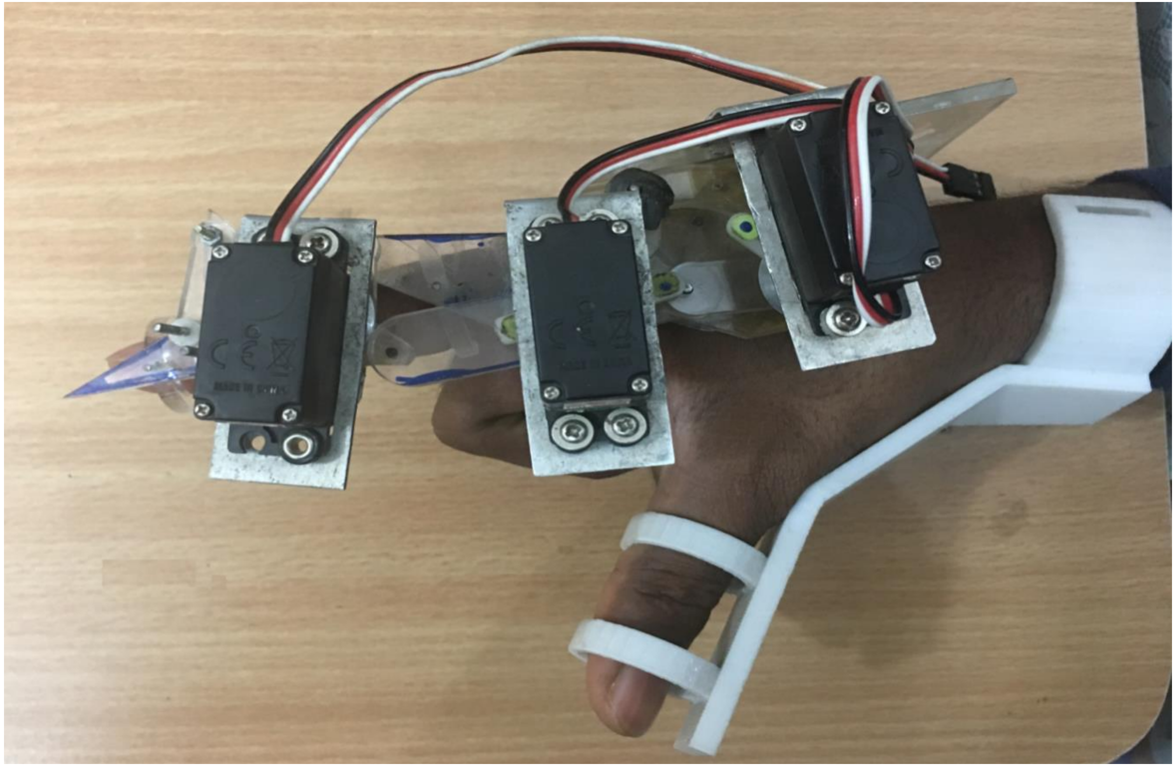
