Robotic Milling : Development of 3D milling forces computation module for tool trajectories adaptation

Valentin DAMBLY, Olivier VERLINDEN, Édouard RIVIÈRE-LORPHÈVRE

Abstract

Robotic machining is a fast-growing technology in the field of mechanical manufacturing since it enables an interesting agility in the cutter motion to deal with complex workpieces geometry. However, inaccuracies resulting either from vibrations or deflections occur while the robot is subjected to cutting forces, inherent to its flexibility inducing structure. It has been shown that compensation methods need faithful models of the operation.

Two aspects of the operation must be modelled, on the one hand the model of the cutting machine, being an industrial robot in robotic machining, and on the other hand, the machining model including the resulting geometry of the workpiece. A coupled model is then proposed with the multi-body model of the robot subjected to machining forces, computed by an in-house 3D machining module. The multi-body model includes the flexibility induced by the structure and the articulations. In order to compensate the deviations, a solution is proposed in which the trajectory is discretized in nodes with a compensation applied on them. The algorithm aims to detect and add nodes at critical locations of the path and re-position them to reduce the deviation.

Introduction

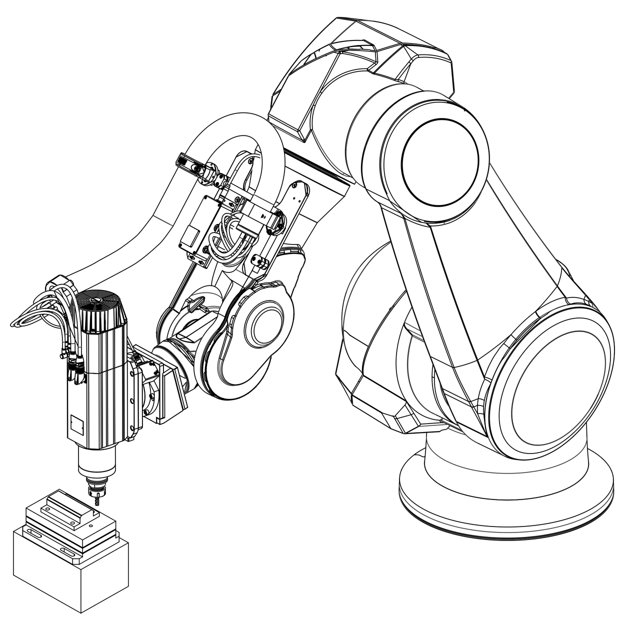

Figure 1: Industrial robot machining a workpiece.

While subjected to external forces, robots are deviated from their initial target due to their flexibility mostly located in the articulations and links. Verl *et al.* detailed the methods to build numerical models and the many improvement directions to act against this behaviour [3]. The main branches to compensate the deviations are :

- **Offline** : adaptation of system input based on numerical models.
- **Online** : adoption or design of specific control strategies.
- **External** : addition of actuated systems working in parallel.

With a reliable model of the robot flexibilities [1, 2], it is possible to predict to deviations by simulating the machining operations and act on the input trajectory to compensate inaccuracies.

1 Milling forces computation

In order to predict the system's response, it is necessary to properly evaluate the excitation being the machining forces. Robots allow complex motion to cut complex workpieces, simulators that enable to compute cutting forces for those complex motions are required. It is necessary to compute the interaction of the tool and the workpiece in space at each time step, hence they are discretized respectively as a stack of slice and a 3D network of lines namely dexels as illustrated in Fig. 2.

