Energy consumption modelling of a 6-axis industrial robot and experimental validation

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Abstract

Industrial robots are increasingly integrated into many industrial processes, including machining operations. They are often considered as an alternative to conventional CNC systems due to their high versatility. Their large workspace, enabled by their significant structural reach, also makes them well suited for tasks requiring extended motion. In addition, they can handle complex geometries with ease, which further motivates their use in advanced manufacturing applications, such as the production of aeronautical structural parts. However, their inherent lack of rigidity, coupled with the behaviour of electromechanical drive systems, make the prediction and simulation of the behaviour of the robot during high-load, high-dynamic machining operations a non-trivial research challenge. These factors inevitably impact the prediction, and ultimately the optimisation, of energy consumption. As manufacturing industries place greater emphasis on sustainability, understanding and reducing the energy consumption of these robotic systems has become a key priority. This therefore motivates the development of reliable mechanical and data-driven models capable of accurately predicting energy consumption for each axis during machining tasks, enabling more efficient process planning and environmentally responsible production.

In this context, the present work contributes to this research effort by establishing a simulation framework that combines a full multibody model of the robot with a motor model to compute instantaneous electrical power during trajectories frequently used in various machining operations and assess how it influences overall energy demand. Such analyses provide a basis for developing optimized trajectory-planning methods and control strategies aimed at reducing energy consumption while maintaining machining accuracy and productivity, thereby supporting more sustainable robotic manufacturing.

This work builds upon recent research [1] and the creation of a multibody model of a Stäubli TX-200 6-axis industrial robot. One of the main results is the development of a comprehensive static and dynamic trajectory-compensation methodology. This approach separates the compensation of structural deflections induced by gravity from the compensation of trajectory deviations generated by machining forces, enabling more accurate path execution during robotic machining. To accurately control each stage of the modelling process, a non-commercial simulator developed in-house, called EasyDyn [3], is employed to represent the robot's multibody structure and to compute the resulting motions and forces.

In the context of the energy study, the computation of the energy consumption of each robot actuator has been integrated into the existing model of brushless DC motors. Preliminary simulation tests, carried out on simple linear toolpaths, reveal that the first three joints of the robot dominate the overall energy demand, accounting for approximately 85% of the total energy consumed [2].

These initial simulation results validate the model with respect to the expected order of magnitude of the robot's energy consumption. The next stage of the study will consist in comparing the simulated energy profiles with experimental measurements obtained from the robot executing the same trajectories, in order to further assess the accuracy and reliability of the proposed modelling framework.

To achieve this, several trajectory types and static poses representative of typical machining operations are selected. These trajectories are implemented using the Stäubli Robotics Suite, the manufacturer's software environment used to program and manage the robot during the experimental phase. For each test, both command and feedback signals are recorded, including joint-level variables such as angular position and velocity, as well as the electrical quantities associated with each motor. This dataset will serve as the basis for comparing experimental measurements with the simulation outputs. The trajectory target values are also used to reproduce these motions within the simulation model. In contrast to the approach adopted in previous work [1], the trajectory-simulation methodology has been revised so that the model can directly process the same command file sent to the robot. This ensures a consistent comparison between simulated and experimental conditions and eliminates discrepancies arising from trajectory preprocessing or reformulation.

Initial results obtained from the experimental measurements are presented in Figure 1, which illustrates several linear passes performed with the tool mounted on the robot, in the absence of any machining operations. It can be observed that, for this type of motion, the control and feedback signals exhibit a very close correspondence, indicating that the robot accurately follows the commanded joint motions under no-load conditions thanks to the implemented controller. The simulated trajectories generated by the proposed model are currently being developed for this case. These simulation results must be established in order to enable a comparison between experimental behaviour and model predictions, which is essential for assessing the validity and fidelity of the energy-consumption model.

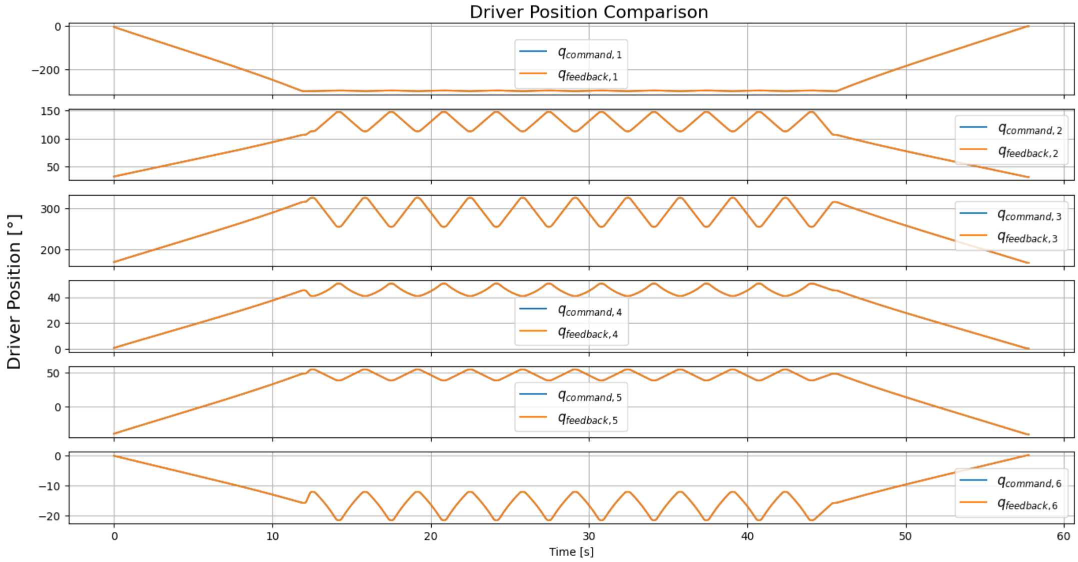

Figure 1: Experimental results: control signals $q_{command,i}$ and feedback signals $q_{feedback,i}$ for the angular position [°] of each joint (i = 1 to 6) as a function of time

References

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