**Master’s Thesis**

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**Title:**

Entwicklung eines methodischen Ansatzes zur Analyze von Prozessparametern und Optimierung von Randbedingungen in Multi-Achs-Roboterprogrammen

Development of a Methodical Approach for Analyzing Process Parameters and Optimizing Boundary Conditions in Multi-Axis Robot Programs

**Initial situation:**

Computer-aided manufacturing (CAM) is used to automatically generate tool paths for computer numerical controlled (CNC) machines. The CAM software considers the models of the blank and finished part, as well as constraints of the machine, the tools and the manufacturing technology. Together with user-configurable parameters, tool paths for 3-axis, 5-axis and robot-based machine tools are generated.

The growing demand for flexibility in machine tools (e.g., the use of multiple manufacturing technologies in one machine or automated loading and unloading) has led to many machine tools having additional mechanical axes. Examples include robots mounted on linear axes and rotary-tilt tables.

The tool paths created in CAM are usually defined in 5 degrees of freedom. The first three are the translational axes X, Y and Z. The tilting and inclining of the tool are defined by the A and B axes. Occasionally an additional rotation of the tool (C-axis) around the Z-axis (e.g., for dragging a swivel knife) is defined.

Machines that have more degrees of freedom than are constrained by the tool path, require constraints given by the user to fully define the machines axis’ movements. One example is the orientation of a part with the help of the rotary-tilt table so that the tool Z-axis always points in the direction of gravity. This is helpful in processes like Fused Deposition Modeling (FDM) and Wire Arc Additive Manufacturing (WAAM).

It is common practice to set the user defined constraints based on experience. A preliminary literature review indicates that the configuration of these degrees of freedom has an impact on the energy consumption and stability of the process.

The definition of these constraints does not affect the tool path as generated by the CAM software. As such, developing a methodical approach to optimize these constraints in terms of efficiency, speed, and energy consumption of the machine is possible. As of now no literature is providing a comprehensive analysis or methodology regarding this optimization problem.

**Aim:**

The aim of this work is to develop a methodical approach that analyze a set of constraints and evaluate the influence of those constraints on a set of defined process variables.

The focus of the work is on a 6-axis robot with a rotary-tilt table, whereby the results should also be transferable to other machines. Furthermore, experiments and validations are limited to the manufacturing processes WAAM and milling.

First, the influence of the constraints on relevant process variables (energy consumption, joint turnover, speed and acceleration peaks, total joint movements, etc.) in a manufacturing process like WAAM is assessed. Subsequently, a process evaluation is developed in the CAM software, by means of which the process quality can be determined.

Depending on the respective process variables, approximation methods or machine learning methods are investigated for process evaluation. The process quality as a one-dimensional variable is determined by weighting the process variables.

Subsequently, a method for the optimization of the constraints is developed. This task corresponds to an optimization problem in which the process quality is to be maximized by the selection of suitable constraints.

Procedure and working method:

The following work packages are conducted within this thesis:

* Literature research
* Familiarization with WAAM and milling machines
* Familiarization with CAM-software
* Selection of suitable process parameters
* Development of the proposed method in a suitable programming language
* Verification and validation of the developed method
* Documentation of the work

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