Object exploration using haptic information by a human-robot team

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Content

Task

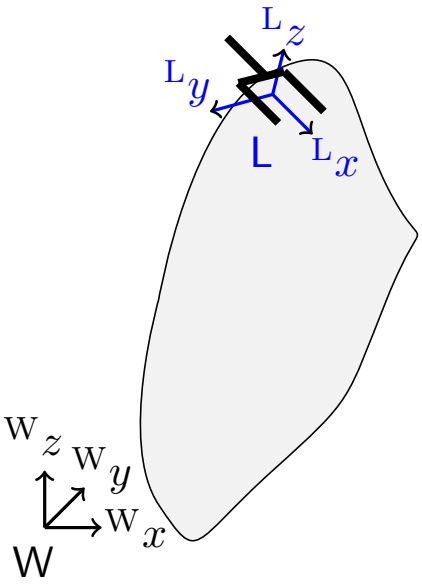
Goal

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]

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

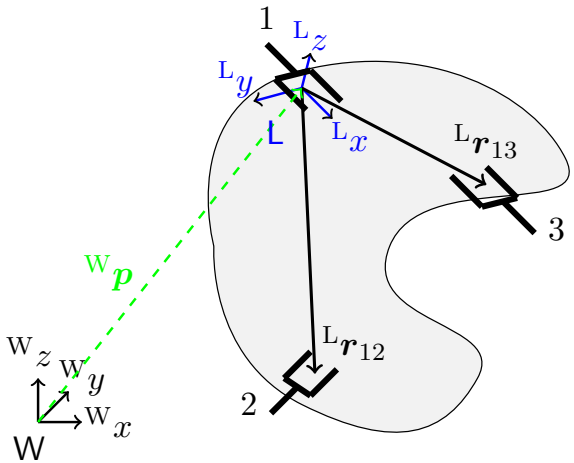
$$^{\mathrm{L}}\boldsymbol{N} = {}^{\mathrm{L}}\boldsymbol{I}\,^{\mathrm{L}}\dot{\boldsymbol{\omega}} + {}^{\mathrm{L}}\boldsymbol{\omega} \times ({}^{\mathrm{L}}\boldsymbol{I}\,^{\mathrm{L}}\boldsymbol{\omega}) + m\,^{\mathrm{L}}\boldsymbol{c} \times {}^{\mathrm{W}}\ddot{\boldsymbol{p}} + m\,^{\mathrm{L}}\boldsymbol{c}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

$\ddot{\boldsymbol{p}}$ EEF acceleration
m Object mass
$\boldsymbol{I}$ Object inertia tensor

RLS Estimation-Parameters:

$$\boldsymbol{\Theta} = [m, mc_{\mathrm{x}}, mc_{\mathrm{y}}, mc_{\mathrm{z}}, I_{\mathrm{xx}}, I_{\mathrm{xy}}, I_{\mathrm{xz}}, I_{\mathrm{yy}}, I_{\mathrm{yz}}, I_{\mathrm{zz}}]^{\mathrm{T}}$$

