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Paper Code: **#SFS22122**

Time-frequency analysis of vibration signals for monitoring the process status in Ultra-Precision machining of complex components

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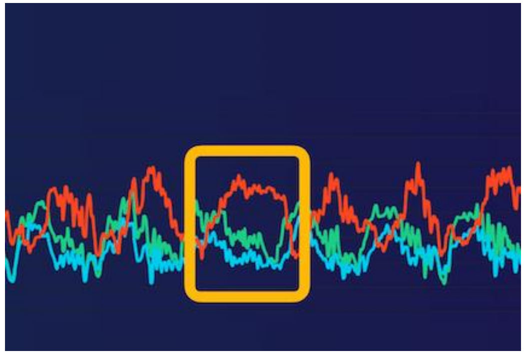


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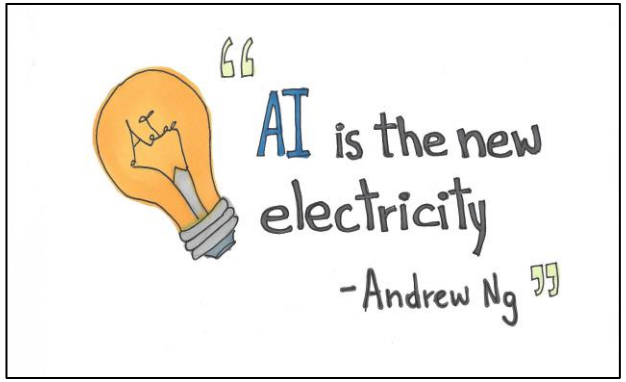
EUSPEN SIG Structured & Freeform Surfaces,
28th- 30th September 2022

Outline



- Introduction
- Ultra Precision Machining
- Signal Processing in Manufacturing
- Experimental Setup
- Time-frequency based anomaly detection
- Conclusion
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INTRODUCTION : NEW ERA DEMANDS