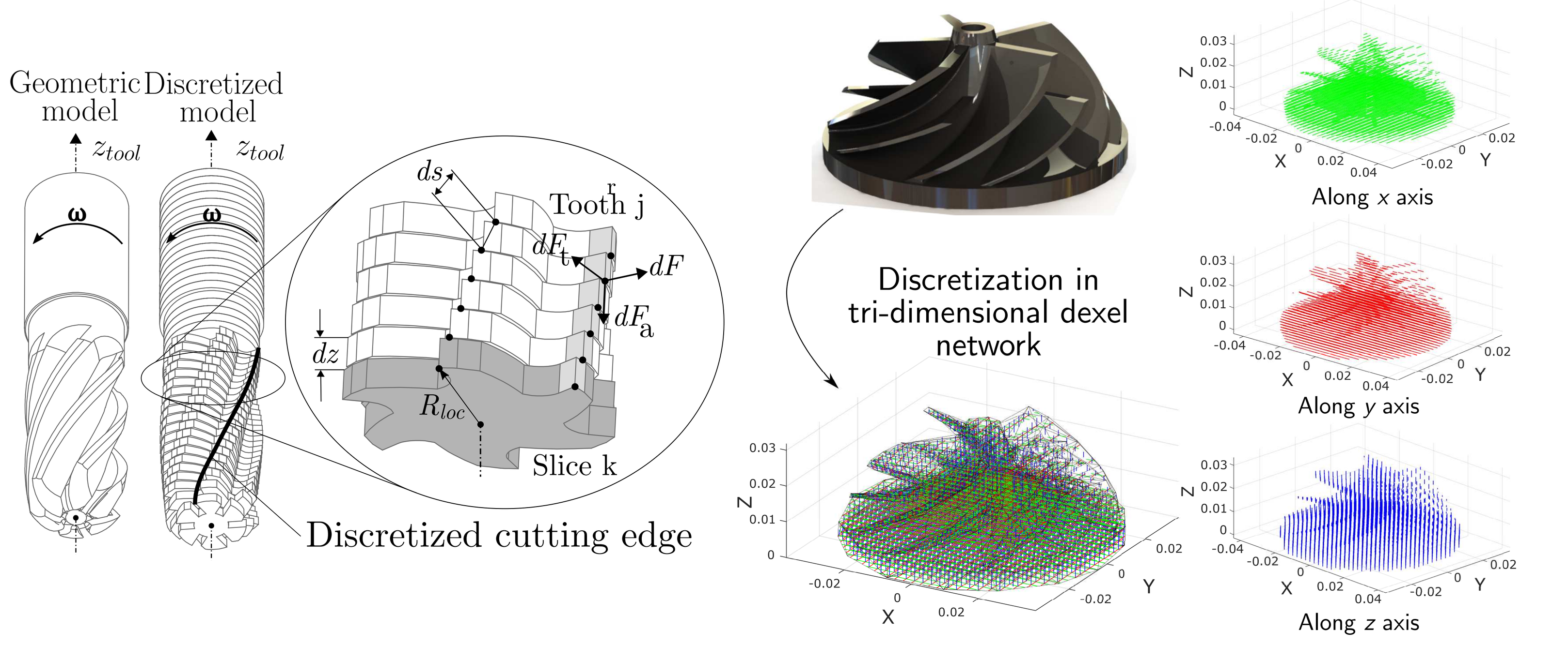

Figure 2: Left: Discretized model of a tool as a slack of slices. Right : Discretized model of workpiece as a dexel network.

The determination of the cutting forces in the tool frame is carried on with empirical model based on the chip thickness, tool parameters and geometry and material properties. The chip is the result of the tool-workpiece interaction and is a key element in the force computation.

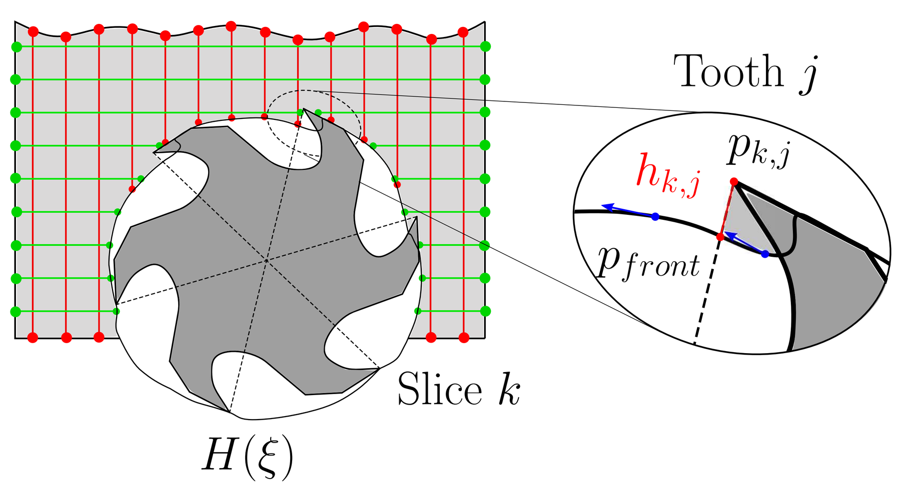

Figure 3: Illustration of tool slice cutting the dexels network. Detailed view of the cutting area for the computation of the chip thickness $h_{k,j}$.

The chip thickness is computed comparing the cutter edge position with a the workpiece surface (Fig. 3). The front of matter is reconstituted through the quadratic interpolation of previous positions ($H(\xi)$). The 3D machining forces computation method proposed is hybrid since it relies on discretized modelling approach and analytical chip determination.

2 Deviation compensation method

The re-positioning of the nodes is carried out by applying the positioning error back to the node, as for mirroring methods. In the simulation the material removal starts at $t = 2.0s$, hence the number of nodes is important in this area to anticipate the deviation. The results of are given in Fig. 4.

