Accurately monitoring tool wear in precision machining

- Precision machining is a vitally important technique in modern manufacturing.
- To maintain product quality, manufacturers need to accurately assess the level of wear in their cutting tools – but this is often difficult to quantify.
- A research team led by Dr George Bollas at the University of Connecticut, USA present an advanced new technique for monitoring tool wear.
- Their approach combines machine-learning algorithms with measurements of vibrations in cutting tools.

Precision machining is an advanced manufacturing technique, which has now become an essential part of the modern manufacturer's toolkit. Essentially, it involves carving out single components from a block of raw material, using specialised cutting tools attached to a 'computerised numerically controlled' (CNC) machine.

By programming these machines with appropriate algorithms, they can be used to create a diverse array of intricate shapes, far more quickly and easily than would be possible with more traditional manufacturing techniques. In turn, it can help manufacturers to reduce costs and assembly times, while ensuring high quality in their final products.

Lacking precision

Despite its advantages, the use of precision machining still faces a major challenge. This is where the research of Professor George Bollas at the University of Connecticut comes in. 'To ensure high-quality machining, it is necessary to monitor the tool condition and optimise the machining process accordingly,' Bollas explains. 'In machining, however, tool wear is challenging to detect visually, and its quantification has been the topic of myriads of scientific studies.'

This is a particularly pressing problem since manufacturers' settings for their CNC machines are usually guided by handbooks, which rarely take tool wear into account. Over time, this will cause handbook recommendations to become less and less accurate as machining tools are ground down by use.

Ultimately, this can lead to lack of precision, lower the quality of final products, increase yields of scrap material, and waste larger amounts of energy. On top of this, tool wear can damage the main components of CNC machines. This inevitably causes them to fail more frequently: interrupting tight manufacturing schedules, and reducing the overall lifespan of valuable equipment.

Monitoring vibrations

To prevent this from happening, it is critical for manufacturers to accurately gauge the level of wear in their tools, allowing them to assess how long it will be before they need to be replaced. In a study led by Dr Debasish

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Mishra, Bollas and his colleagues developed a new approach for tracking the progress of tool wearing.

The researchers started with an experiment in which they attached a rapidly spinning cylinder to a CNC machine and used it to continuously carve away material from a block of stainless steel. To examine the effects of wearing on the machine's performance, they attached an accelerometer to the cutting tool. This allowed them to detect its vibration, which they expected to change as the tool wore down through use. Next, they processed these time-varying vibration signals to pick out any features which differed from those they expected to see when using a new, unworn tool. This difference can be quantified mathematically with a value named its 'distance metric'.

'After signal processing and feature extraction, we computed tool wear indicators based on distance metrics of temporal machine features,' Bollas describes. 'These novel indicators, invented by Dr Mishra, were seen to accurately infer tool wear progression from the dynamics of the machining process.'

Applying machine learning

The team then used a machine-learning algorithm named 'Jenks Natural Breaks', which allowed them to group features together if they displayed any similar vibration patterns. Crucially, the algorithm was able to do this completely unsupervised.

This enabled Bollas' team to monitor the state of the cutting tool from its vibrations alone, without any need to measure its level of wear directly. When the team compared their algorithm's outputs to more traditional methods for assessing tool wear, the results were almost identical – clearly showcasing its reliability.

Universal application

For the team's approach to succeed in practice, they would not only need to confirm its accuracy. It would also be crucial to ensure the quality of its results can be maintained when applied to CNC machines across a diverse range of scenarios: spanning a variety of industrial specifications, machining capabilities, and standards for cutting parameters.

Through their experiments, Bollas and his colleagues clearly demonstrated that their approach to tool wear monitoring could be applied universally, regardless of the specific details of the machine's use. 'Compared to traditional methods, our monitoring system stands out for highly accurate concomitant indicators, unsupervised modelling, and applicability to diverse machining conditions,' says Bollas. 'In follow-up work we are trying to generalise this method to become completely agnostic to machine specificities and be a turn-key solution for manufacturers.'

Advantages for manufacturers

In showcasing these advanced capabilities, the team are now confident that their monitoring system could feasibly assist manufacturers in making more informed decisions about the condition of their tools. In turn, it could help them to avoid using tools which have become too worn – ultimately minimising any damage to their valuable equipment.

The advantages don't end there: in addition, the approach is based on real-time measurements taken while CNC machines are in use, using just a single accelerometer and a simple machine-learning algorithm. Together, this could ensure minimal costs for manufacturers, require little computing power, and minimal changes to their usual operations.

Through current and planned work, the researchers will now aim to expand the potential uses for their monitoring approach even further. 'We envision the potential for further advancements in our monitoring system by extracting more features, exploring additional machine-learning algorithms, and extending to other manufacturing processes,' Bollas predicts.

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Personal response

Why is it so challenging to monitor tool wearing with more traditional methods?

Traditional methods rely on human inspection and periodic measurements. These methods require stopping the manufacturing process to inspect tools, leading to downtime and reduced productivity. This interruption is detrimental to industries, especially in industries where continuous production is essential. Further, human inspection is subjective and inconsistent, leading to variations in assessment between different operators.

Why do tools undergo changing vibration patterns as wearing progresses?

As a cutting tool wears, its geometry changes. The alteration in the tool surface affects the forces acting on the tool during machining, resulting in variations in vibration patterns.

What features does the Jenks Natural Breaks algorithm search for when making its assessments?

The Jenks Natural Breaks algorithm clusters data by identifying transitions or breaks in the data where the values change significantly. The algorithm considers different ordering of the data values to find the arrangement that optimally separates the data into distinct classes. It aims to minimise the variance within clusters and maximise the variance between clusters.

Details

e: george.bollas@uconn.edu
w: iase.engr.uconn.edu/person/george-bollas

Bio

Dr George Bollas is the Pratt & Whitney Endowed Chair Professor in Advanced Systems Engineering with the Chemical and Biomolecular Engineering Department at the University of Connecticut. He is also the Director of the Pratt & Whitney Institute for Advanced Systems Engineering at UConn. His laboratory pursues a balanced approach to information theory for the design, optimisation, control, operation, and maintenance of cyber-physical systems, with applications on energy, chemical industry, manufacturing, naval and the aerospace industry.

Further reading

Mishra, D, Awasthi, U, Pattipati, KR, Bollas, GM, (2023) Tool wear classification in precision machining using distance metrics and unsupervised machine learning, *Journal of Intelligent Manufacturing*, 1, 25.