Auto-Tuning Sync in the Acoustic Emission Mapping for CFRP Milling

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Introduction

Driven by the growth of Industry 4.0, the advancement of machine integration and manufacturing automation through IoT systems are progressing rapidly, as the new factories' layout tendency is aimed to remote centralized control of the machinery [1 2]. In this context, the scaling complexity of the production process grows the necessity for systems with higher self-management, which requires larger and more accurate amounts of data. In this work, it is proposed an Auto-Tuning Sync in the Acoustic Emission Mapping algorithm, implemented in the Matlab software. This method utilizes RMS calculus to determine the concentration of energy in each map section and then uses standard deviation to evaluate the alignment of acoustic energy peaks in said map with the physical phenomenon, followed by comparing the resulting parameters of each syncing frequency and automatically selecting the optimal spindle frequency.

Objective

To create a method capable of synchronizing acoustic maps without a external syncing signal, thus avoiding the need of a additional channel and hardware.

Methodology

For acoustic mapping, the use of an external synchronization signal is common; however, this method requires an additional channel for acquiring the signal, leading to a more complex and expensive data acquisition system. To avoid the need for an external synchronization signal, it was observed that a correction index can be derived from the misalignment of cutting edges seen in the acoustic map.

Due to the geometry and translational movement of the cutting tool, the pressure exerted by the cutting edge on the CFRP with each tool revolution results in an alternance of peaks in the acoustic emission signal. These variations appear as cyclical vertical bands on the acoustic map, which show an inclination due to a lack of synchronization between the programmed spindle rotation speed and the actual speed. From the misaligned map, the alignment of energy peak strips is calculated using root mean square (RMS) statistics, standard deviation, and error estimation. Based on this error, the actual spindle speed is calculated, which can be used to correct and align the acoustic map, eliminating the need for an external synchronization signal.

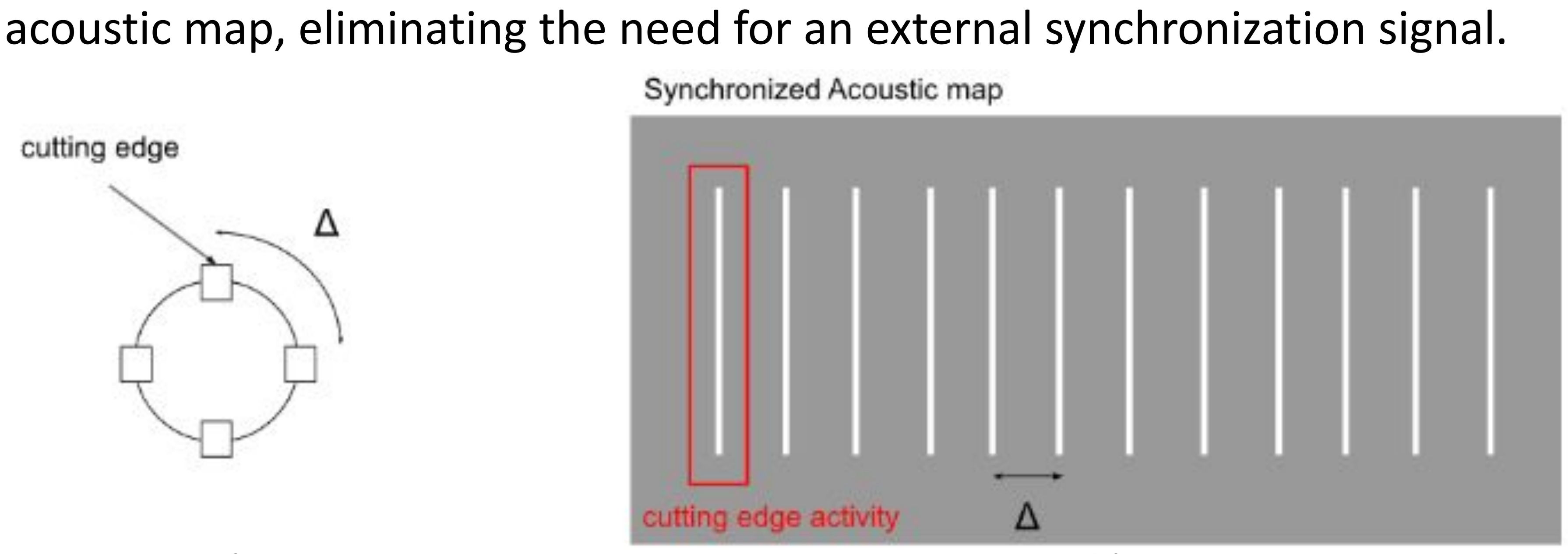

Figure 1: Cutting edges of the tool (a) and synchronized acoustic map (b).

