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ROS-based Toolbox for Motor Parameter Identification of Robotic Manipulators

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Premise of study

- Complexity vs utility
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- Physical systems discrepancies

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Objectives

- Identify torque-current and friction coefficients in robot manipulators

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- Identify torque-current and friction coefficients in robot manipulators
- Open-source toolbox of the procedure

General Dynamic Model

- Standard Denavit-Hartenberg kinematic convention [1]

General Dynamic Model

- Standard Denavit-Hartenberg kinematic convention [1]
- General dynamic model of robot manipulator [2]

$$\tau_m - \tau_{ext} - \tau_{dist} - \tau_f = M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) \quad (2.1)$$

where $q = [q_1, q_2, q_3, ...q_n]^T$ are joint positions and $\dot{q}$ and $\ddot{q}$ are joint velocities and accelerations respectively, while τ are forces/moments of the robot.

Case study on the UR5 (Universal Robots, Odense, Denmark)

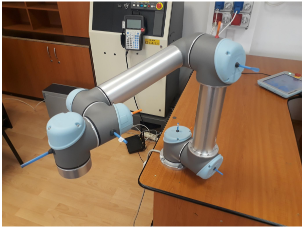

Figure 2.1: Installed UR5

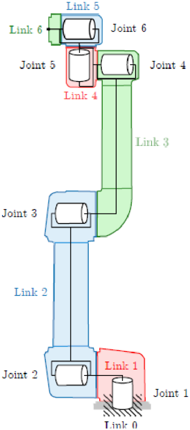

Figure 2.2: Schematic of the UR5

Simplified Dynamic Model

Equation for the motor torque current relationship [3]

$$\tau_m = k_{ct} i \tag{2.2}$$

Friction model [4]

$$\tau_f = k_{fc} sign(\dot{q}) + k_{fv} \dot{q} \tag{2.3}$$

where $i = [i_1, ...i_n]^T$ represent joint currents.

Simplified Dynamic Model

- Constant velocity, no acceleration influence

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Simplified Dynamic Model

- Constant velocity, no acceleration influence
- No end-effector applied forces during experiments
- No disturbances during experiments
- One joint at a time, minimal joint cross-correlation

Simplified Dynamic Model

Model used in identification process

$$k_{ct} i = C(q, \dot{q})\dot{q} + G(q) + k_{fc} sign(\dot{q}) + k_{fv}\dot{q} \tag{2.4}$$

Simplified Dynamic Model

Model used in identification process

$green$ - constant values in one experiment

$pink$ - coefficients to find by fitting

$$k_{ct} i = C(q, \dot{q})\dot{q} + G(q) + k_{fc} sign(\dot{q}) + k_{fv}\dot{q} \tag{2.5}$$

Simplified Dynamic Model

Model used in identification process

$green$ - constant values in one experiment

$pink$ - coefficients to find by fitting

$$k_{ct} i = C(q, \dot{q})\dot{q} + G(q) + \underbrace{k_{fc} sign(\dot{q}) + k_{fv}\dot{q}}_{\tau_f} \quad (2.6)$$

Simplified Dynamic Model

$$\tau_f = k_{fc}\, sign(\dot{q}) + k_{fv}\, \dot{q} \qquad (2.7)$$

Simplified Dynamic Model

- Special cases for joints 1 and 6, for G(q)

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- Special cases for joints 1 and 6, for G(q)

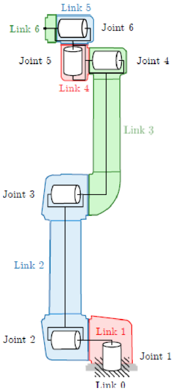

Figure 2.3: UR5 schematic

Figure 2.4: Joint 6 additional mass

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Identification procedure

1. The identification of torque-current coeffcient k_{ct} and the total friction torque τ_f
2. The identification of viscous k_{fv} and Coulomb friction parameters k_{fc}
3. The analysis of all acquired data to find a triplet (k_{ct}; k_{fv}; k_{fc}) as the conclusive parameters for each joint.

Identification procedure

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Identification procedure

1. The identification of torque-current coefficient k_{ct} and the total friction torque τ_f (m being the measurement and n the timestep)

$$i_{mn} = \tau_{fmn} + \frac{G_{mn} + C_{mn}\dot{q}_m}{k_{ct}} \tag{3.1}$$

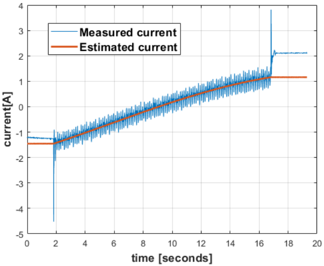

Figure 3.1: Sample of current fitting

Identification procedure

2. The identification of Coulomb k_{fc} and viscous k_{fv} friction parameters

$$\tau_f = k_{fc}\, sign(\dot{q}_m) + k_{fv}\, \dot{q}_m \tag{3.2}$$

Identification procedure

3. The processing of all acquired data to find a triplet (k_{ct}; k_{fv}; k_{fc}) as the conclusive parameters for each joint. The k_{ct} set found has to be averaged for each velocity in order to apply the fitting for the friction coefficients.