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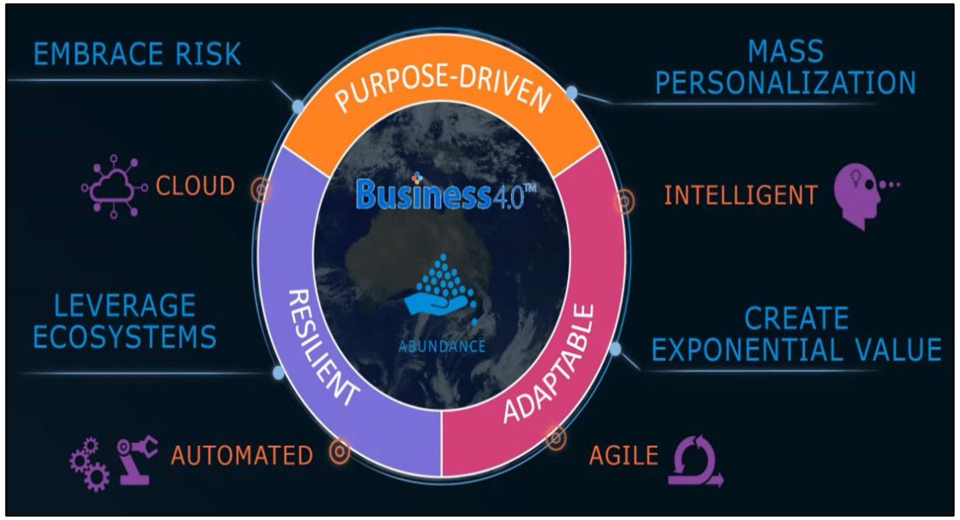
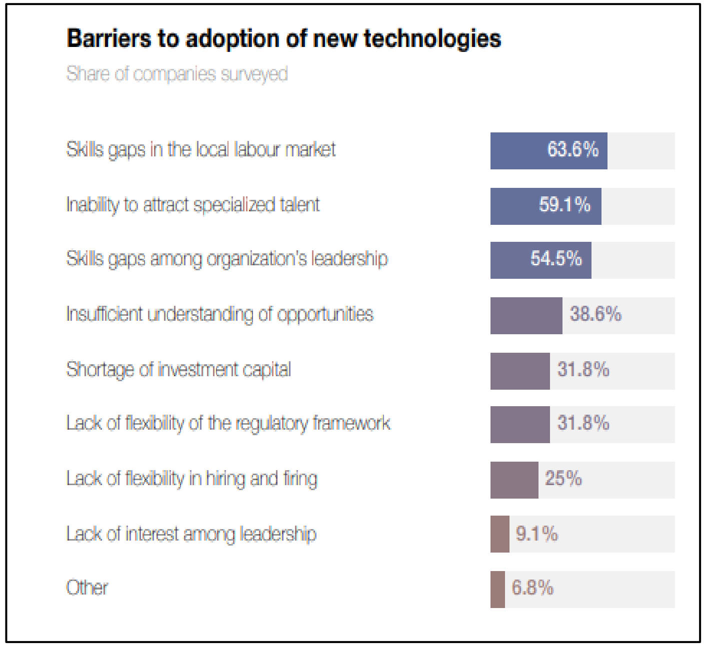
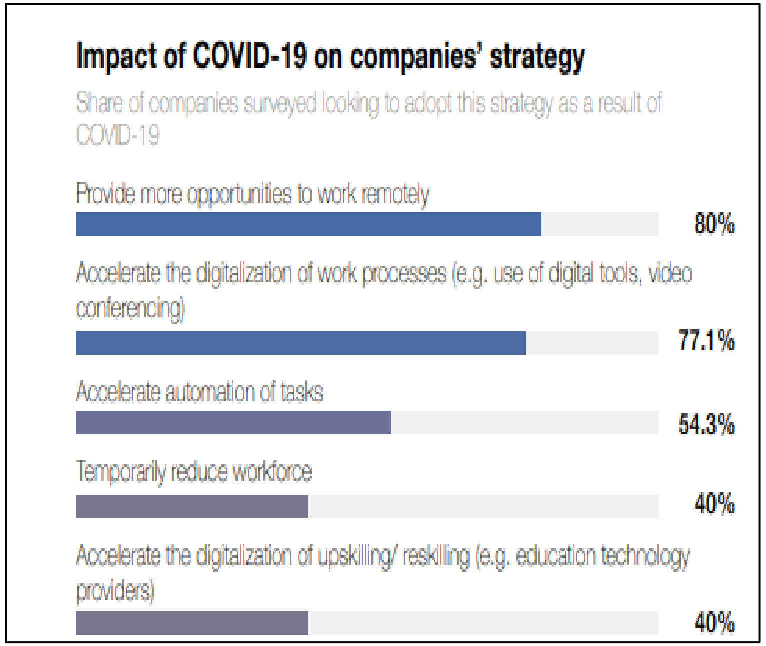
- Explainable Artificial Intelligence has a very positive outlook to meet the Futuristic demand in the area of manufacturing.
- The artificial intelligence in manufacturing has encountered a turning point mainly due to advancements in machine learning, which allows machines to learn, improve, and perform a specific task.
- Due to the inherent transients & nonlinear dynamics in UPM necessitate the need for intelligent manufacturing which has emerged as wave for future.