Results and Discussion

Figure 2 shows the conditions of the acoustic map obtained both with and without the alignment of the synchronization signal. Despite the speed configured on the machine, the technique allowed for the determination of the actual spindle speed, which was 6993 rpm. Additionally, the vertical bands on the map, corresponding to the tool's cutting edges, were clearly visible that is, 3 revolutions of the tool with 4 cutting edges each, totaling 12 vertical bands.

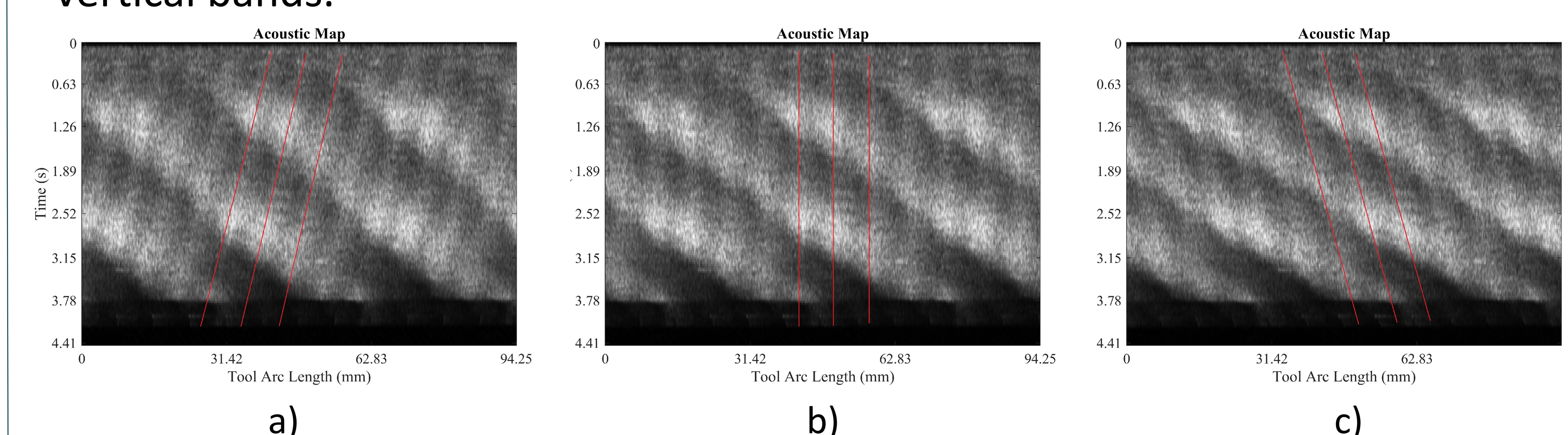

Figure 2: Generated acoustic maps for 6988 RPM (a), 6993 RPM (b), and 7000 RPM (c).

Table 1 presents a summary of the parameters obtained through the implemented technique, demonstrating the increase in the mean energy standard deviation (σ) when acoustic map synchronization is achieved. It also shows the average peak separation (Δ'), which reflects the physical spacing between the cutting edges of the milling tool. Ideally, this value should be close to 80 points, corresponding to an arc length between edges of approximately 7.85 mm.

Table 1. Operation parameters

Syncing Frequency	Mean energy standard deviation 'σ'	Mean peaks separation 'Δ'
6988 RPM	1.782787	85.200000
6993 RPM	7.020648	79.818182
7000 RPM	1.218722	73.333333

Conclusion

Experiments conducted on a CNC machine generated acoustic maps that described the milling process of CFRP plates, revealing that the actual tool rotation speed diverged from the programmed speed, leading to desynchronization. The results demonstrated that the algorithm was effective in distinguishing the synchronized map from the unsynchronized ones and in estimating the distance between the tool's cutting edges.

These findings suggest that, under specific machining conditions, the use of an external synchronization signal for constructing the acoustic map is unnecessary, thereby simplifying the data acquisition system, making it more economical, and computationally less complex. This advancement represents a significant contribution to the development of embedded IoT sensor solutions aimed at Industry 4.0.

References

[1] J. Chen, F. Zhang and Y. Li, "Sound-Based Real-Time Scrap Falling State Monitoring in the Shearing Process of Wide Heavy Plate Mill," in IEEE Sensors Journal, vol. 23, no. 15, pp. 17092-17102, 1 Aug.1, 2023, doi: 10.1109/JSEN.2023.3284517.

[2] J.-B. Duo, "A new model for intelligent steel mill central control and management," Sci. Technol. Inf., vol. 1, no. 18, pp. 1–3, 2021.