MEASURING AND OPTIMIZATION METHODS OF ROBOTIC SYSTEMS IN A SIMULATION ENVIRONMENT

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Abstract: At this time it is necessary to use design tools and virtual model validation to plan the adaptation of algorithms to reduce costs and increase the efficiency of production systems. Using software tools it is possible to obtain and after that analyze data from the simulation environment. Using models and 3D space, it is also possible to analyze ranges of manipulators and collision areas. It is also possible to test robotic programs and find out the energy consumption, and possible cooperation of more robotic manipulators. This article discusses the use of ABB RobotStudio simulation tool for testing optimization algorithms and thus optimizing energy consumption. The article describes the measurement chain and contains measurement in simulation followed by the analysis of measured data.

Keywords: Trajectory planning, Simulation, Energy dependence, Optimization, Manufacturing systems

1 INTRODUCTION

Mechatronic industry most often uses industrial robotic systems. It is mainly used for material transfer, welding, machining, processing, joining, etc. Robotic systems can be characterized by high accuracy, speed, and great efficiency. For this reason, they are increasingly being used in industrial applications.

Simulation tools are increasingly used not only for research, but also for industrial applications, pre-commissioning testing, or for optimizing speed, power consumption, or multi-system collaboration. These simulations not only reduce production costs and thus reduce the cost of the final product, but also reduce the environmental burden by reducing electricity consumption or increasing energy efficiency. Other great advantages of the simulations are also the reduction of the error rate and the time to shut down the line when deploying or converting parts or entire production lines into production. In the simulation environment, you can test innovative ideas and algorithms to create methods to increase efficiency faster.

Robotic manipulators can be divided into two types - parallel and serial. However, the article deals only with the serial ones. Effector trajectory planning is an essential element of robotics and there are several ways to define the trajectory.

Most robotic systems are used for pick-and-place operations where it is not necessary to accurately track the endpoint of the effector. In this case, is depending only on the pick and place position. However, there are, for example, welding robots where it is necessary to define precisely an exact trajectory, including the required acceleration speeds, etc., in which case the energy optimization options are considerably reduced. For this reason, the article deals with the optimization of point-to-point movements, where trajectories can be adapted to the actual need for production, the load of the effector, etc.

2 OPTIMIZATION METHODS

There are a number of optimization methods for each stage of adjustments and also for different types of robotic systems. The implementation of optimization algorithms can be divided into three phases of creation of robotic workplaces - production line (process) design, commissioning, changes in the production process.

The biggest changes are possible at the design stage of the manufacturing process, at which time different types of robotic systems can be considered and one that has the best parameters and power consumption ratio for the application. It is also possible to choose a lighter robot with lower rigidity (precision and repeatability), but with significantly lower consumption, such a robotic system is particularly suitable for pick-and-place applications. The choice of a robot with optimal maximum payload is also critical at this stage. The robotic system with greater load capacity has much more weight and also energy consumption.

When commissioning and debugging production steps, a large part of idle times and operations, where the robotic system has to wait for another robot can be eliminated in case of shared workspace. The most challenging optimization can be during the runtime. In this case, it is a great advantage to use a simulation tool to test optimization algorithms without stopping production.

Nowadays, technologies for virtual commissioning or for the creation of digital twins are coming to the fore. This is very useful for energy optimization of these systems. It is possible to calculate their consumption from the known models of used machines and equipment. Some software already has built-in modules for energy consumption calculations (ABB RobotStudio, Siemens Tecnomatix Process Simulate, Catia, DS Delmia, Fanuc RoboGuide, etc.) that can be used for optimization.

The energy losses of robotic systems consist of mechanical and electrical losses. Actual consumption can be expressed as product of angular velocity and torque with consideration on mechanical and electrical efficiency (Equations 1) [5].

$$P = \sum_{n=1}^{n} M_n \cdot \omega_n \cdot \eta \quad [W] \qquad \eta = \frac{1}{\eta_m \cdot \eta_e} \tag{1}$$

The optimization problem can be viewed from several perspectives and thus define multiple criteria functions: minimal motion effort, minimal torque, minimal power consumption, minimal mechanical power consumption and minimum power consumption from the grid (considering recuperation between axes or robots).

$$\begin{gathered} \int_0^T M(t)^2 dt = minimal \qquad \int_0^T \dot{M}(t)^2 dt = minimal \qquad \int_0^T u(t)i(t)dt = minimal \\ \int_0^T \omega(t)M(t)dt = minimal \qquad \int_0^T u_{grid}(t)i_{grid}(t)dt = minimal \end{gathered} \tag{2}$$

After determining the optimization or criterion function, algorithms can be used to find optimal parameters and trajectories of robotic systems. When optimizing the trajectory, it is not always necessary and sometimes undesirable to change the path of the robot, but it is possible to change the parameters of speed, acceleration, and jerk to create more optimal parameters for predefined routes. Several algorithms are used to find the optimal trajectory can be find in papers [1], [2] etc. The optimal trajectory and parameters needs to be converted for robot commands [6].

