Enabling smartness in a legacy Lathe Machine

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2024 16th International Conference on COMmunication Systems & NETworkS (COMSNETS) | 979-8-3503-8311-9/24/$31.00 ©2024 IEEE | DOI: 10.1109/COMSNETS59351.2024.10427161

***Abstract*—We provide the first-ever low-cost, low-power, easily adaptable solution for tool monitoring and analysis of Lathe machines. An alternate looping system is employed to provide automatic coolant dispensing and to classify tools based on their sharpness using the CNN model. The first objective is achieved using thermal profiling of the tool, whereas a vision-based edge detection approach is used for the latter. A correlation between raise in temperature and tool degradation is inferred.**

***Index Terms*—Lathe tool, Thermal profiling, Coolant dispenser, Canny edge detection, IIoT, CNN-based classification.**

I. Introduction & Motivation

A large number of machines in mechanical workshops and factories are operated and controlled manually. For instance, the operator periodically pours the coolant on the tool of a lathe machine during its operation. The tool material is selected based on cutting speed, feed rate, depth of cut, and material of the workpiece. The tool can be made of high-speed steel (HSS), carbide, diamond or cubic boron nitride. The workpiece can be of metals such as stainless steel, aluminium, titanium, copper, and iron. The sharpness of these tools plays a vital role in achieving the desired surface finish and is currently monitored manually by the operator. The mechanical friction between the tool and the workpiece causes the tool to tear off eventually. Additionally, the process causes a change in thermal characteristics, hastening the tool's deterioration. Thus, monitoring the tool's condition for its sharpness and thermal profile is important.

In this work, we describe an edge intelligent Internet of Things (IoT) solution to monitor the condition of the tool. Our major contributions in this work are:

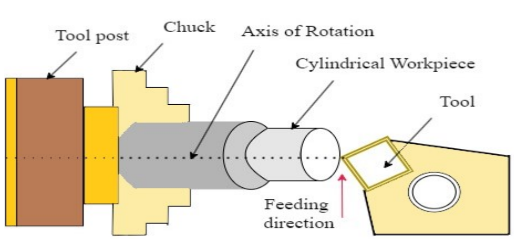

Fig. 1: Lathe operation

Funded by - Ministry of Electronics and Information Technology Special Manpower for Development Programme - SP/MITO-20-0009. Fellowship for Corresponding author Laxmikant D. Pai Angle was funded by Centre for Networked Intelligence (a Cisco CSR initiative) at the Indian Institute of Science, Bengaluru.

- We provide a thermal profile of the tool throughout the machining of the job.
- We present an intelligent solution coolant pouring system based on the thermal profile.
- We present a tool classification algorithm using a Convolution Neural Network (CNN) based on its level of degradation.

The solution is divided into a fast loop and a slow loop, where the fast loop is an edge solution to actuate the coolant system based on the thermal profile of the tool. In a slow loop, the sharpness of the tool is captured and categorized into three classes namely: Sharp, Semi-sharp and Blunt tool.

II. Related works

There are few works in the literature that describe the autonomous monitoring of a conventional lathe machine. The authors in [1] provide an experimental study on multi-sensor solution that encompases thermal as well as vibration analysis of the tool. The solution is high-cost and is difficult to deploy in a workshop setting. The work in [2] provides vibrational analysis of a lathe and is limited to the study of remaining useful life. In summary, there is no existing IoT-based solution for real-time monitoring of lathe operation in mechanical workshops.

III. Experimental Setup

The experiments were conducted in an industrial setting and were tested across various lathe machines. An abundant amount of thermal and image data were collected from various factories in and around the local industrial area. We considered the brazed and carbide tools as shown in Figure 2, on a cylindrical stainless steel workpiece to perform facing and turning operations. Carbide inserts are comparatively harder than HSS and provide longer tool life but cannot be used for shorter cutting speeds due to their brittleness. To obtain the heat map of the tool, we selected Grid-Eye Infrared array