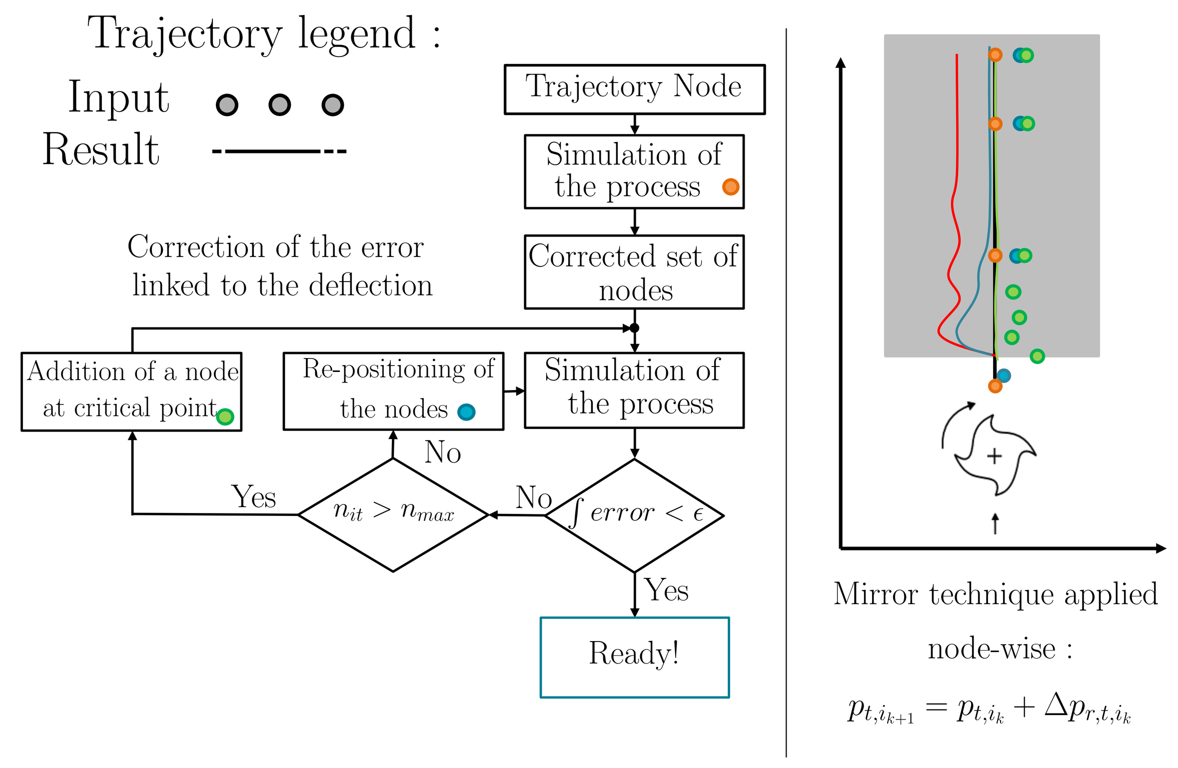

Figure 4: Node re-positioning algorithm for trajectory compensation.

3 Results

The milling simulation and comparison is carried out for a two-teeth flat-end mill with a 2 mm radius with an helix angle of 20°. In order to compare with validated cases of the in-house simulator DyStaMill, a 2.5D case is studied. Experimental data are collected from the face milling of Ti6Al4V plate. The depth of cut is 2 mm for a cutting thickness of 1 mm, the rotation speed and tooth feed being 11940 rpm and 10$\mu m/tooth$.

