

Camera-Based Tool Wear Monitoring for Enhanced CNC Machining Processes

ACM Classification Keywords

- Real-time system architecture
- Computer-aided manufacturing
- Forecasting

Justification of the Research

Modern CNC machining requires consistent tool integrity to maintain product quality and cost-efficiency. Undetected tool breakage or edge fractures can compromise part accuracy, increase downtime, and escalate costs. Traditional monitoring methods, relying on indirect signals or manual checks, are often slow, imprecise, or incompatible with Industry 4.0 demands. This research employs a cost-effective camera-based vision system to analyze tool geometry directly. By counting pixels in high-resolution images captured at the tool's reference position—a standard CNC feature—it detects material loss with precision, enabling prompt intervention, reduced scrap, and reliable, data-driven maintenance strategies.

Methods

A custom camera-based system was developed to capture high-resolution videos of CNC tools at a consistent tool-changing position. Classical image processing techniques—background subtraction, thresholding, and morphological closing—were used to segment and analyze the tool geometry. Metrics like tool height and pixel area were extracted, and rotational angles were correlated with pixel area distributions to establish a baseline pattern. Deviations from this pattern indicated material loss, including fractures or breakage. This approach integrates seamlessly with existing CNC setups using only a camera, OpenCV libraries, and a stable mount, avoiding complex sensors.

Student's Own Results

All experiments were designed and implemented by the student, who recorded custom datasets representing various tool conditions. Findings demonstrated a clear link between pattern dis-

tortions and tool fractures, resulting from independent efforts and methodological refinements.

Conclusions

This camera-based strategy achieves near real-time detection of tool breakage and fractures by comparing observed patterns with a baseline. Unlike conventional sensors or manual checks, it identifies subtle material losses as soon as the tool reaches its reference position. Its simplicity, scalability, and minimal hardware requirements make it ideal for modern manufacturing environments. By ensuring timely intervention and reducing downtime, this system enhances product quality and aligns with Industry 4.0 principles. Future work may leverage machine learning for enhanced pattern recognition and predictive maintenance, further advancing machining operations.