ECSA-11 2024 Conference

11th International Electronic Conference on Sensors and Applications

Assessment of Cosine Similarity for Acoustic Emission Based Tool Condition Monitoring in Milling Processes.

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Introduction

Tool Condition Monitoring (TCM) systems have gained prominence in industrial automation due to the need to enhance efficiency and reduce manufacturing costs. These systems use advanced sensors to capture signals during machining processes, enabling early fault detection and prediction of tool lifespan (ILIYAS et al., 2020).

Objective

The proposed project aims toexplore the potential and feasibility of using distance-based metrics, such as condition indicators based on Cosine Similarity (CS), to analyze Acoustic Emission (AE) signals and monitor tool wear during milling operations. The goal is to increase productivity, reduce manufacturing costs, optimize tool lifespan, lower the risk of damage during milling, and enable quick corrective actions.

Methods and Procedures

The CS method was used to correlate the events in AE signals with tool wear during the milling process, as described by Equation 1.

$$CS\,(X,Y) = \frac{\sum_{i=1}^{N} x_i . y_i}{\sqrt{\sum_{i=1}^{N} {x_i}^2} . \sqrt{\sum_{i=1}^{N} {y_i}^2}} \qquad (1)$$

The vectors x and y represent acoustic signals recorded under reference conditions and after potential damage, such as tool wear. Detailed data and documentation on the experiment setup and data collection are available in [2]. Table 1 lists the various conditions to which the tool was exposed.

Table 1. Cases with different cutting parameters and materials

Case	Cutting Depth (cm)	Feed (cm/rev)	Material
1	0,75	0,25	Steel
2	1,5	0,5	Cast Iron
3	0,75	0,5	Steel Cast
4	0,75	0,25	Iron

Results

In this preliminary study, data from Case 1 were analyzed to assess tool condition at various levels of flank wear. The signals from this test include 9,000 points, covering the entire tool path on the workpiece. Cosine similarity was computed by comparing signals from a tool with no flank wear to those showing progressive wear. The results of these CS calculations for the samples are shown in Figure 1. For comparison purposes, wear measured directly from the tool to each sample in Case 1 is shown in Figure 2.

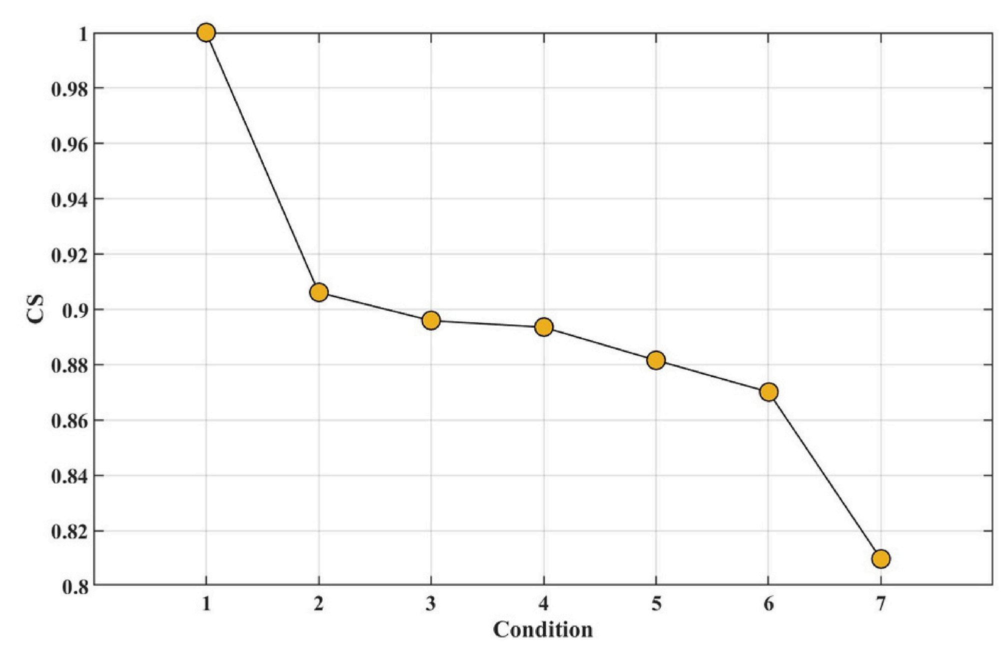

Figure 1: Cosine Similarity Calculation for Case 1

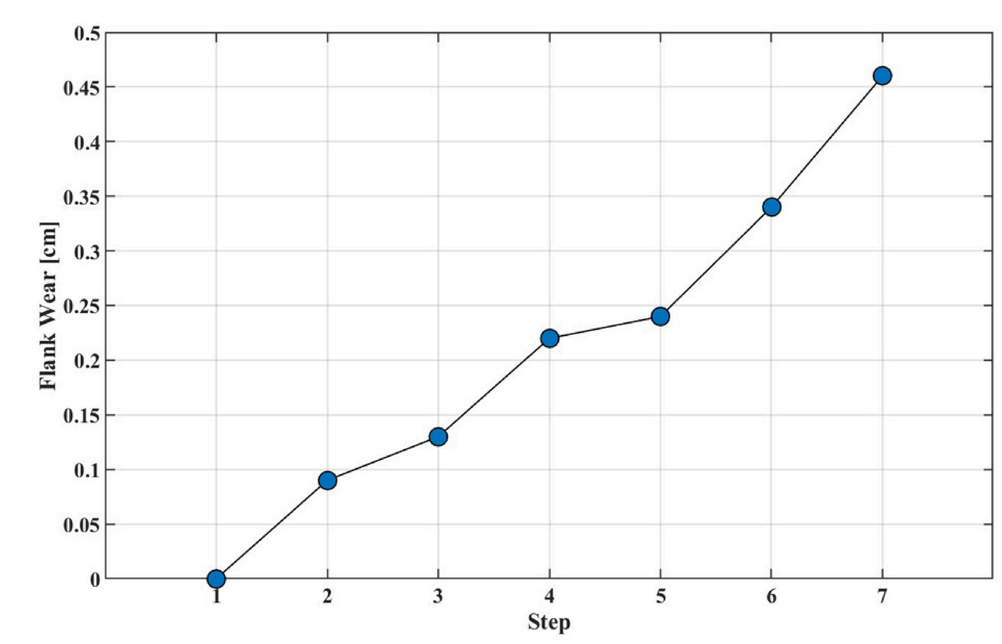

Figure 2: Tool Wear for Case 1

Conclusions

Preliminarily, it appears that the CS method is effective for condition monitoring, as it tracks tool wear in a manner consistent with the measured wear in each case. As the tool wears down over time, its similarity to the intact tool decreases. However, it's important to note that the curves for tool wear and CS do not always match proportionally. For instance, between passes 3 and 4, the tool wear curve shows a sharper increase, indicating a more abrupt change compared to the previous state. In contrast, the CS curve shows a smoother decline during the same period, reflecting a less sudden change. This underscores the need for a sufficient amount of data when using this method for condition monitoring. A longer sampling period is necessary for the signal to reveal significant variations that can detect changes in similarity, ensuring a more robust and conclusive analysis.

Acknowledgements

I would like to thank FAPESP for their financial support of this project (process number 2023/11275-2).

References

[1] ILIYAS, A. M; YUSOF, Y.; DAUD, M.E. et al. Machine monitoring system: a decade in review. Int J Adv Manuf Technol 108,3645–3659 (2020).

[2] AGOGINO, A.; GOEBEL, K. Milling Data Set. NASA Prognostics Data Repository, NASA Ames Research Center, Moffett Field, CA (2007).