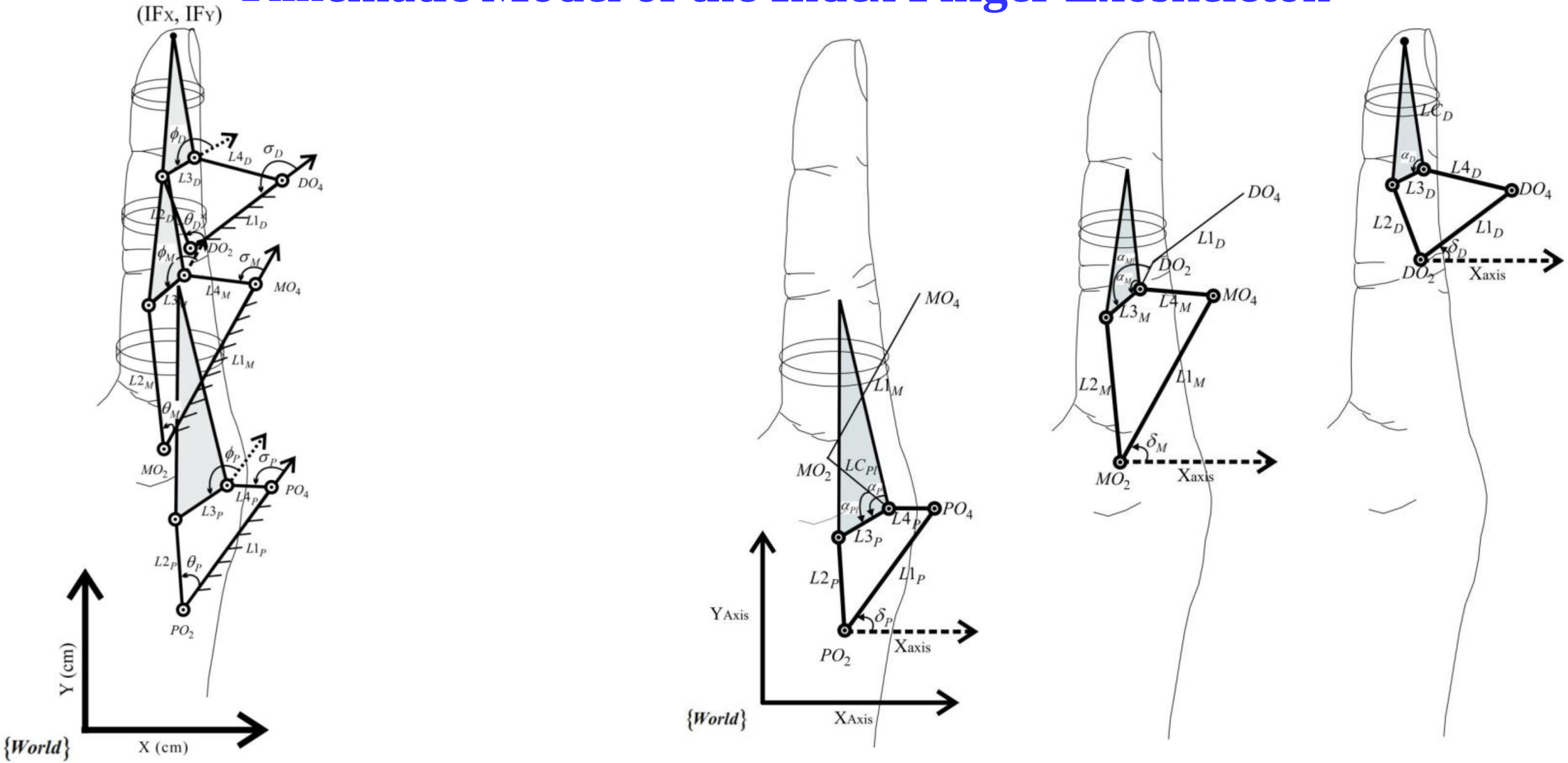


