This is a preprint of the paper that appeared in:
Proceedings of Robotik 2008, Munich, Germany

High speed cutting with industrial robots: Towards model based compensation of deviations

Modeling and numerical simulation of the industrial robot with elastic joints

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Abstract

Application of industrial robots for high speed cutting currently is limited to tasks with very low precision demands due to the low stiffness of industrial robots compared to machine tools. However, industrial robots are more affordable and have a larger workspace. This paper presents first steps towards model based compensation of deviations caused by the undesired elasticities. A model of the industrial robot which takes into account the elasticities is introduced.

1 Introduction

For complex tasks in high speed cutting currently mainly machine tools are used because of their high stiffness and high accuracy. Industrial robots are cheaper in terms of cost compared to workspace and are more flexible for application to different tasks. Their drawback is their higher compliance.
In this project, the problems related to the relatively high compliance of industrial robots in comparison to machine tools shall be overcome without modifying the hardware of the robot and without extension of the robot by additional output drive side sensors. Instead,

the trajectories that are given to the robot control shall be modified in a way that the resulting path the robot drives is as close as possible to the desired one. For this, models of the robot and the high speed cutting process that can reproduce the static and dynamic interactions between robot structure and cutting process realistically must be set up. Then the deviations can be compensated by modifying the joint angle trajectories. As a first step towards the goal of the project, in this paper the model of the industrial robot is described and first observations on the numerical results and comparisons of the numerical and experimental results are given.

2 Problem Statement

Mainly three kinds of deviations occur due to the compliance of industrial robots during high speed cutting: static offset, low frequency oscillations and high frequency oscillations. In the first part of the current project, the static offset (cf. Figure 1), which has the highest impact on overall cutting accuracy shall be compensated. Elasticity of the gears

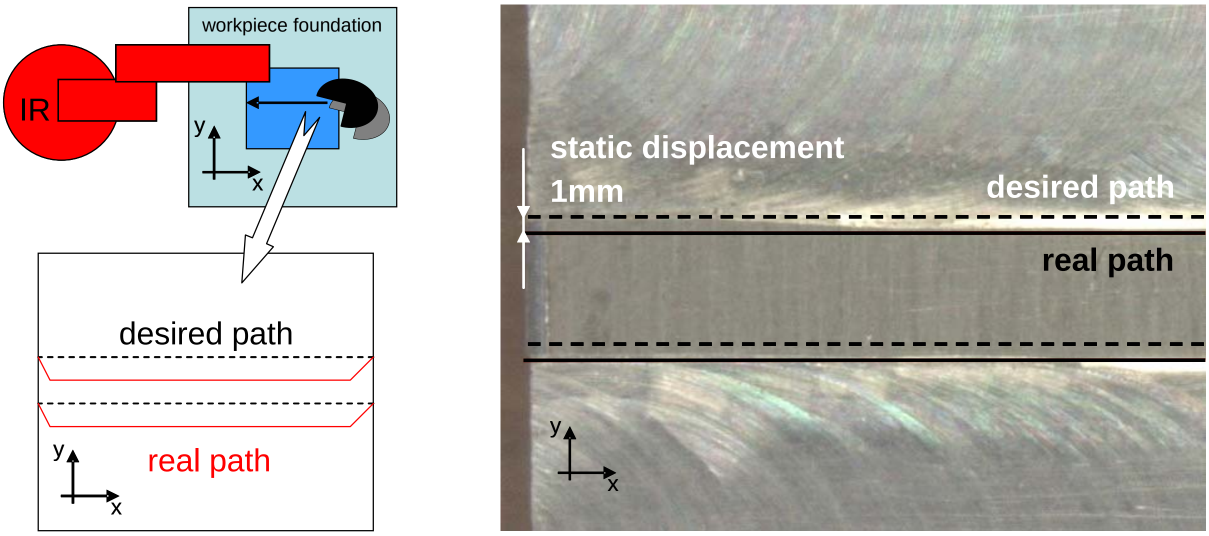

Figure 1: The path of the tool center point shows an offset from the desired path. This is mainly due to the elasticity of the joints.

and bearings in direction of the joint motion and tilting elasticity orthogonal to the joint motion are the main causes of the deviations [1]. Thus, a standard stiff robot model is extended by those elasticities in the direction of the joint motion and orthogonal to it.