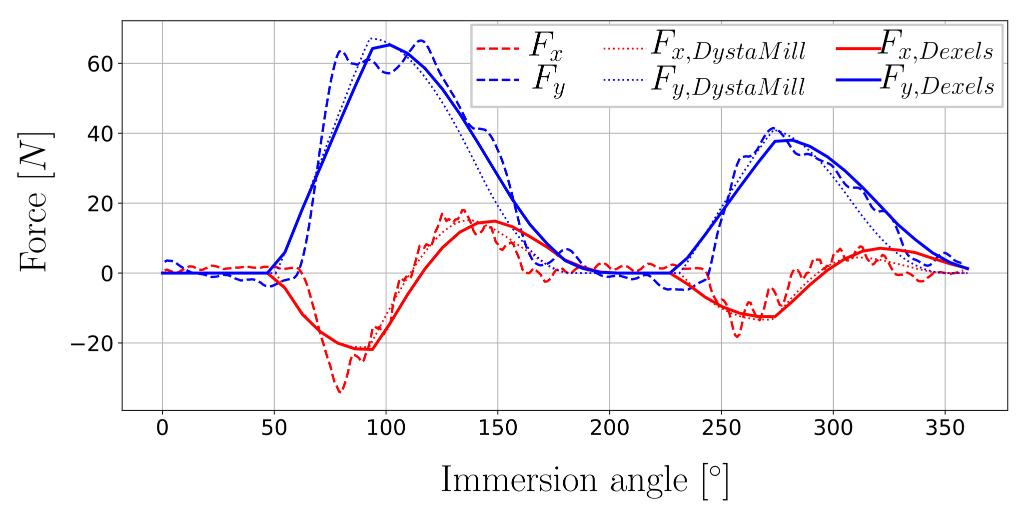

Figure 5: Comparison of the machining forces over a revolution between Dystamill, dexel module and experimental data. Measurements were collected with a Kistler dynamometer and filtered under 2kHz.

The result of the compensation algorithm is presented in Fig. 6 for the entering phase of a face milling operation.

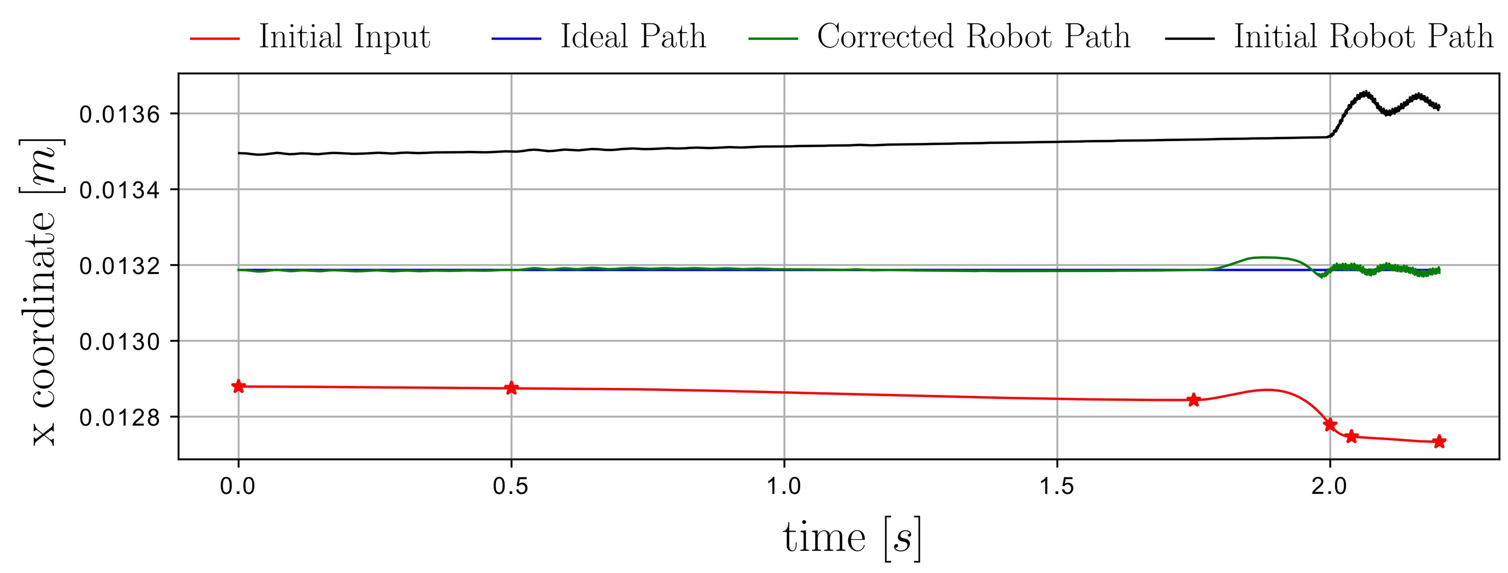

Figure 6: Comparison between the initial input trajectory / robot actual path before and after compensation.

4 Conclusions & Perspectives

- The hybrid analytical/dexel model approach allows to estimate the milling forces, enabling simulations for complex robot motions. Discrete modelling approaches are increasing computation time, sophisticated implementation should be considered.
- The compensation algorithm for the spacial re-positioning of the nodes reduces the simulated path errors after several iteration, however the amount of iterations and nodes may be reduced by using inverse dynamics optimisation-based methods.

References

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Université de Mons
Faculté Polytechnique
Valentin DAMBLY
Service de Mécanique Rationnelle, Dynamique et Vibrations
valentin.dambly@umons.ac.be