Kinematic Model of the Index Finger Exoskeleton



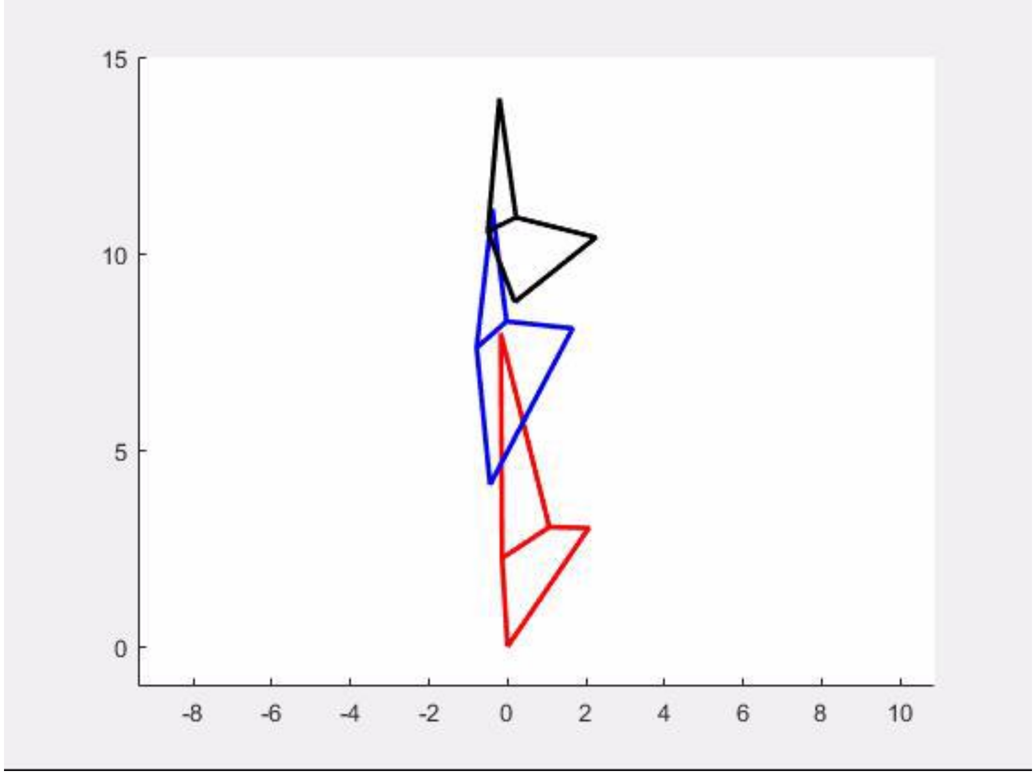
(a) Serially connected 4-bars

(b) Proximal 4-bar

(c) Middle 4-bar

(d) Distal 4-bar

Kinematic Model of the Index Finger Exoskeleton



Kinematic Model of the Index Finger Exoskeleton (cont'd)

$$X_{IF} = \cos(\delta_M)\times(L1_M + L4_M\times\cos(\sigma_M) + LC_{Ml}\times\cos(\phi_M - \alpha_{Ml})) - \sin(\delta_M)\times(L4_M\times\sin(\sigma_M)$$

$$+LC_{Ml}\times\sin(\phi_M - \alpha_{Ml})) + \cos(\delta_P)\times(L1_P + L4_P\times\cos(\sigma_P) + LC_{Pl}\times\cos(\phi_P - \alpha_{Pl}))$$

$$-\sin(\delta_P)\times(L4_P\times\sin(\sigma_P) + LC_{Pl}\times\sin(\phi_P - \alpha_{Pl})) + \cos(\delta_D)\times(L1_D + L4_D\times\cos(\sigma_D)$$

$$+LC_D\times\cos(\phi_D - \alpha_D)) - \sin(\delta_D)\times(L4_D\times\sin(\sigma_D) + LC_D\times\sin(\phi_D - \alpha_D))$$

$$Y_{IF} = \sin(\delta_M)\times(L1_M + L4_M\times\cos(\sigma_M) + LC_{Ml}\times\cos(\phi_M - \alpha_{Ml})) + \cos(\delta_M)\times(L4_M\times\sin(\sigma_M)$$

$$+LC_{Ml}\times\sin(\phi_M - \alpha_{Ml})) + \sin(\delta_P)\times(L1_P + L4_P\times\cos(\sigma_P) + LC_{Pl}\times\cos(\phi_P - \alpha_{Pl}))$$

$$+\cos(\delta_P)\times(L4_P\times\sin(\sigma_P) + LC_{Pl}\times\sin(\phi_P - \alpha_{Pl})) + \sin(\delta_D)\times(L1_D + L4_D\times\cos(\sigma_D)$$

$$+LC_D\times\cos(\phi_D - \alpha_D)) + \cos(\delta_D)\times(L4_D\times\sin(\sigma_D) + LC_D\times\sin(\phi_D - \alpha_D))$$

Force Control Strategy

- To derive the force control law based on the Jacobian transpose method, ideal dynamics of index finger exoskeleton is assumed.