Cooperative Online Load Estimation



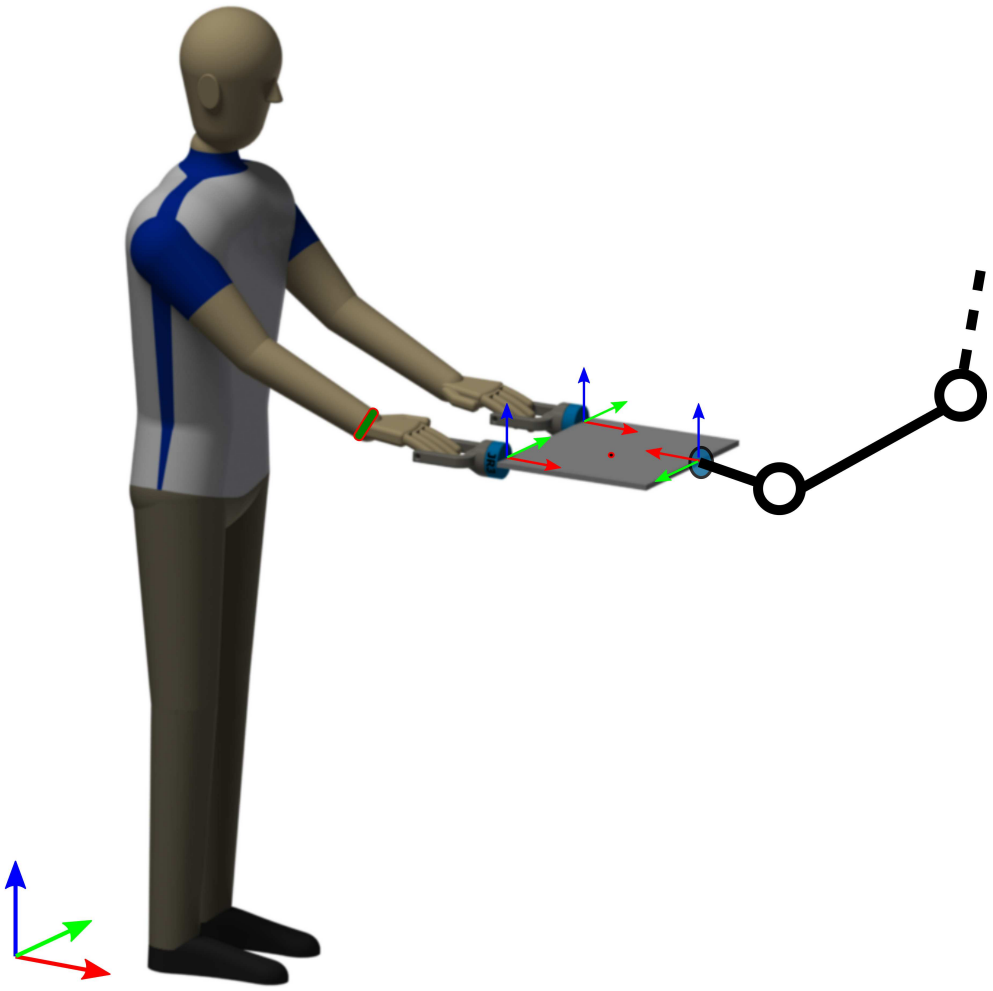
${}^{\mathrm{L}}\boldsymbol{F}_i$: Forces acting at grasping point i, measured w.r.t. the EEF frame L.