3 SIMULATION TOOL

Robot cell simulation tools primarily serve to test robotic programs, robot ranges in the space model, and collaboration between robots, but this software are increasingly being used to optimize not only robot speeds but also for energy optimization. One of the tools that can be used for these simulations is ABB RobotStudio. The authors of the paper [3] deal with the choice of optimal parameters, wherein the simulation software they test the change in motion parameters depending on energy consumption and duration of the movement.

3.1 ABB ROBOTSTUDIO

ABB RobotStudio is the official software application for offline programming and simulation of ABB robots and robotic applications. Virtual robot models are in the application database and the software simulates a virtual controller that is identical to a real robot controller. Among other things, you can import your own models, assign them physics and test the functionality of not only the robot but the entire robotic line. RAPID language or virtual teach-pendant can be used for programming. By making the whole simulation offline, it is possible to test the design or construction of a new production line without stopping the existing one.

For energy optimization purposes, we use ABB RobotStudio to measure the energy demands of motion, depending on parameter changes and trajectory. These data can be transmitted via TCP communication to other software such as Matlab, where it is possible to evaluate in real-time to adapt the trajectory or robot parameters. Another option is to make a series of measurements and log these data using RobotStudio and then export as CSV.

3.2 ENERGY MEASUREMENT

The simulation was performed with an ABB robot IRB 120 3kg 0.58m and with a fixed payload of 2.5kg. Using RAPID, the motion parameters were modified and the same trajectory was executed.

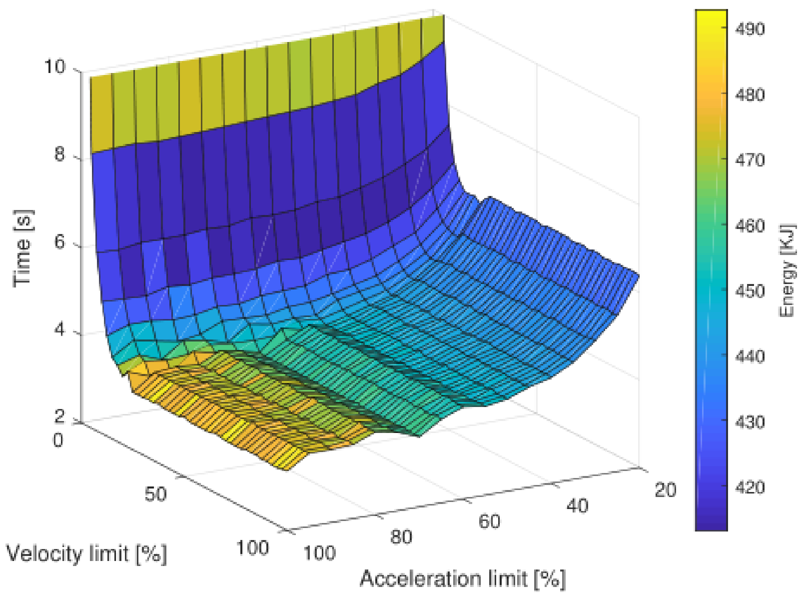

Figure 1: Energy consumption and robot motion time as a function of acceleration and speed percentage limits

3.3 ROBOT PARAMETERS AND ENERGY-TIME DEPENDENCY

Using the module *Signal analyzer* actual drive power, total consumption and time were recorded.

