About system identification of industrial robots

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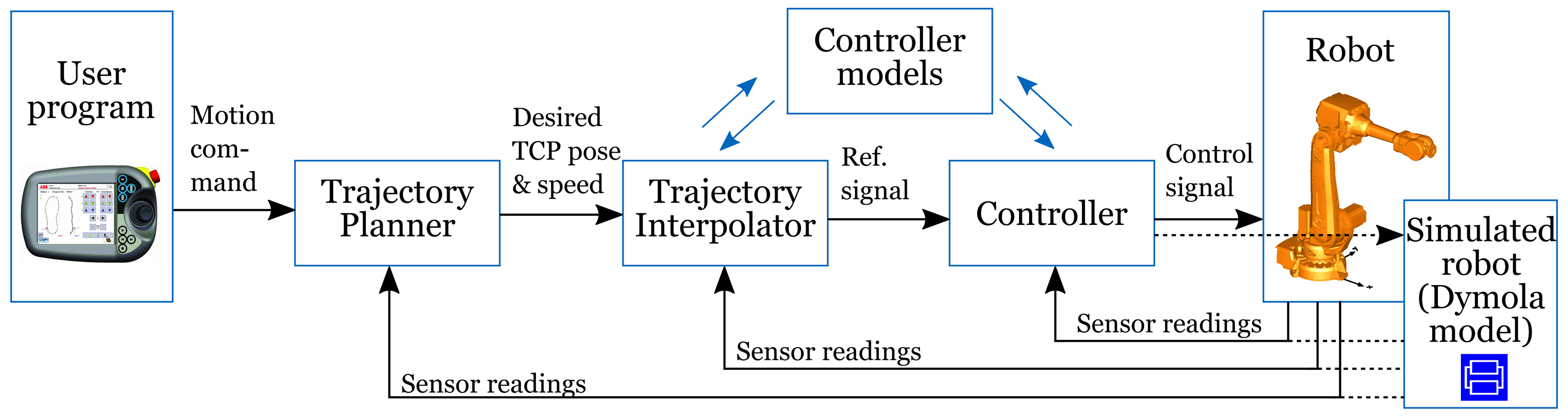
Introduction

A modern industrial robot control system relies on models for the performance. Therefore, the quality of the model, as well as the efficiency in defining the model structure is of high importance. Furthermore, a fast and easy-to-use process for finding the model parameters from pre-known and experimental data is required.



Simplified motion control system for a robot.

Motivation

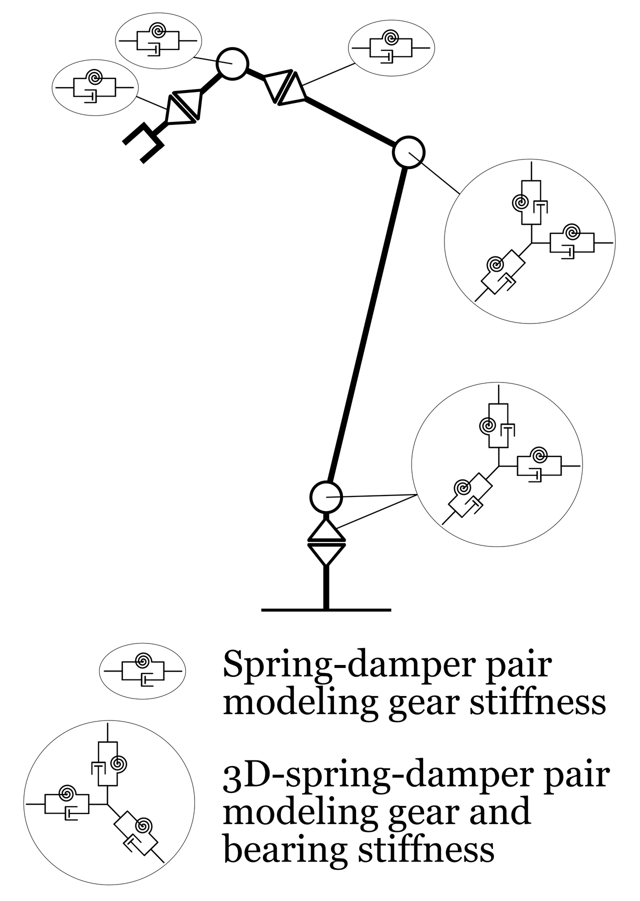
Identification of industrial robots is a challenging task. A closed-loop system must be identified, and several nonlinearities are present. Using a general off-the-shelf method will therefore often fail. The problem instead requires a combination of

- Tailored identification methods
- Well chosen experiment design in terms of
  - Required experiment time
    (Long experiment time (3-4 hours) is currently required for estimating non-parametric Frequency Response Functions (FRFs) of the robot system in several positions. This makes an identification for each robot individual costly.)
  - Excitation amplitudes
    (For high model accuracy, large excitation amplitudes are desired. This involves the risk of wear or damage of the robot or some of its components)
- A skilled user, applying all available knowledge about the robot system.

Gray-box modeling

The rigid body model parameters (dimensions, mass, inertia) are assumed to be known from design (CAD model).
All the parameters related to elasticity, damping and friction must be identified from measurements.

An industrial robot.



A lumped parameter robot model.

Robot identification process: A closed-loop gray-box frequency-domain method [1]

1. Estimation of (local) **non-parametric Frequency Response Functions** (FRFs) in a number of robot positions.
   - Multi-sine excitation superimposed with a square wave signal around an arbitrary robot position
   - Several robot positions in space, several experiments in each position
   - Measurement of applied motor torque and angular position
2. A **nonlinear parametric robot model** (gray-box, see col. 2) is linearized in each of the robot positions, resulting in parametric FRFs.
   - Spring parameters (linear or nonlinear) and damping constants need to be identified
   - Model is linearized at zero speed in each robot position
3. An error between the parametric model FRFs and the estimated non-parametric FRFs is computed. The **parameter vector is optimized** in order to minimize the error's size.

[1] E. Wernholt, S. Moberg, *Nonlinear gray-box identification using local models applied to industrial robots*, Automatica, Volume 47, Issue 4, 2011, Pages 650-660, ISSN 0005-1098, https://doi.org/10.1016/j.automatica.2011.01.021

Research questions

Model complexity and structure

- Location and number of spring-damper pairs
- Identifiability of the different parameters
- More detailed modeling of components in the system, e.g. gears and motors, or flexible structure
- Method for improving the model based on an experiment at a customer site
- Consider adding a black-box disturbance model

Experimental design

- Type of excitation (multi-sine, chirp, ...)
- Amplitude spectrum and frequencies of the input signal
- Definition of robot positions in work-space, as well as suitable number of positions, in which the system is excited
- Impact of the wrist load mounted to the robot
- Parameter accuracy and problems related to local minima, versus measurement time and excitation energy
- Measurement data: Use of one or several additional sensors, e.g. IMU at the tool, or accelerometers mounted on the structure

Identification method

- Selection of weights for the parametric estimators (combining the user choices and the estimated FRF uncertainty)
- Consider time-domain identification and compare to approach [1]

Overall research goals

For adding the most value to the current identification procedure, the research will be focused on the following goals:

1. Reduce the risk of wear of robot components by reducing the excitation amplitudes.
2. Reduce time it takes to do the experiments by reducing the amount of data needed for the FRF estimation.
3. Maintain or improve the quality of the model estimates while satisfying 1 and 2.

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