Torque-current coefficient

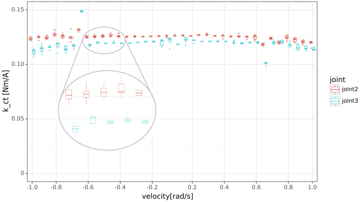

Figure 4.1: The current-torque coefficient (k_{ct}) comparison for the 2nd and 3rd joint

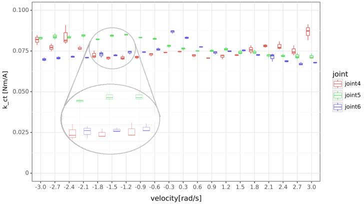

Figure 4.2: The current-torque coefficient (k_{ct}) comparison for the last 3 joints

Total friction term

$$\tau_f = k_{fc} sign(\dot{q}) + k_{fv}\dot{q} \tag{4.1}$$

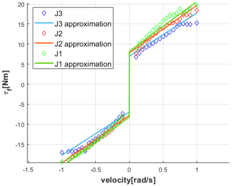

Figure 4.3: The friction term (τ_f) comparison for the first 3 joints

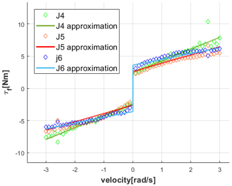

Figure 4.4: The friction term (τ_f) comparison for the last 3 joints

Interpretation of results

Table 1: Final values for the identified torque-current k_{ct}, viscous k_{fv}, and Coulomb k_{fc} coefficients

Joint	k_{ct}	k_{fv}	k_{fc}
1	12.3	8.1272	12.3141
2	12.6351	7.7891	11.881
3	12.0383	6.9762	10.7667
4	7.7366	2.4405	1.8286
5	7.9228	2.6265	1.2794
6	7.4723	3.6058	0.8921

Interpretation of results

1. Low variability for each separate joint

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Interpretation of results

1. Low variability for each separate joint
2. Particularity of each joint

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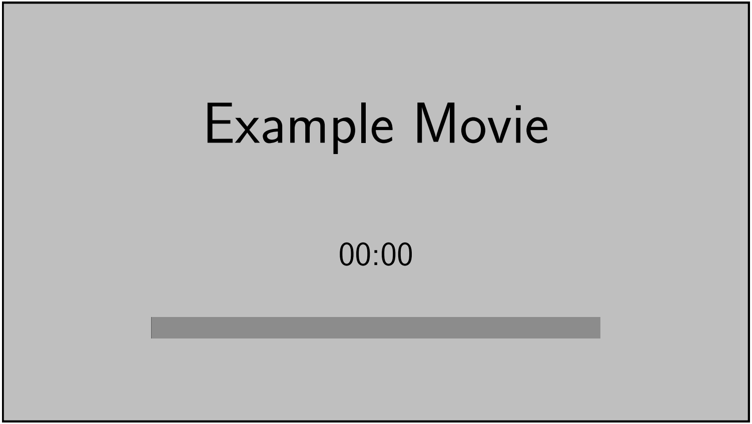
ROS framework



*found at https://gitlab.utcluj.ro/true-rehab/robot-identification

The open-source toolbox

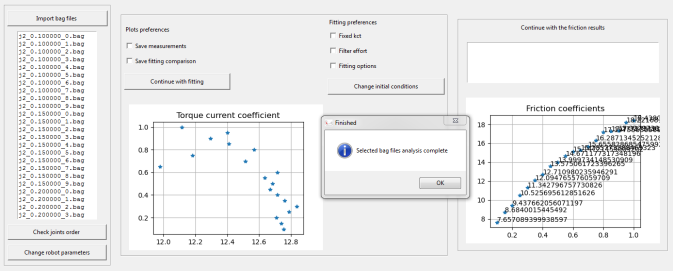


Figure 5.1: Results of the identification

*found at https://gitlab.utcluj.ro/true-rehab/robot-identification

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Summary

- Higher accuracy in simulations and analysis
- Helpful in model-based control
- Simple enough to easily be implemented by other parties, complex enough to catch main features

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[3] "Calibration of drive chain of robot joints", P.P. Restrepo and M. Gautier, International Conference on Control Applications, 1995

[4] "A survey and comparison of several friction force models, for dynamic analysis of multibody mechanical systems", F. Marques, P. Flores, J. C. P. Claro and H. M. Lankarani, Nonlinear Dynamics, volume 86, 1407-1443, 2016

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