- Hence, the joint torque is given by

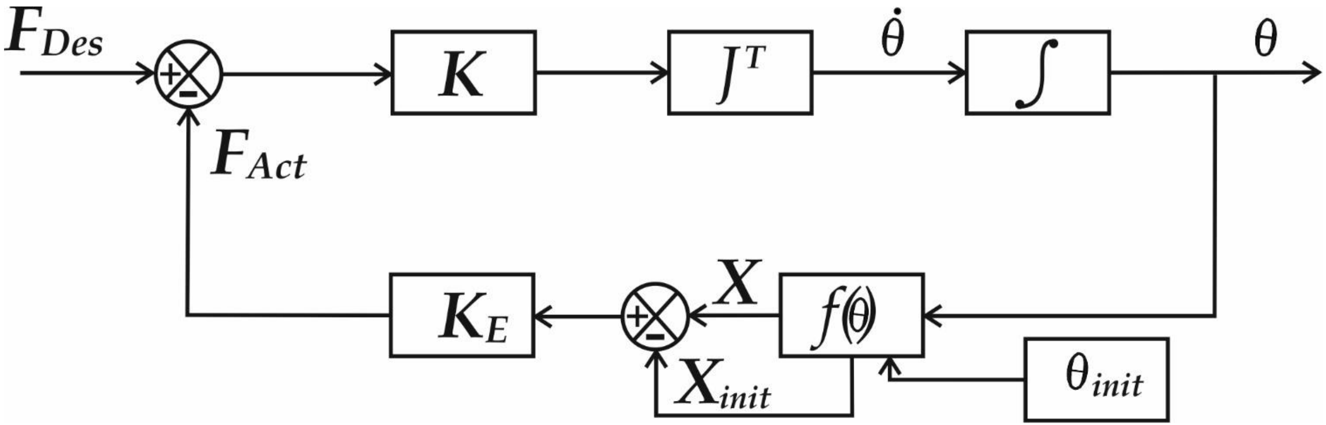
$$\tau = \dot{\theta}$$

- Thus the update law

$$\dot{\theta} = J^T K E$$

- Force KE to regulated the tip of the exoskeleton towards the desired force.

Force Control Strategy



F_{Des} ⟶ Desired Force

F_{Act} ⟶ Actual Force

K_E ⟶ Stiffness Matrix

Stability Analysis

The Lyapunov function is taken as,

$$V(E) = \frac{1}{2}E^T K E \qquad V(E) > 0 \ \forall \ E \neq 0 \qquad V(0) = 0$$

By Differentiating,

$$\begin{aligned}
\dot{V} &= E^T K \dot{E} \\
&= E^T K(\dot{F}_{des} - \dot{F}) \\
&= E^T K \dot{F}_{des} - E^T K K_E(\dot{X} - \dot{X}_{init}) \\
&= E^T K \dot{F}_{des} - E^T K K_E \dot{X} + E^T K K_E \dot{X}_{init}
\end{aligned}$$

Where,

$$F = K_E(X - X_{init}) \text{ and } \dot{F} = K_E(\dot{X} - \dot{X}_{init})$$

Stability Analysis (cont'd)

Again,

$$\dot{V} = E^T K \dot{F}_{des} - E^T K K_E J(\theta)\dot{\theta} + E^T K K_E J(\theta)\dot{\theta}_{init}$$

Substituting the joint velocity control law

$$\begin{aligned}\dot{V} = E^T K \dot{F}_{des} - E^T K K_E J(\theta) J^T(\theta) K E \\ + E^T K K_E J(\theta_{init}) J^T(\theta_{init}) K E\end{aligned}$$

Assuming, $\dot{F}_{des} = 0, \quad \dot{X}_{init} = 0,$

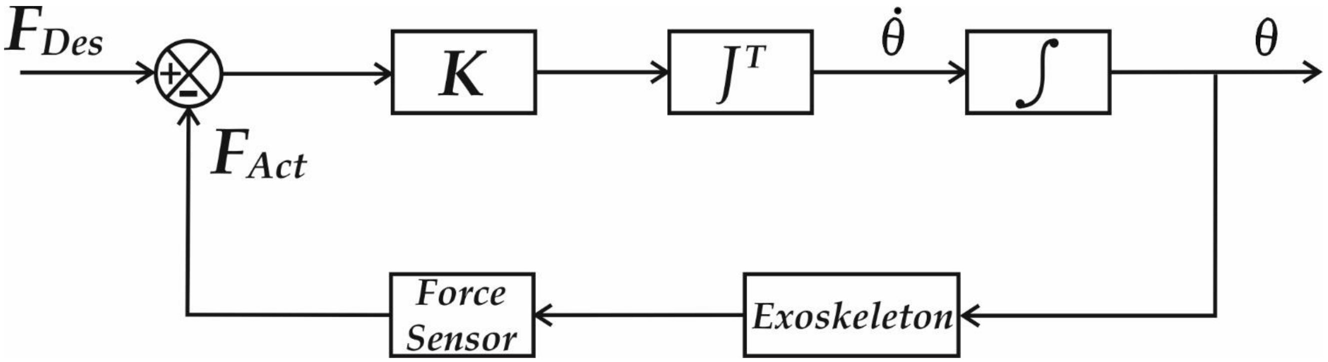
So, from the above assumption, $\dot{V} = -E^T K K_E J(\theta) J^T(\theta) K E$