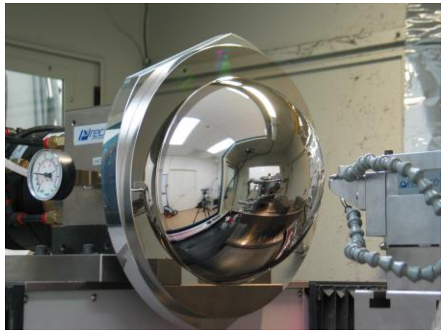




The Global Smart Industry Readiness Index (SIRI) Initiative: Manufacturing Transformation Insights Report 2022 (WEF)
Dong-Hyeon & Kim, Thomas & (2018). Smart Machining Process Using Machine Learning

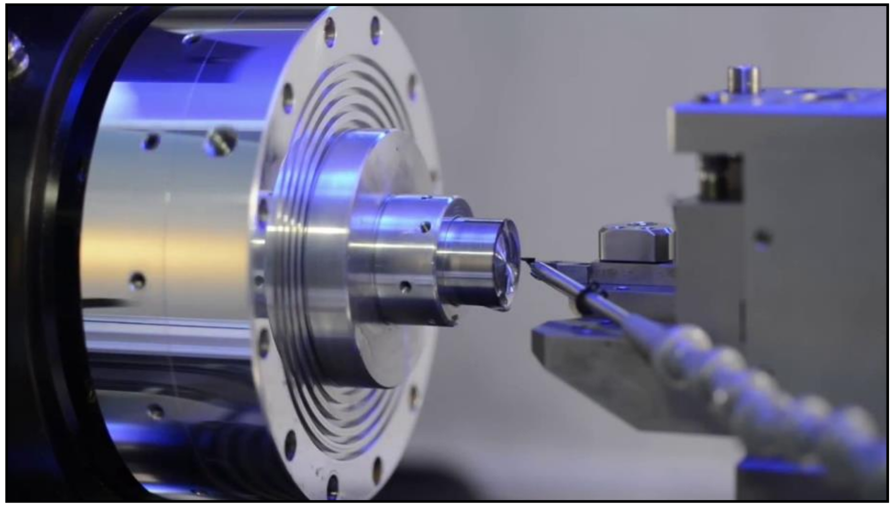
ULTRA-PRECISION MACHINING (UPM)

- Ultra Precision Machining (UPM) has enabled generating critical products and optical surfaces with nanometric characteristics and high levels of smoothness.
- High Precision machining need is increasing due to the requirement of miniaturized component.