3 Robot Model

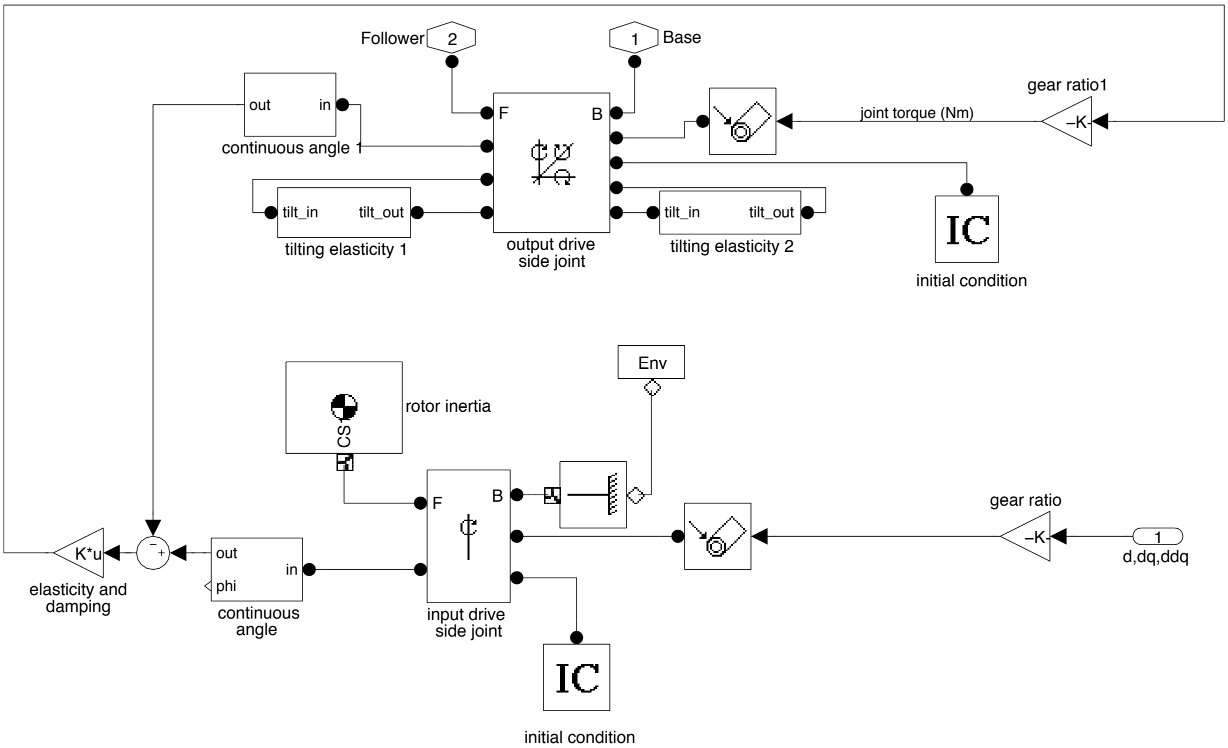

Figure 2: The first three joints are modeled to have elasticities and damping orthogonal to the direction of motion ("tilting elasticity 1" and "tilting elasticity 2") besides the elasticities and damping in direction of motion.

The model of the 5 axes robot, which will be used for cutting, is currently implemented in the SimMechanics toolbox of Matlab/ Simulink for fast development and debugging possibilities, see Figure 3. The model comprises the kinematic and kinetic data of the robot (masses, inertia, distances), and elasticities and damping in the direction of the motion of each axis. In the first three axes, additional tilting elasticities and damping orthogonal to the direction of motion is modeled, see Figure 2. Motor control, hysteresis effects and backlash of joints and gears are not taken into account. Maximum motor output will be taken into account by constraints to the optimal control problem for compensation of the deviations.

