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Digital Twin-driven tool condition monitoring for the Milling process

The authors wish to thank the editor and reviewers for accepting our manuscript for further processing in your esteemed Journal "Sensors." The authors expressed their sincere thanks to the reviewers for finetuning this manuscript. We have taken utmost care to address all the comments raised by the reviewers with suitable justifications. The changes that we are made are highlighted in red color. We shall be happy if our revised manuscript is accepted for publication in view of our explanations in this reply and revision of the manuscript. The detailed information is given below for your kind reference.

Response to Reviewer 1 comments:

This is a very good topic, but the organization of the author's research is somewhat beside the point.

1. Generally, the model trained by measurement data differs from the twin model. However, the paper should elaborate on establishing the tool twin model from the point of view of the mechanism. Measurement data should be used as the basis for the revision of the model.

Response: Thank you very much for your suggestion. The DT model was developed based only on the acquired vibration and sound signals. Initially, 75% of the data was used to train the model, and 25% of the remaining data was used for testing and validation. The acquired data is used for model training and validation.

The "Tool Twin Model" is a concept that refers to the digital representation or virtual counterpart of a physical tool or machine. It is commonly used in the context of Industry 4.0 and the Internet of Things (IoT) to enhance manufacturing processes and enable advanced functionalities. From the perspective of the mechanism, the establishment of a tool twin model involves several steps:

- Data Acquisition: The first step is to collect data about the physical tool or machine. Data Acquisition can include information about its geometry, components, sensors, actuators, control systems, and operating parameters. Data acquisition methods may involve manual measurements, sensor integration, or leveraging existing CAD or digital design data.
- Data Integration: The acquired data needs to be integrated into a unified digital representation. This involves combining the data with other relevant information. The data integration ensures that the digital model accurately represents the physical tool. Here the data is integrated with different tool conditions.

- Model Development: Once the data is integrated, a Machine learning model is created based on the acquired information. This model aims to capture the tool condition. Various machine learning algorithms are used to develop the model. The model which has the highest classification accuracy is used for DT. Here the DT model is developed using MATLAB/ Simulink toolbox.
- Calibration and Validation: The developed Simulink model must be calibrated and validated to ensure accuracy. This involves comparing the behavior of the digital model with real-world measurements or performance data obtained from the physical tool. Calibration may involve adjusting model parameters or refining the model structure to achieve better alignment with the physical system.
- Integration and Data Exchange: For real-time application, the developed model has to be integrated with a CNC machine to monitor the tool condition. This enables real-time monitoring, data exchange, and synchronization between the digital twin and its physical counterpart. Sensor data from the physical tool can be used to update and refine the digital model. In contrast, the digital twin can provide insights, predictions, or optimization suggestions to enhance the operation and maintenance of the physical tool.

Overall, establishing a tool twin model from the perspective of the mechanism involves acquiring, integrating, modeling, calibrating, and validating data to create a digital representation that closely resembles the physical tool or machine. This enables advanced analysis, optimization, predictive maintenance, and other value-added functionalities in the context of Industry 4.0 and smart manufacturing.

2. The 3D information twin model should be given.

Response: thank you very much for your suggestion. Instead of using a 3D model for DT, the authors used a data-driven approach.

A "3D information twin model" could potentially refer to a digital representation or simulation of a three-dimensional object, system, or environment that captures and incorporates various information related to that object or system. This information could include geometric data, spatial relationships, material properties, textures, colors, and possibly dynamic aspects such as motion or behavior.

Such a model could be used in various fields, including computer graphics, virtual reality, augmented reality, computer-aided design (CAD), engineering simulations, architectural visualizations, and more. It would aim to provide an accurate and detailed representation of the physical entity in a digital form, enabling analysis, visualization,

interaction, or other forms of manipulation. For the milling process creation of 3D model is challenging. So the authors used the data-driven approach to develop the DT model through Machine learning algorithms.

3. Figure 1 and Figure 2 are not clear.

Response: thank you very much for your suggestion. The Figure quality is enhanced in the revised manuscript.



New Tool



Single Tip Broken Tool



Two-Tips Broken Tool



Triple Tips Broken Tool



Four Tips Broken Tool



Figure 2. Experimental setup

4. Figure 3, figure 5, and Figure 11 are not necessary; they do not clearly give the necessary twin model information.

Response: Thank you very much for your suggestion. Figures 3, 5, and 11 are removed in the revised manuscript.