Mirrors

Aspheric lenses

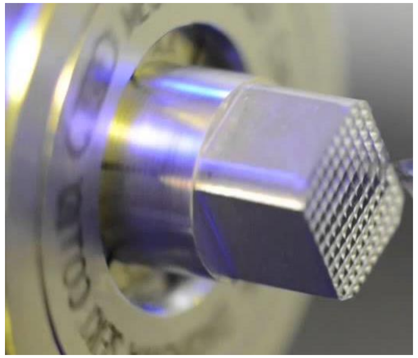


Bio-medical

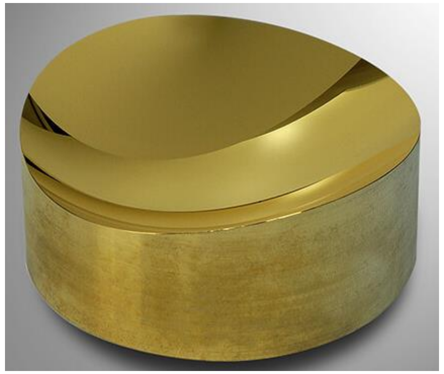
Avionics

Defence

Optics



Lenslet array



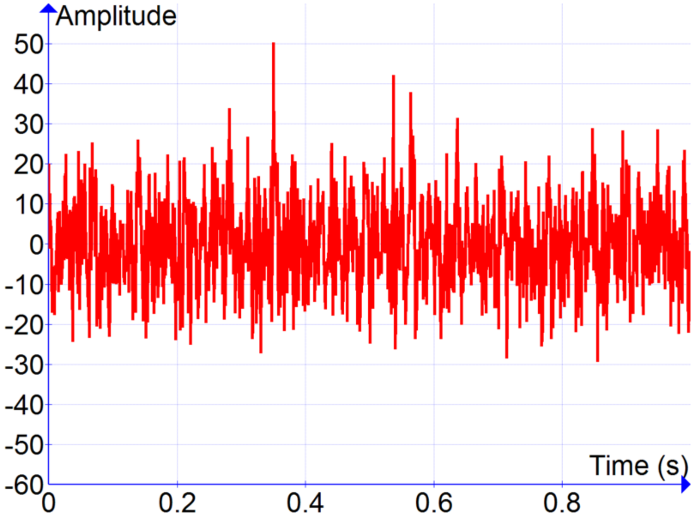
Freeform optics

http://www.itl.nist.gov, National Institute of Standards and Technology
http://www.mitsubishicarbide.net, Mitsubishi Material,
http://www.plastics.bayer.com/landingpages/makrolon-com.aspx, BAYER Material Science AG

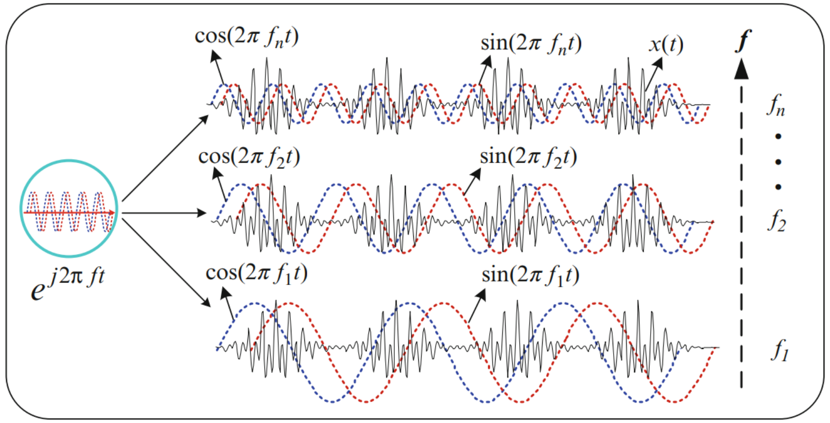
SIGNAL PROCESSING IN MANUFACTURING

The goal of signal processing is about the operation status of the machines and use the information for the following purposes:

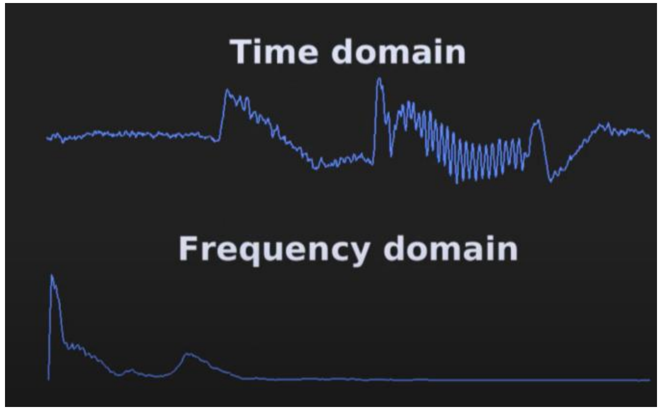
1. Identification of machine faults at the incipient stage.
2. Maintenance and production scheduling.
3. More accurate control of the quality of products being manufactured.



Time-domain signal



Fourier Transform



Limitations of static spectral analysis

Detection of negatively impacting signals can be challenging, as these signals are generally short in duration and weak in amplitude and often buried under heavy Nosie.

