

Object exploration using haptic information by a human-robot team

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Goal

Human-Robot cooperative estimation of load uncertainties.

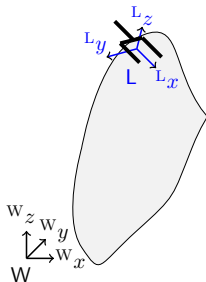
Key-Questions

- How to fuse and process sensor feedback, resulting in a reliable load-identification?
- How should the agents excite the load?
- How to exchange information between agents?

Online Load Estimation

Model:

[Hatsopoulos and W. Warren 1996]



$${}^L\mathbf{F} = m {}^W\ddot{\mathbf{p}} + m {}^L\mathbf{g} + {}^L\dot{\boldsymbol{\omega}} \times m {}^L\mathbf{c} + {}^L\boldsymbol{\omega} \times ({}^L\boldsymbol{\omega} \times m {}^L\mathbf{c})$$

$${}^L\mathbf{N} = {}^L\mathbf{I} {}^L\dot{\boldsymbol{\omega}} + {}^L\boldsymbol{\omega} \times ({}^L\mathbf{I} {}^L\boldsymbol{\omega}) + m {}^L\mathbf{c} \times {}^W\ddot{\mathbf{p}} + m {}^L\mathbf{c} \times {}^L\mathbf{g}$$

$\ddot{\mathbf{p}}$ EEf acceleration

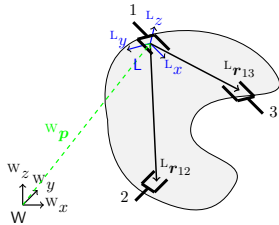
m Object mass

\mathbf{I} Object inertia tensor

RLS Estimation-Parameters:

$$\boldsymbol{\Theta} = [m, mc_x, mc_y, mc_z, I_{xx}, I_{xy}, I_{xz}, I_{yy}, I_{yz}, I_{zz}]^T$$

Cooperative Online Load Estimation



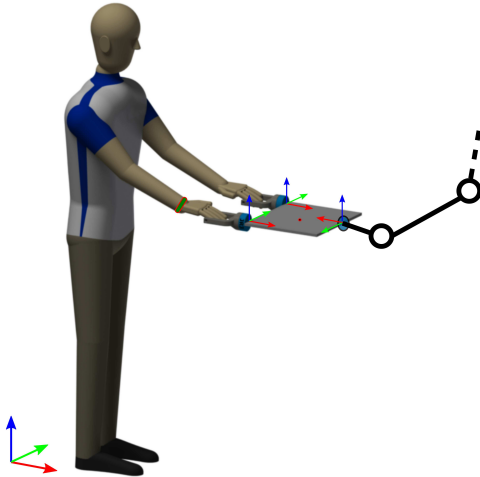
${}^L\mathbf{F}_i$: Forces acting at grasping point i , measured w.r.t. the EEF frame L .

${}^L\mathbf{N}_i$: Torques acting at grasping point i , measured w.r.t. the EEF frame L .

$$\sum_{i=1}^n {}^L\mathbf{F}_i = f({}^W\ddot{\mathbf{p}}, {}^L\boldsymbol{\omega}, {}^L\dot{\boldsymbol{\omega}}, {}^L\mathbf{c}, m)$$

$$\sum_{i=1}^n {}^L\mathbf{N}_i + \sum_{i=2}^n {}^L\mathbf{r}_{1i} \times {}^L\mathbf{F}_i = f({}^W\ddot{\mathbf{p}}, {}^L\boldsymbol{\omega}, {}^L\dot{\boldsymbol{\omega}}, {}^L\mathbf{c}, {}^L\mathbf{I}, m)$$

Cooperative Online Load Estimation

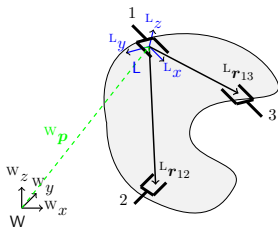


RLS convergence prerequisites

- Reference trajectory must be persistently exciting(PE)
- Non-zero acceleration of EEF in 6-DoF [Yoshida 1999]

CHALLENGE: Satisfaction of actuator limits, especially when trying to identify big objects.