(a) Carbide Insert (b) Brazed Tool

Fig. 2: Types of tools used in lathe machine

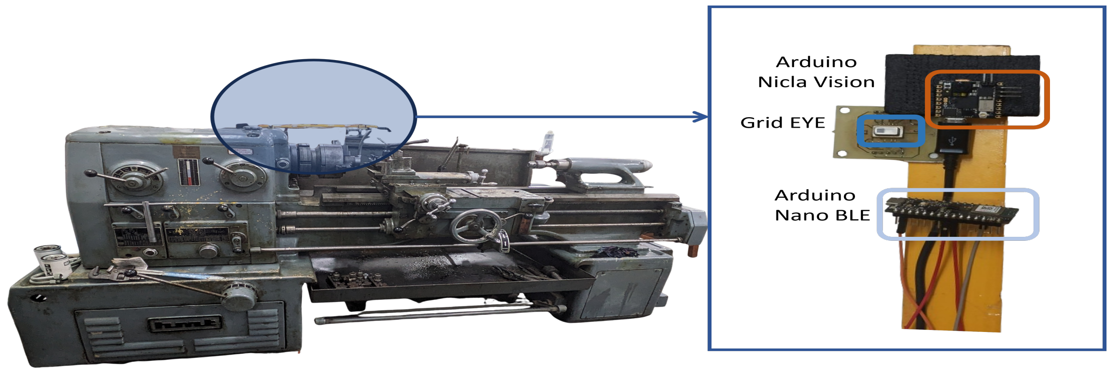

Fig. 3: Lathe machine tool monitoring set-up comprising of infrared and camera module deployed on a legacy lathe.

sensor [3] an 8×8 thermopile sensor. The choice was driven by the requirement of monitoring the tool's tip using contactless sensing. The desired temperature range is 18°C to 120°C. The survey for non-contact infrared temperature sensors included AIT1000, MLX90614 and MLX90640 THERM CAM 110 DEGREE. Despite AIT1000 being a low-cost sensor, it does not meet the required temperature. Although MLX90614 and MLX9060 work for higher temperatures, they are limited by field of view (FOV) and, therefore, are sensitive to placement. Grid-Eye complies with the temperature requirement and provides a broad FOV of 60°. As a result, the placement of the sensor can be generalised across multiple tools. The sensor is connected to an nRF52840 controller [4] via I2C communication. We use a Wi-Fi and Bluetooth Low Energy (BLE) enabled low-power, lightweight, compact 2MP camera module - Arduino Nicla vision, [5] for capturing and transferring the images. A $20000mAh$ battery is used as a power supply for the entire system. The system is placed on the lathe, parallel to the tool, at a distance of $20cm$ as shown in Figure 3.

IV. Methodology

The entire algorithm is portrayed in Figure 4. As mentioned earlier, the proposed system is a two-loop solution: Fast loop and Slow loop. The two loops are synchronized to function alternately. A fast loop is used to check the tool's temperature

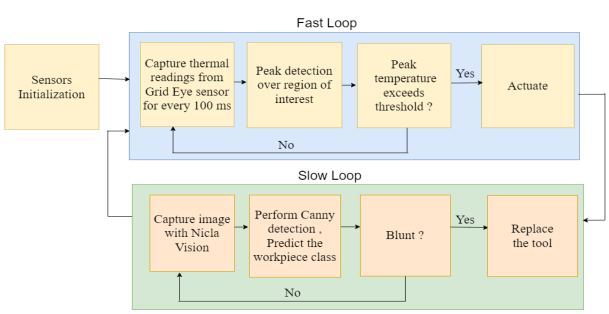

Fig. 4: Work flow of fast and slow looping

during the entire cut which lasts for 10 minutes. A constant gap of one minute is maintained between each cut. In a slow loop, the tool's picture is taken between the cuts when the machine is stable. A five second camera stabilization period is maintained before capturing images to obtain clearer pictures.

A. Fast Looping for automatic coolant system

A threshold is determined by the tool's material. As part of initialization, a region of interest (ROI) is set with an emphasis on the tool-workpiece junction. The fast loop provides an instantaneous response to the change in temperature in the defined ROI. Grid-Eye sensor captures thermal images every 100 ms. Figure 5 depicts the thermal map of an intermediate cut at the start and end of a cycle. Peak detection is carried out across the ROI. If the peak value exceeds the set threshold, a coolant dispenser is activated using a solenoid valve. Otherwise, the fast loop is continued. The temperature increase beyond a threshold affects the tool's health causing an erroneous finishing of the job. Thus, fast loop ensures that the coolant is dispensed well within 315 ms decelerating tool degradation. The actuation time breakup is given as follows: 100 ms for sensing, 5 ms for I2C between nRF52840 and Grid Eye, 10 ms for relay actuation and 200 ms for Valve actuation.