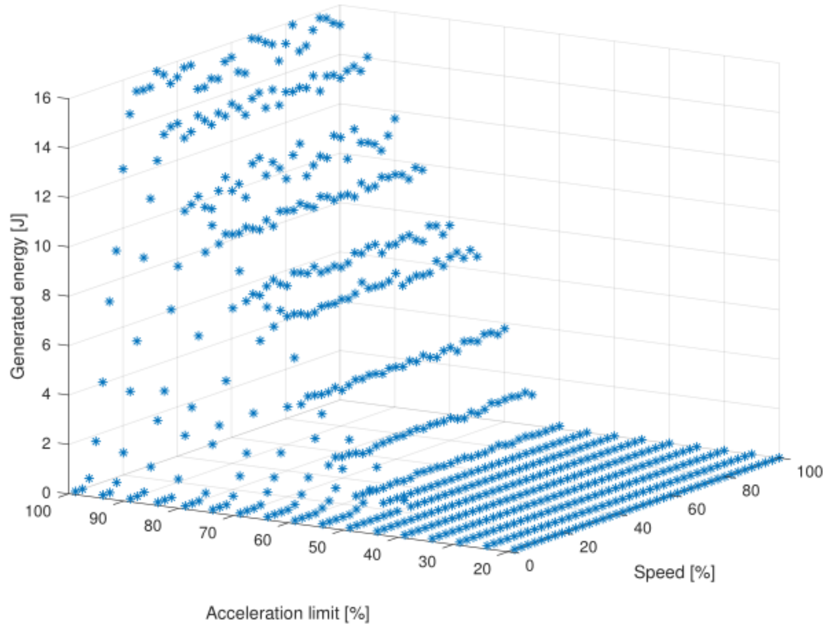

Figure 2: Dependence of recovered energy on robot acceleration and speed percentage limits

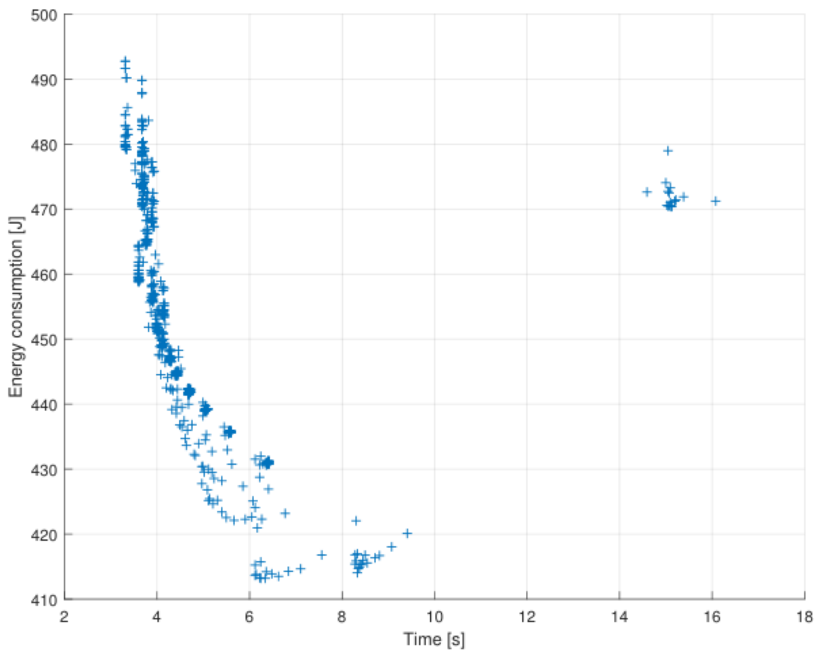

Figure 3: Varying acceleration and speed percentage limits compared to time and energy consumption

These data were then evaluated in Matlab. It's obvious (see Figure 1), that energy consumption can be reduced by optimizing movement parameters. Measurements can also be used to find out when it needs to brake with drives, the time when the robot starts to generate energy.

From measurements in simulation (see Figure 2) it can be argued that if the acceleration and ramp parameters are higher than 55 % then the robot almost always has to actively brake. The only exception is the very low robot speed when it was not necessary to break actively.

The following Graph 3 shows the possibility of variation of robot parameters, while not changing motion time, energy consumption can be changed considerably up to 15 %.

4 CONCLUSION

The paper deals with possible optimization methods for minimizing the energy consumption of robotic systems. The first part of the article defines the criteria by which it is possible to optimize the robotic system (see Chapter 2).

ABB RobotStudio software was used for the measurement (see Chapter 3.1), which uses the module *Signal analyzer* is able to measure selected data and export. These data can then be analyzed. Matlab software was used for data analysis. Measured data (see Chapter 3.3) show that by altering the parameters a considerable amount of energy can be saved. At higher speeds and accelerations, an energy generation that corresponds to approximately 7 % total energy consumed during movement can be measured. In my opinion, however, with the increasing weight of the robot and the payload, the proportion of the recuperated energy will increase.

Future work on this problem involves creating a robotic site with two or more robots to schedule their movements so that recuperated energy can be used. Another extension is the autonomous trajectory planning, depending on the optimum utilization of the recovered energy of the entire system. Sharing a DC link is addressed by the authors of the paper [4], where they are considering the use of energy storage (capacitors) for storing and possibly sharing an energy that would normally be burned on the braking resistor.

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