Dynamic Robot Model Parameter Identification via Domain Specific Optimization

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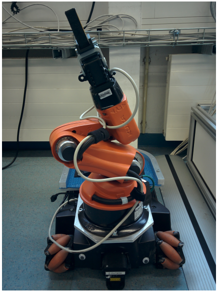
- Model parameter from the manufacturers are not accurate [11]

(a) youBot

Introduction

- Model parameter from the manufacturers are not accurate
- Dynamic robot model **parameters estimation**



(a) youBot

[1] https://www.pcper.com/files/imagecache/article_max_width/news/2014-09-29/intel-creative-realsense.png

Introduction

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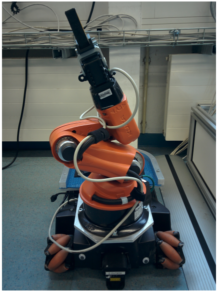


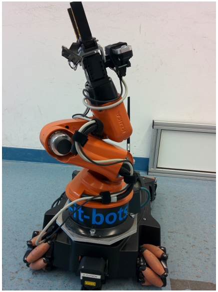
(a) youBot

+

[1]

(b) Additional component

$\Longrightarrow$



(c) youBot + camera

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Introduction

- General optimizers are used in [11]:
  - Off-line estimation method
  - Optimization gets complex if there are more than 9 parameters
  - Analyzing the data in multi-dimensions
  - Guiding the optimizer with the rigid-body mass
- Hence the domain specific optimization is chosen:
  - Modified recursive Newton-Euler formulation
  - Model fitting technique

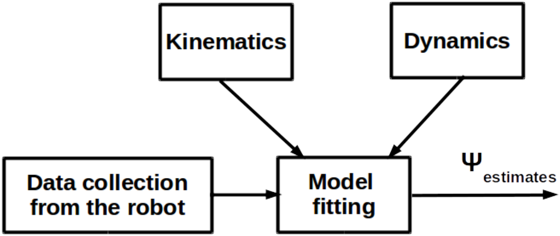
Related work

- The **Newton-Euler formulation** is linearized from a general formulation [1] [2]
- The **model fitting** method **ridge regression** [1] is used for the parameter estimation and the similar approach is followed in this work
- Trajectory input decides the performance of the controller and the **excitation trajectories** can improve the efficiency of the estimates [1] [9]
- **Frictional effects** have been modeled and compensated in many industrial based application with the use of a simple friction model [9] [10]

Problems addressed

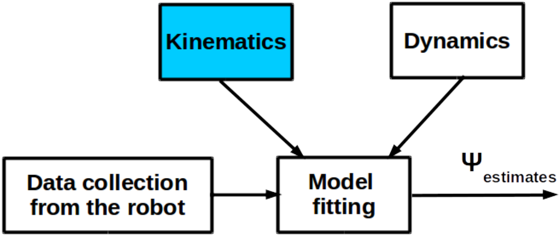
- Estimation of the 10 unknown model parameters:
  - Mass - m
  - Center Of Mass (COM) - $[c_x, c_y, c_z]$
  - Inertial parameters - $[I_{xx}, I_{xy}, I_{xz}, I_{yy}, I_{yz}, I_{zz}]$
- Break-away friction estimation
- Trajectory selection

Approach



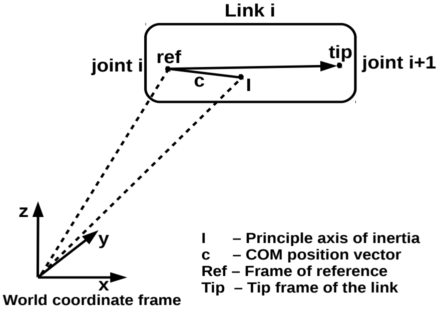
Kinematics
Dynamics
Data collection from the robot
Model fitting
Ψ estimates

