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Robot Identification for Accurate Dynamic Simulation

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Introduction

Robotised laser welding, figure 1, is an application which requires high speed combined with high precision. Off-line programming is used to reduce the expensive down-time while programming the accurate and high-speed motion. Unfortunately, the robot will deviate from the programmed trajectory due to dynamic limitations at the high welding speed.

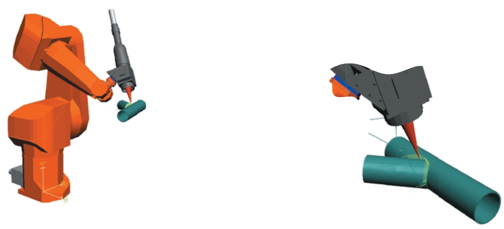

Figure 1: Robotised Laser Welding.

Goal

In order to *a priory* predict the dynamic performance of the robot during laser welding of a specific product, realistic dynamic simulations are combined with Off-line Programming. Realistic dynamic simulations require realistic models of the robot and controller. Robot identification techniques will be used to find the unknown model parameters.

Robot Identification

A 3 degree of freedom (3DOF) robot model has been formulated which includes lumped inertia parameters, stiffness parameters of the gravity compensation spring and a -three parameter- friction model to describe joint friction. The equations of motion are expressed in the vector of generalised coordinates $\underline{q}$ and the vector of model parameters $\underline{p}$

$$\underline{\tau} = M(\underline{q},\underline{p})\ddot{\underline{q}} + C(\underline{q},\dot{\underline{q}},\underline{p})\dot{\underline{q}} + K(\underline{q},\underline{p})\underline{q} + \underline{g}(\underline{q},\underline{p})\,,$$

where $M(\underline{q},\underline{p})$ is the reduced mass matrix, $C(\underline{q},\dot{\underline{q}},\underline{p})\dot{\underline{q}}$ represents the Coriolis and the centrifugal forces as well as the friction model, $K(\underline{q},\underline{p})\underline{q}$ includes stiffness properties and $\underline{g}(\underline{q},\underline{p})$ is the vector with external nodal forces, including gravity, and the driving torques are expressed by vector $\underline{\tau}$. The model parameters $\underline{p}$ are estimated using experimental parameter identification. The set of model parameters is found using a linear least squares method. This linear least squares method requires that the robot dynamic model is rewritten in a parameter linear form

$$\underline{\tau} = \Phi(\underline{q},\dot{\underline{q}},\ddot{\underline{q}})\underline{p}\,,$$

where $\Phi(\underline{q},\dot{\underline{q}},\ddot{\underline{q}})$ is known as the regression matrix. Evaluation of the dynamic model in a number of samples $i = 1\ldots n$ along the trajectory $(\underline{q},\dot{\underline{q}},\ddot{\underline{q}})$ yields the data-set

$$\underline{b} = A\underline{p}\,,$$

where

$$\underline{b} = \begin{bmatrix} \underline{\tau}_1 \\ \vdots \\ \underline{\tau}_n \end{bmatrix} \quad \text{and} \quad A = \begin{bmatrix} \Phi_1(\underline{q}_1,\dot{\underline{q}}_1,\ddot{\underline{q}}_1) \\ \vdots \\ \Phi_n(\underline{q}_n,\dot{\underline{q}}_n,\ddot{\underline{q}}_n) \end{bmatrix}\,,$$

The least squares solution is given by:

$$\underline{p}_{LS} = (A^TA)^{-1}A^T\underline{b} = A^+\underline{b}\,.$$

To be able to apply a least squares fit, A should have full rank. Consequently, the regression matrix should also have full rank. This is obtained when the set of parameters $\underline{p}$ that will be estimated is minimal.

The quality of the least squares fit depends strongly on the condition of matrix A. Using excitation trajectories $(\underline{q},\dot{\underline{q}},\ddot{\underline{q}})$ consisting of a Fourier series with 5 frequencies, this condition can be manipulated by choosing the phases and amplitudes. Non-linear optimisation techniques are used to find the best phase and amplitude combination while obeying motion constraints.

Results & Conclusion

A parameter estimation for a 3DOF model has been performed. The torques are obtained by measuring the servo currents and transforming them to joint torques. The trajectories are programmed in the robot control software. All experiments are done without modifications to the original industrial robot. The simulations are performed using SPACAR and MATLAB. Simulation of the 3DOF robot model shows good agreement with the experimental results. The identified model parameters closely match the values given by the robot manufacturer. The end goal is a realistic 6DOF robot model which enables the accurate and realistic simulations needed with off-line programming for laser welding.