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

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

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

Cooperative Online Load Estimation



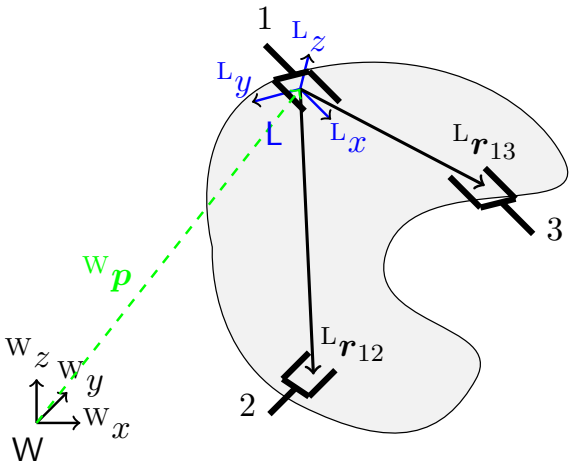
Excitation Pattern

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



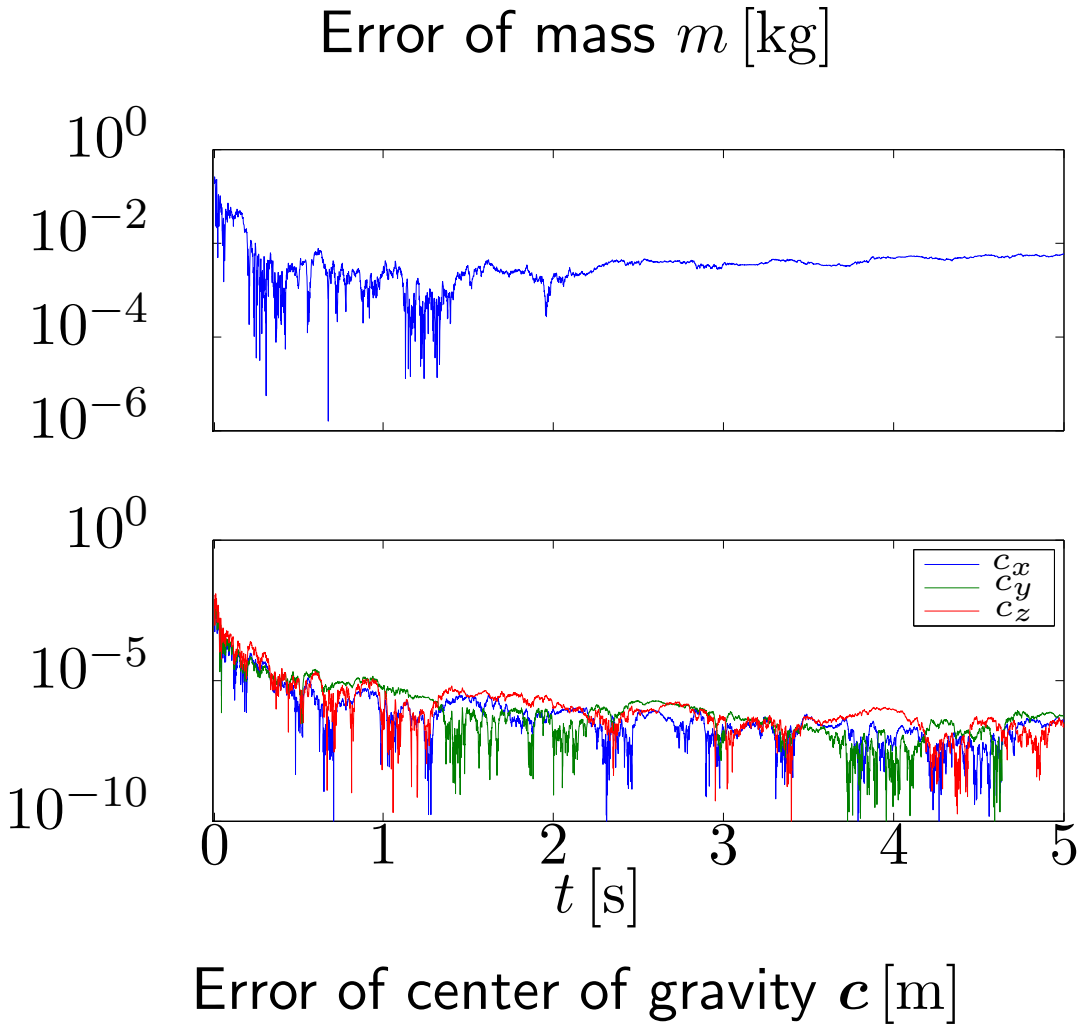
Information	Tool	Frame Rate [Hz]
${}^{\mathrm{L}}\boldsymbol{F}_i, {}^{\mathrm{L}}\boldsymbol{N}_i$	JR3	8000 → 100
	QUALISYS	100
${}^{\mathrm{L}}\boldsymbol{\omega}$	QUALISYS	100
${}^{\mathrm{W}}\boldsymbol{p}$	QUALISYS	100
${}^{\mathrm{L}}\boldsymbol{r}_{1i}$	QUALISYS	100