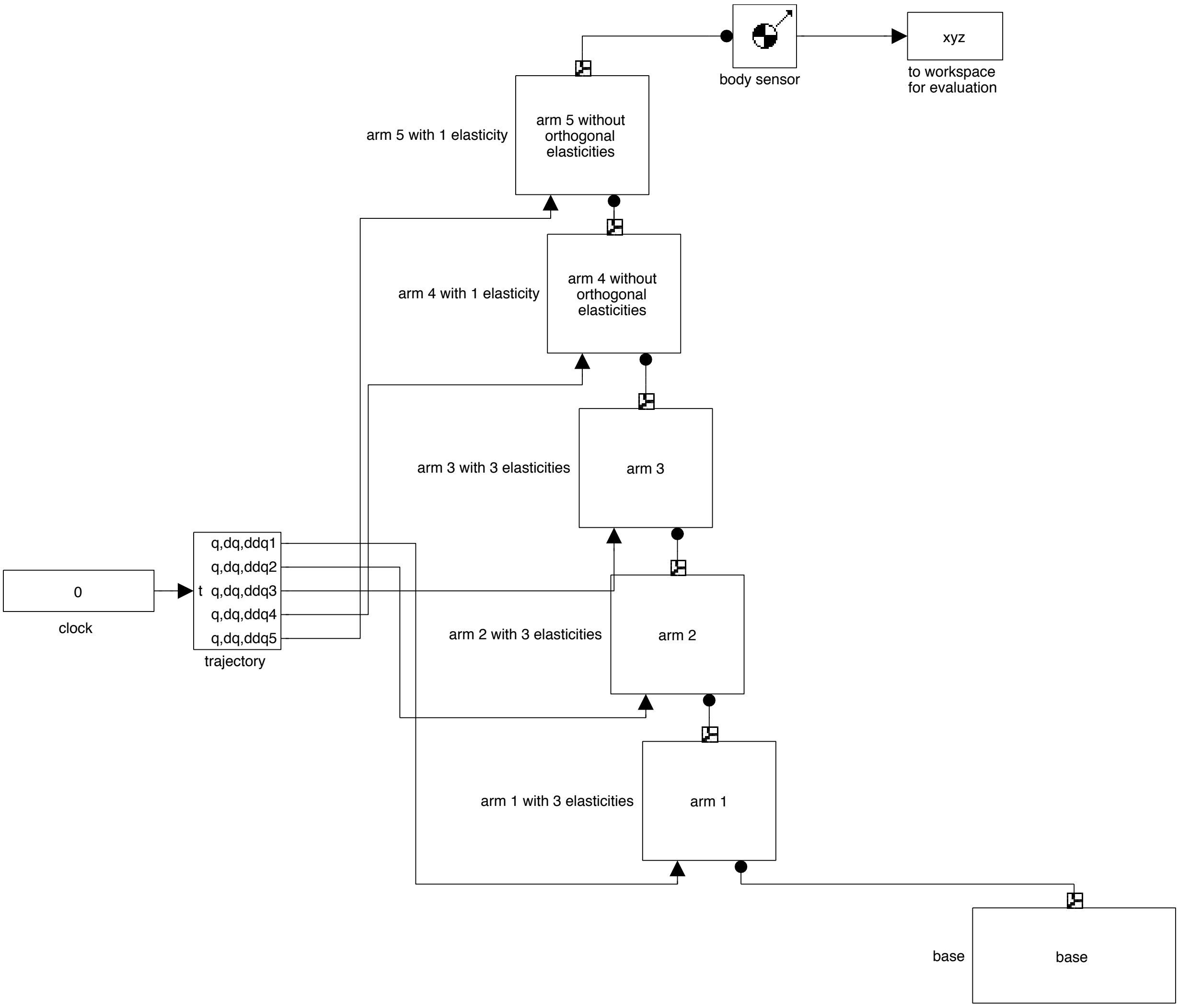

Figure 3: The model of the robot consists of blocks, each with one joint with one or three elasticities and dampers and one stiff link ("arms").