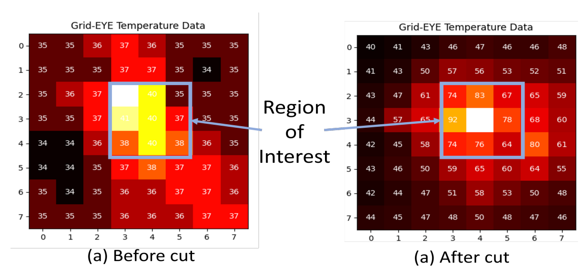

Fig. 5: Heat map of the carbide tool during operation

B. Slow Loop for tool health analysis

A CNN model is developed to classify the image according to its sharpness. Based on the degree of degradation, the model defines three classes: sharp, semi-sharp, and blunt tool. After completion of every cut, the image of the tool is captured using the camera sensor. The tool's image is transmitted to the server for further processing. A canny pre-processing algorithm is applied over the image to detect edges. Figure 6a & Figure 6b depicts the edge focused canny images corresponding to 1^{st} and 4^{th} cut. The degradation can be determined by using pixel mapping or by the CNN model. In pixel mapping, an ROI is defined based on the edge of the tool that is being monitored. Further, the ROI is divided into an 8×8 grid for pixel mapping. Deterioration is calculated based on the number of pixels occupied. Figure 7 shows the deterioration of the tool

(a) After 1st Cut (b) After 4th Cut

Fig. 6: Canny images of Tool

obtained after every cut. On the other hand, the Red Green Blue (RGB) data of the image is passed to a trained CNN model to classify the tool.

V. Results

We provide a detailed temperature analysis of the lathe's tool, as well as the overall current consumption of the proposed solution.

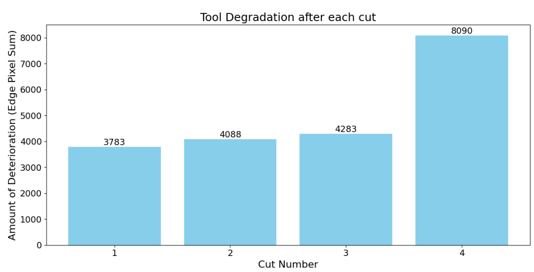

Fig. 7: Tool degradation after every cut

1) Inference from heat mapping: From the experiments, we inferred a correlation between the rise in temperature and tool degradation. We recorded the thermal profile of the tools from the sharp stage to the blunt stage. The experiment was conducted by considering a sharp tool and monitoring its thermal profile throughout its lifetime. For our evaluation, four consecutive cuts separated by one minute were taken into consideration. Figure 8 shows the rise in temperature of the tool over the four cuts. Figure 7 shows the deterioration for the corresponding cut. From both the graphs it can inferred that the temperature rises quickly as the tool deteriorates. Thus, further extending the scope of the work to predict the tool's sharpness using just the thermal profile.

2) Current Consumption: Table I provides a detailed split-up of current consumed by the proposed system in various stages. The current consumption from the thermal sensing is 23.5 mA and constitutes the least current-consuming component. While on the other hand, image capturing and transferring over Wi-Fi takes a maximum of 200 mA. By interleaving

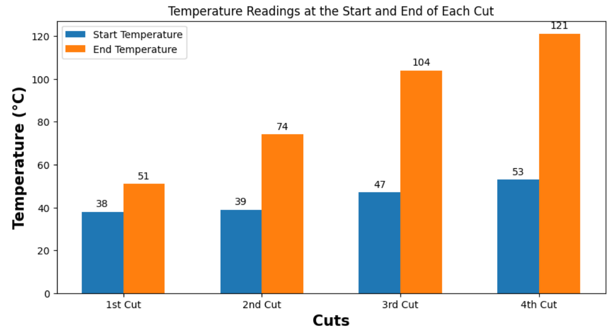

Fig. 8: Temperature variations for every cut

TABLE I: Current Consumption and corresponding time required for each process.

Stages	**Current in mA**	**Time duration in ms**
Every heat map capture	23.5	100
Camera sensor in sleep phase	0.374	6e5
Camera sensor initialization and stabilization	112	458+5000
Camera sensor during image capture	141	51
Camera sensor with camera initialized and Wi-Fi enabling	115	463
Camera sensor during image capture and Wi-Fi enabling	143	56

this state once every cut and keeping the camera module in sleep state during the rest of the operations power consumption is reduced.

VI. Conclusions & Future Scope

The work provides an easily deployable IoT solution for lathe tool maintenance. The system is tested for different types of tools in an industrial setting. From the results, it is clear that using a thermal profile can predict the tool's degradation. In future work, we aim to investigate the prediction of sharpness based on its temperature signature. Furthermore, the coolant supply rate and even the tool replacement can be initiated using just a thermopile sensor.

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