Approach - Kinematic analysis



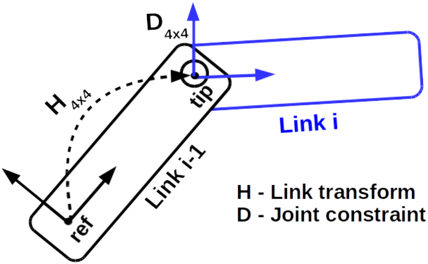
Rigid body

- Body-fixed point reference



Forward position kinematics

- Link and joint transform creates a segment

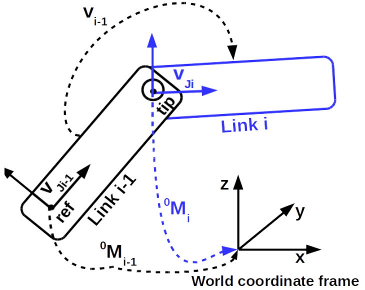


- Transformation from link i-1 to i = H·D

Forward velocity and acceleration kinematics

- The velocity twist of a link as follows

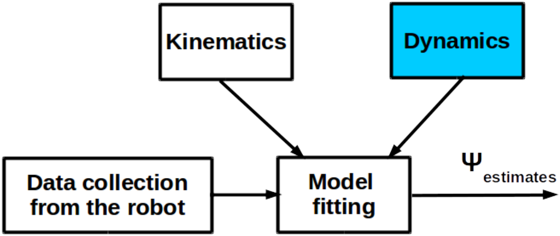
$$v_i = v_{i-1} + {}^0M_i \cdot v_{Ji} \tag{1}$$



- The same technique for the acceleration

$$a_i = a_{i-1} + {}^0M_i \cdot (z\ddot{q}_i) + v_i \times ({}^0M_i \cdot v_{Ji}) \tag{2}$$

Approach - Dynamics



Modeling of the dynamics I

- The general Newton-Euler formulation [3] can be given as

$$\tau = M(\theta)\ddot{\theta} + C(\theta, \dot{\theta})\dot{\theta} + N(\theta, \dot{\theta}) \tag{3}$$

- The linearized recursive Newton-Euler formulation [1] [2]

$$\overbrace{\begin{bmatrix} f_{link} \\ \tau_{link} \end{bmatrix}}^{\text{wrench}} = \overbrace{\begin{bmatrix} \ddot{p} - g & [\dot{\omega}\times] + [\omega\times][\omega\times] & \mathbf{0}_{3\times3} \\ \mathbf{0}_{3\times1} & [(g - \ddot{p})\times] & [\cdot\dot{\omega}] + [\dot{\omega}\times][\cdot\omega] \end{bmatrix}}^{A} \times \overbrace{\begin{bmatrix} m \\ m \cdot [c_{3\times1}] \\ I_{xx} \\ I_{xy} \\ I_{xz} \\ I_{yy} \\ I_{yz} \\ I_{zz} \end{bmatrix}}^{\psi} \tag{4}$$

Modeling of the dynamics II

- The joint acceleration is mapped into the body coordinates by

$$\ddot{q} = \ddot{p} + \dot{\omega} \times c + \omega \times (\omega \times c) \tag{5}$$

- Inertial frame with respect to joint origin

$${}_J I_c = I_c + m[(c^T c)\mathbf{1}_{3\times 3} - (cc^T)] \tag{6}$$

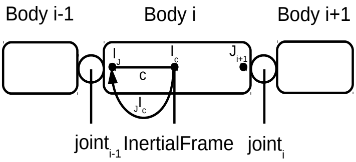


Figure : Parallel-axis theorem

Modeling of the dynamics III

- Total wrench at a particular joint by summing w of distal links
- The wrench at joint i from link movement

$$w = K(q, \dot{q}, \ddot{q}) \cdot \psi \tag{7}$$

- The projection of the wrenches based on the joint's internal axis

$$\tau = S \cdot w \tag{8}$$

where,

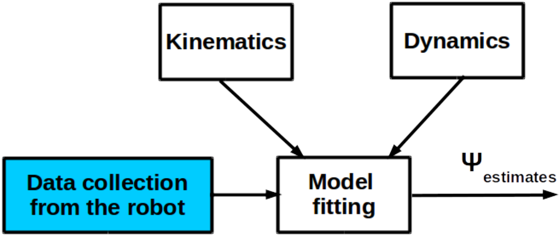
  - $S = [0\ 0\ 0\ 0\ 0\ 1]^T$ is sub-space matrix
  - w in 6 DoF and it is projected into 1 DoF