4 First Experimental Results

The effects of elasticity in the model are significant, especially at edges of the trajectory of the tool center point, cf. Figure 4.
As a first test case, the unloaded case is considered: The robot is used to cut into soft model material, where the cutting forces are low compared to gravitational and Coriolis forces. Thus, the robot part of the model can be validated on its own before taking into account the forces of high speed cutting into aluminum in the next step. Here, both in simulation and experiments a deviation in vertical direction is observed at edges of the tool

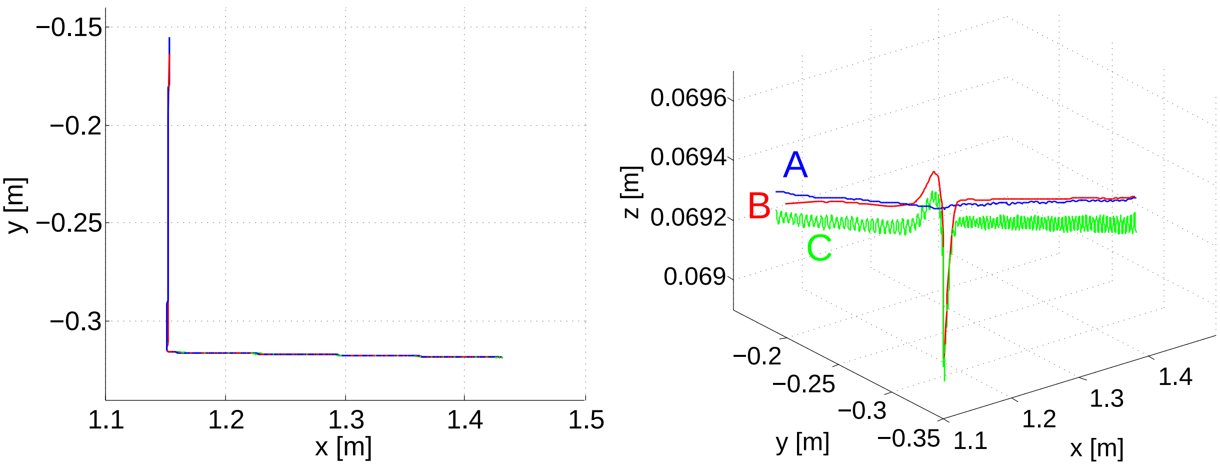

Figure 4: Path of the tool center point at a corner of its trajectory: From a computational model without any elasticity (A; blue), with joint angle elasticity (B; red), and with both joint angle and tilting elasticities (C; green). Note the different scales of the axes.

center point trajectory.
The path that the tool center point cuts into the model material has been measured and can now be compared to the results of the simulations. Two kinds of deviations can be observed from the measurements (Figure 5, top): a low frequency oscillation and high deviations in the corners of the TCP trajectory. Both deviations can be resembled by the results of the computational model with different parameter sets (Figure 5, bottom). The next task in the project will be to refine the model and find parameters so that the simulation matches the robot behavior and thus can reproduce both kinds of deviations simultaneously.

5 Summary and Outlook

Ongoing work aims at building up the model in an efficient object oriented C++ implementation [2] with suitable extension for the elastic joints, the inclusion of the forces generated by the high speed cutting process, and compensation of the static deviation in the presence of cutting forces by optimization.
The trajectories that are given to the robot shall be modified offline, so that the actual path of the robot end effector (the cutting tool) matches the desired one (i.e. the path an ideal robot (without elasticities) would cut). It is planned to extend the model and optimization methods to overcome not only the static deviation but also the low frequency oscillating deviation in a later phase of the project.