Experimental Results

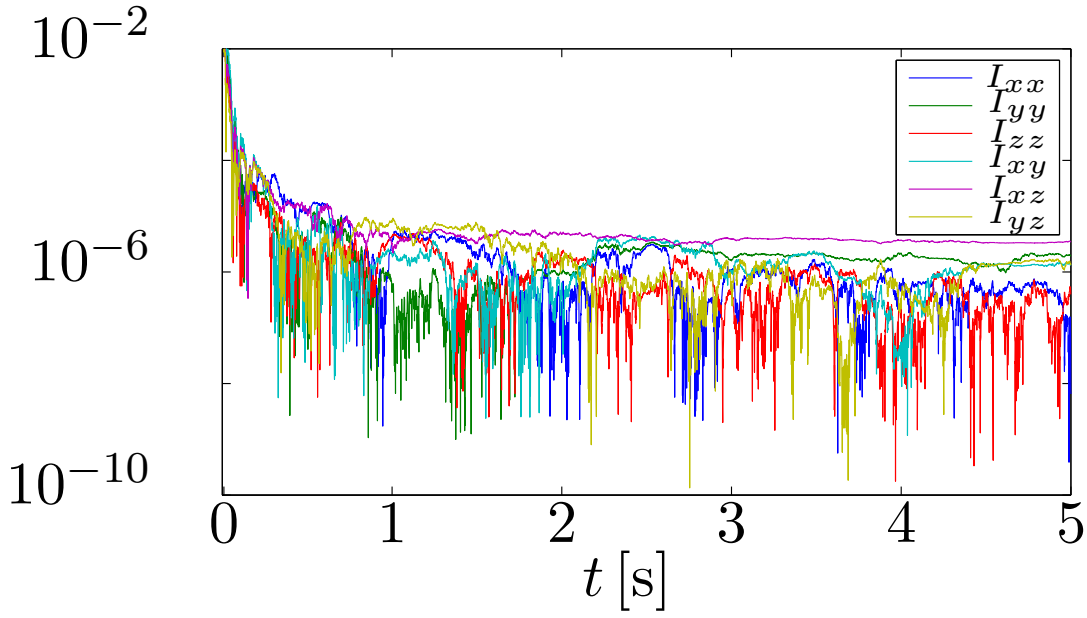
Conducted experiments: PROPOSAL

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

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



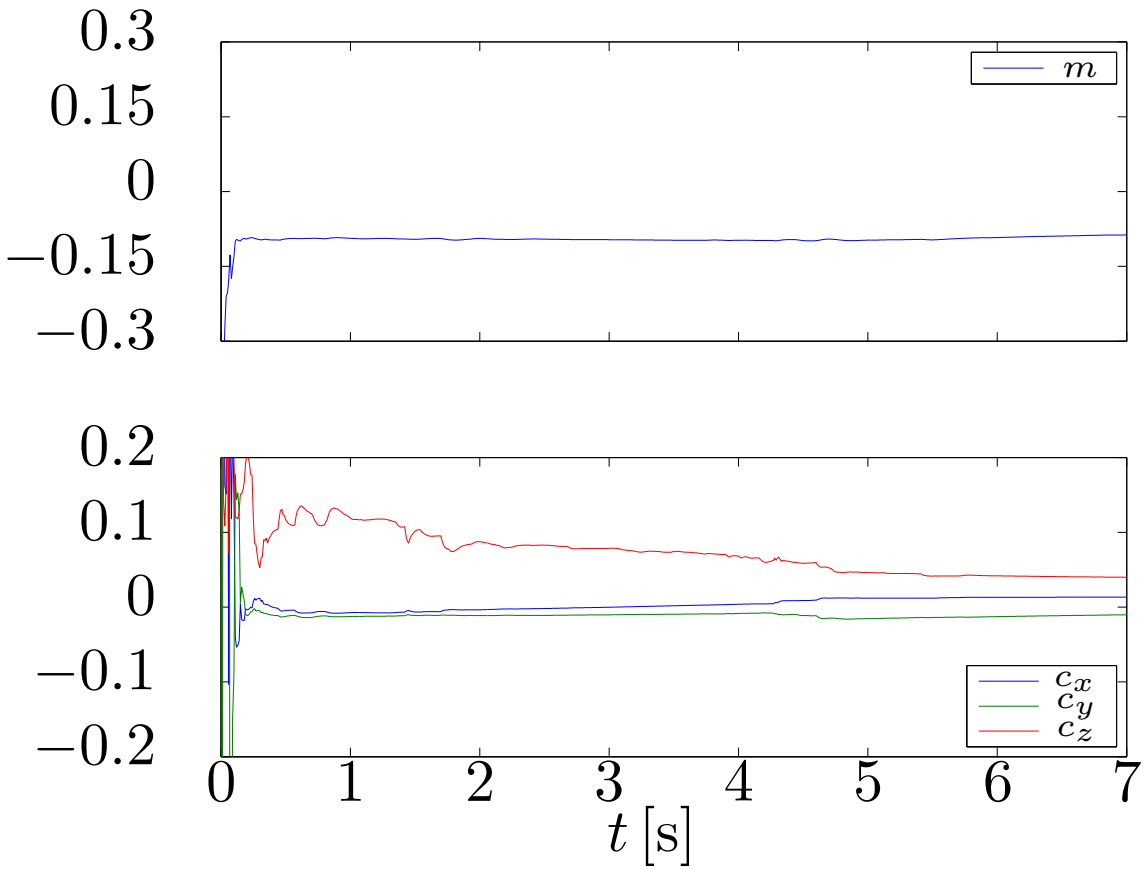
Simulation Results with Noise ($P = 0.05\,\mathrm{W}$)