- For the model fitting, the observation matrix and torques are stacked

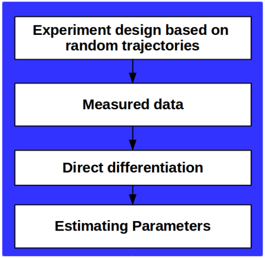
$$K = [K_1 \cdots K_N]^T \tag{9}$$

$$\tau = [\tau_1 \cdots \tau_N]^T \tag{10}$$

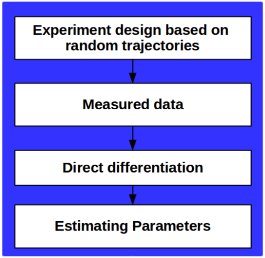
Approach - Trajectory selection

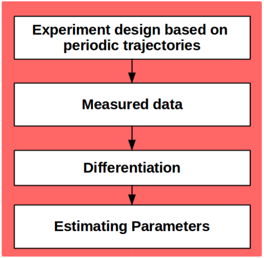


Trajectory selection method



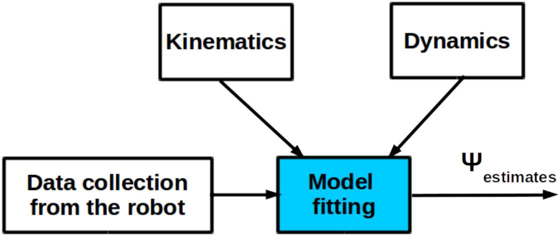
Trajectory selection method





[9]

Approach - Model fitting



Model fitting

- Ridge regression is chosen over the linear least-square method:
  - To avoid the rank-deficiency problem
  - For analyzing the multi-regression data
  - Variance is minimal and stable prediction
- The linear least-square method can be derived from

$$\begin{bmatrix} K_{1,1} & . & . & . & K1,n \\ . & . & & . & . \\ . & & . & & . \\ . & . & & . & . \\ K_{m,1} & . & . & . & K_{m,n} \end{bmatrix} \begin{bmatrix} \psi_1 \\ . \\ . \\ . \\ \psi_n \end{bmatrix} = \begin{bmatrix} \tau_1 \\ . \\ . \\ . \\ \tau_m \end{bmatrix} \tag{11}$$

- Ridge regression is obtained from (11)

$$\psi_{estimates} = (K^T K + \lambda_{min} I)^{-1} K^T \tau \tag{12}$$

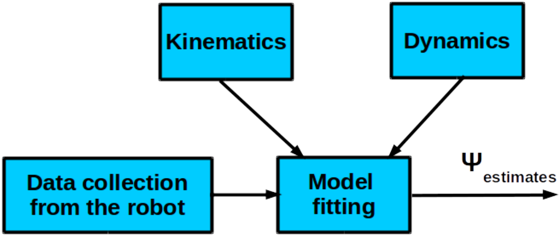
Parameter estimation pseudocode

```
Input: τ, q, q̇, q̈
Output: ψ

Number of experiments m;
for i ← 0 to m do
    τ = fileTorqueInput(m)
    Number of joints n;
    for i ← 0 to n do
        K = observationMatrix(q, q̇, q̈)
    end
    ψ = (K^T K + λ · I)^{-1} τ
end
Function ObservationMatrix(q, q̇, q̈):
    pose, twist, acceleration = getPosesTwistAcc(q, q̇, q̈)
    A = Acceleration(q̈, ω, ω̇)
    w = [w1 w2 w3 w4 w5]^T
    return w
end
```

Algorithm 1: Parameter estimation

Approach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Experimentation

Experiments conducted

- Estimation of the dynamic model parameters
- Break-away friction on youBot base and the manipulator

Softwares used

- **OROCOS KDL [5]** - Inverse dynamics solver for validation
- **Simbody** - To visualize the youBot manipulator

Experiment setup

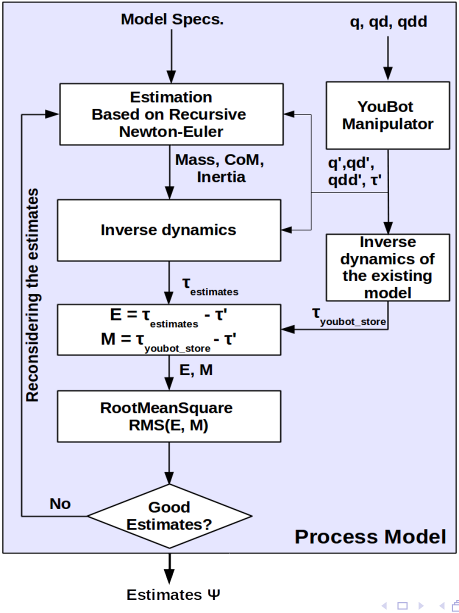
- Totally 25 automated experiments
- To avoid the **gravity effects** on the joints **2, 3, 4**
- The break-away friction estimation logic is tested on the **wheel-joints** at first
- Then, on the youBot's 5 DoF **manipulator**