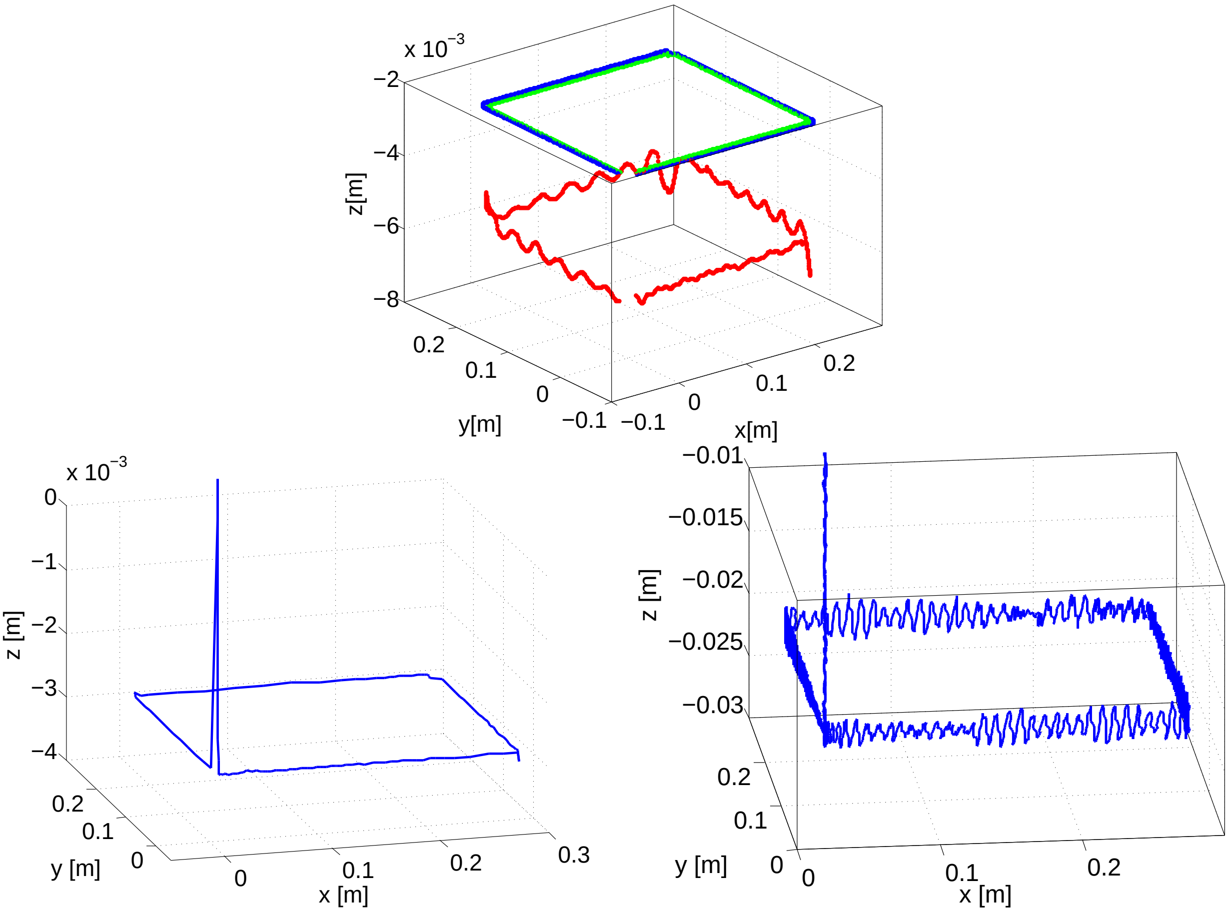

Figure 5: Measurement of the path that is cut into the soft model material (top) and simulation results for two different parameter sets (bottom). Note that the cut path is measured in terms of inboard, outboard and bottom line of the cut channel.

Acknowledgements. The research presented in this paper is supported by the German Research Foundation DFG under grants STR 533/5-1 and AB 133/34-1 (SPP 1880 ProWeSP).

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