Error of inertias $I\,\left[\mathrm{kg}\cdot\mathrm{m}^2\right]$

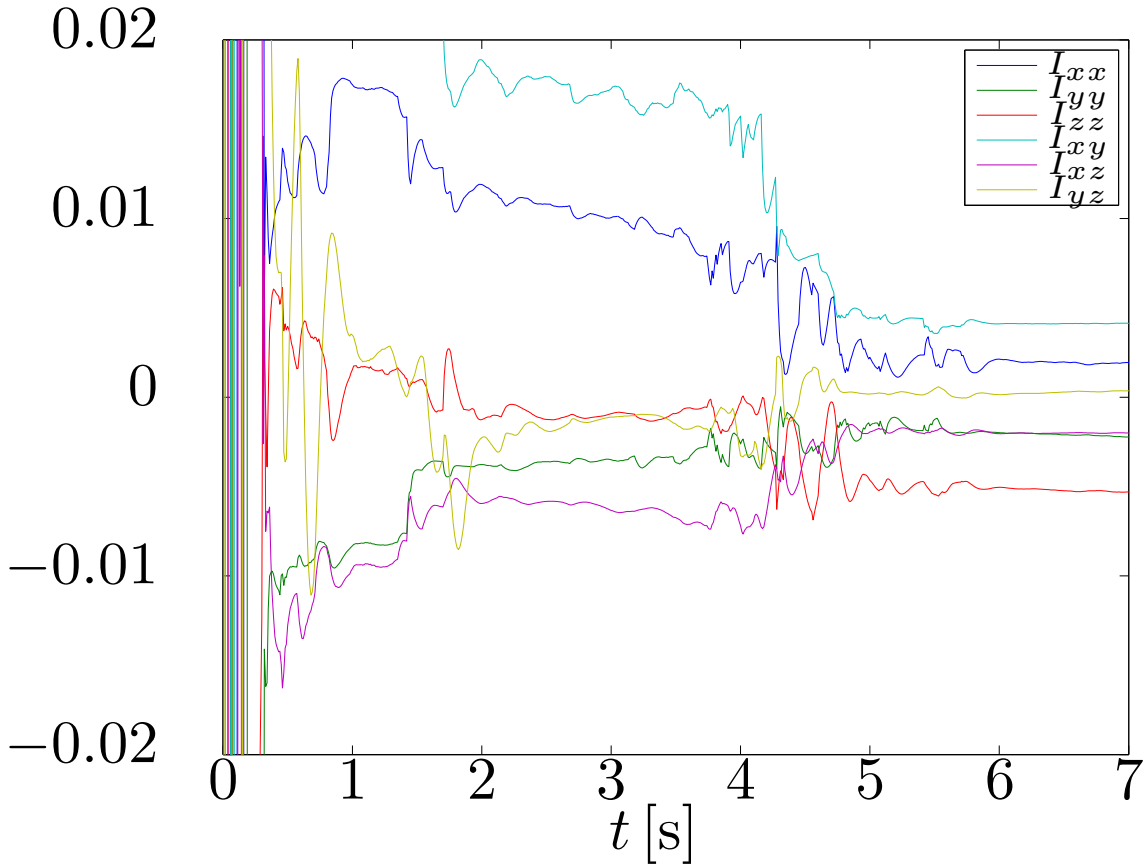
One Grasping Point

Error of mass m [kg]



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

One Grasping Point



Error of inertias I $\left[\mathrm{kg} \cdot \mathrm{m}^2\right]$

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.