Parameter estimation

Table : Parameter estimation on the youBot manipulator

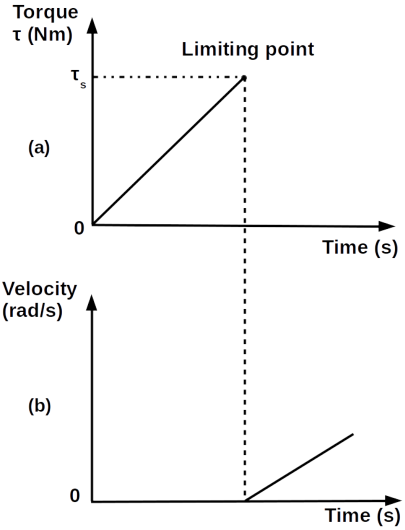
Parameters	**Link 1**	**Link 2**	**Link 3**	**Link 4**	**Link 5**
m (kg)	0.0	0.442	-0.075	-0.188	0.041
$m \cdot c_x$ (kg.m)	0.0	0.028	-0.029	-0.001	-0.008
$m \cdot c_y$ (kg.m)	0.0	-0.002	0.016	-0.082	0.042
$m \cdot c_z$ (kg.m)	0.0	7.012	-0.408	-0.356	-0.069
I_{xx} (kg.m^2)	0.0	-0.894	0.245	-0.033	0.051
I_{xy} (kg.m^2)	0.0	0.327	0.054	-0.107	0.131
I_{xz} (kg.m^2)	0.0	0.541	0.292	0.214	0.033
I_{yy} (kg.m^2)	0.0	0.901	-0.366	-0.129	-0.003
I_{yz} (kg.m^2)	0.0	-0.029	-0.013	-0.094	0.002
I_{zz} (kg.m^2)	-0.239	0.377	0.042	-0.456	0.112

Process model



Break-away friction estimation

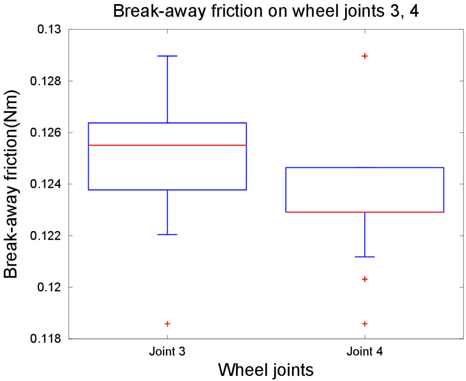
Break-away friction estimation

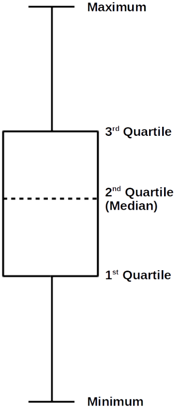


- (a) Input - Linear torque increment

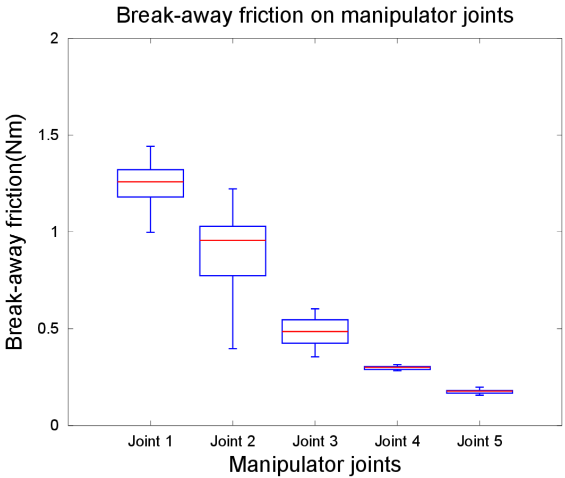
- (b) **If** velocity > 0 **then** break-away torque $= \tau_s$

Static friction estimation on youBot platform wheel joints





Static friction estimation on youBot manipulator



Conclusions

- Dynamic robot model parameter identification method:
  1. Joint motion(random trajectories) and torque data
  2. The manual plausibility check is not successful
  3. Visualization on the Simbody
- The break-away friction estimates on:
  1. Wheel joints 3, 4 are 0.126, 0.123 Nm respectively
  2. Manipulator joints 1, 2, 3, 4, 5 are 1.260, 0.956, 0.486, 0.300, 0.177 Nm respectively

Future work

- Debugging the implementation of the estimation procedure
- To apply the validation method after the parameter estimation
- Static friction compensation with the dynamic model
- Kinetic friction modeling and compensation
- Controller gains need to be optimized

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Questions???

The End