$$< 0$$

Therefore, $V > 0$ and $\dot{V} < 0$

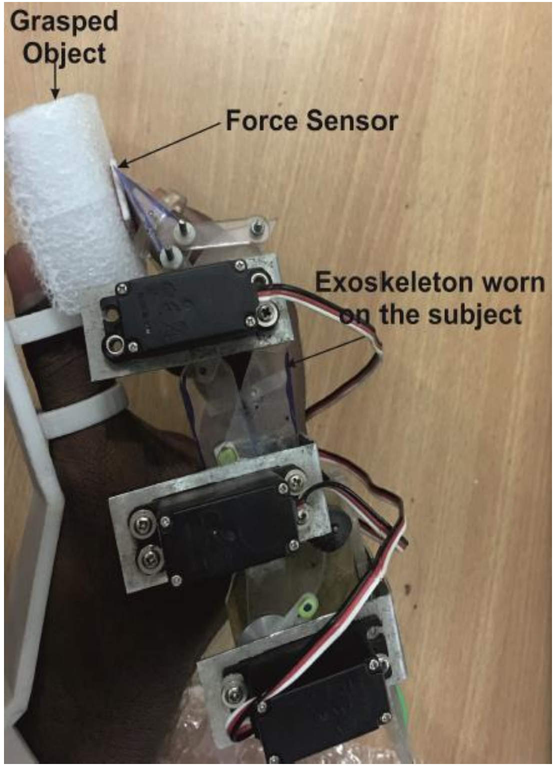
The error is converges to zero so, the system is asymptotically stable

Experiment



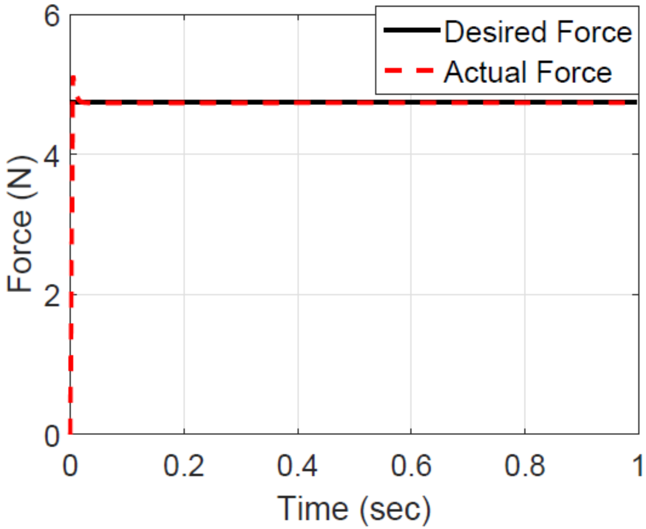
Force Sensor (FSR402) used in our Study

Experiment

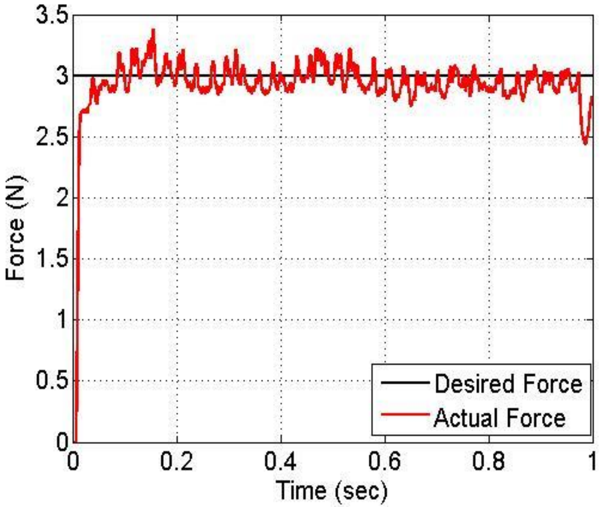


Human Subject Grasping a Deformable Object

Results



Desired Force
Actual Force
Force (N)
Time (sec)
0
2
4
6
0
0.2
0.4
0.6
0.8
1



Desired Force
Actual Force
Force (N)
Time (sec)
0
0.5
1
1.5
2
2.5
3
3.5
0
0.2
0.4
0.6
0.8
1

Results

Time domain specification for simulation

S. No.	Parameters	Values
1.	Rise time (sec)	0.0037
2.	Peak time (sec)	0.0050
3.	Settling time (sec)	0.0121
4.	Maximum overshoot (%)	8.2053
5.	Peak value (N)	5.1263

Time domain specification for experiment

S. No.	Parameters	Values
1.	Rise time (sec)	0.0046
2.	Peak time (sec)	0.1531
3.	Settling time (sec)	0.9972
4.	Maximum overshoot (%)	16.1111
5.	Peak value (N)	3.3768

Limitations

- Only static force analysis; Dynamics?

- Robustness?

- Statistical analysis with rehabilitation paradigms?

Conclusion

- A primitive study on force analysis is performed on the index finger exoskeleton

- Future study on Robust control strategy – disturbance analysis.

Thank You!