Data Acquisition



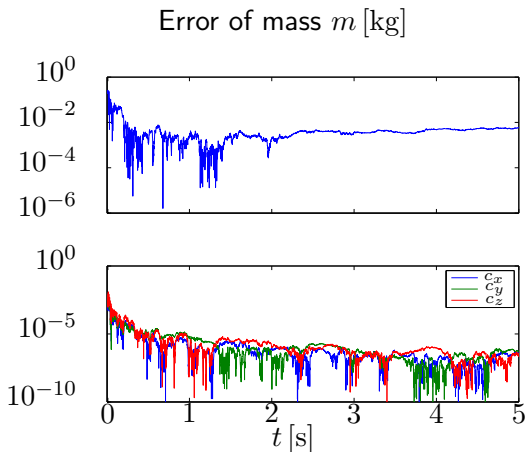
Information	Tool	Frame Rate [Hz]
${}^L F_i, {}^L N_i$	JR3	8000 \rightarrow 100
	QUALISYS	100
${}^L \omega$	QUALISYS	100
${}^W p$	QUALISYS	100
${}^L r_{1i}$	QUALISYS	100

Experimental Results

Conducted experiments: PROPOSAL

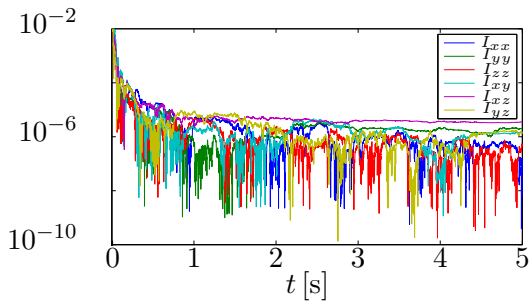
- Multiple grasping points in simulation
- One grasping point
- Multiple grasping points

Simulation Results with Noise ($P = 0.05 \text{ W}$)



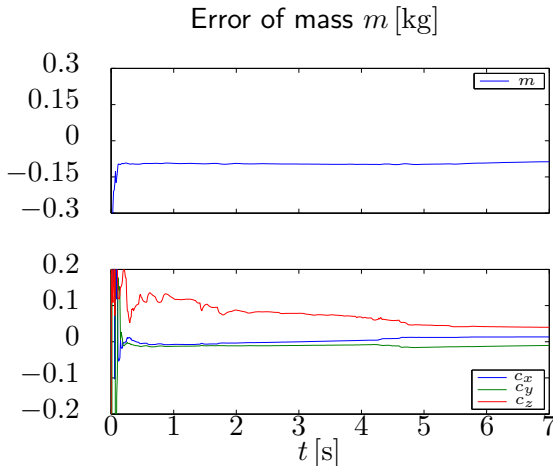
Error of center of gravity $c \text{ [m]}$

Simulation Results with Noise ($P = 0.05 \text{ W}$)



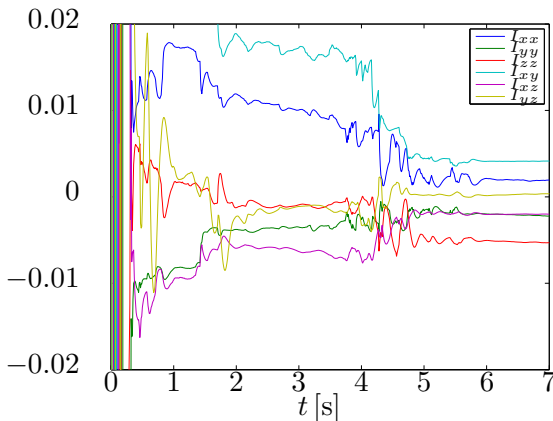
Error of inertias $I \text{ [kg} \cdot \text{m}^2]$

One Grasping Point



Error of center of gravity c [m]

One Grasping Point



Error of inertias I [$\text{kg} \cdot \text{m}^2$]

Multiple Grasping Points

Multiple Grasping Points

Conclusion

References



N. Hatsopoulos and Jr. W. Warren. **Resonance Tuning in Rhythmic Arm Movements.**
In: *Journal of Motor Behaviour* 28.1 (1996), pp. 3–14.



K. Yoshida. **Swing-Up Control of an Inverted Pendulum by Energy-Based Methods.**
In: *American Control Conference* 6 (1999), pp. 4045–4047.