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TIME-FREQUENCY DOMAIN SIGNAL PROCESSING

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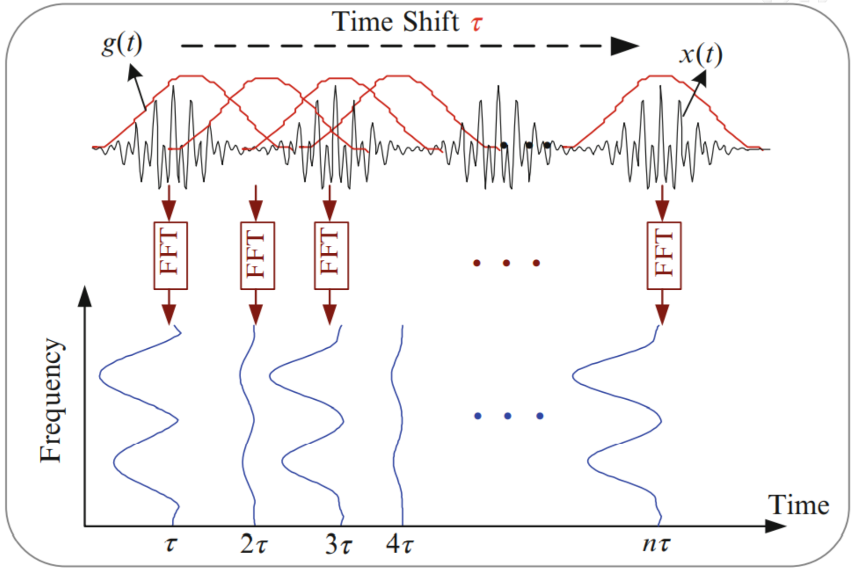
Shot Term Fourier Transform(STFT) was developed to address the limitation of the FT. A solution to this problem is to perform a "time localized" Fourier transform within a sliding window, as in the case of STFT.

$$STFT(u, f) = \int_{-\infty}^{\infty} x(t)\, w(t-u) e^{-j2\pi f t}\ dt$$

Where x(t) is the time series signal, w(t-u) is also window function that shifted in time and modulated in frequency.

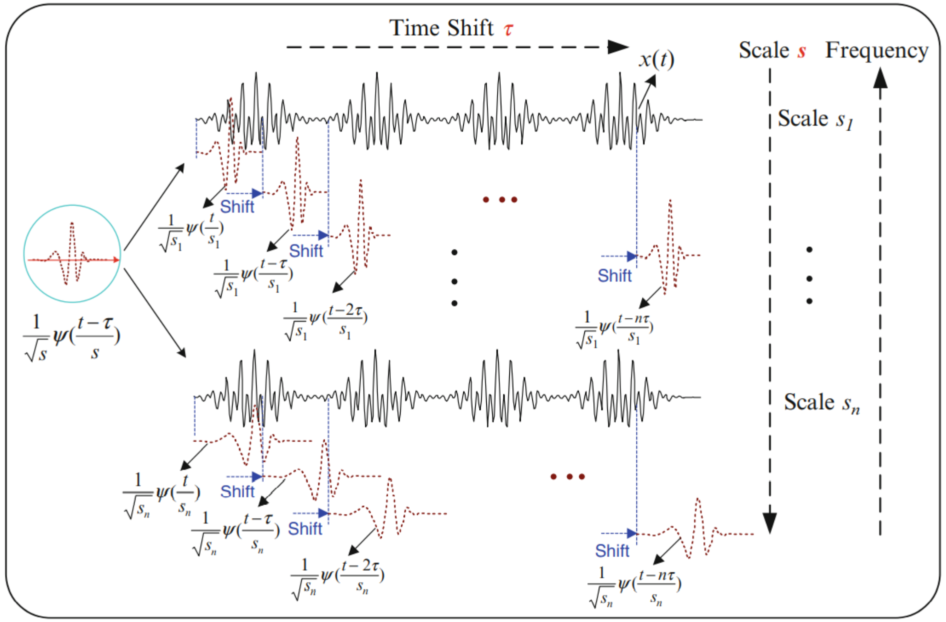


STFT

Wavelet is a rapidly decaying wave like oscillation that has zero mean. Unlike sinusoidal which extents to infinity a wavelet exits for a finite duration.

$$\psi_{u,s}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \text{ a,b} \in \text{R}$$

Here a and b are called Dilation and translation parameters respectively



Wavelet transform

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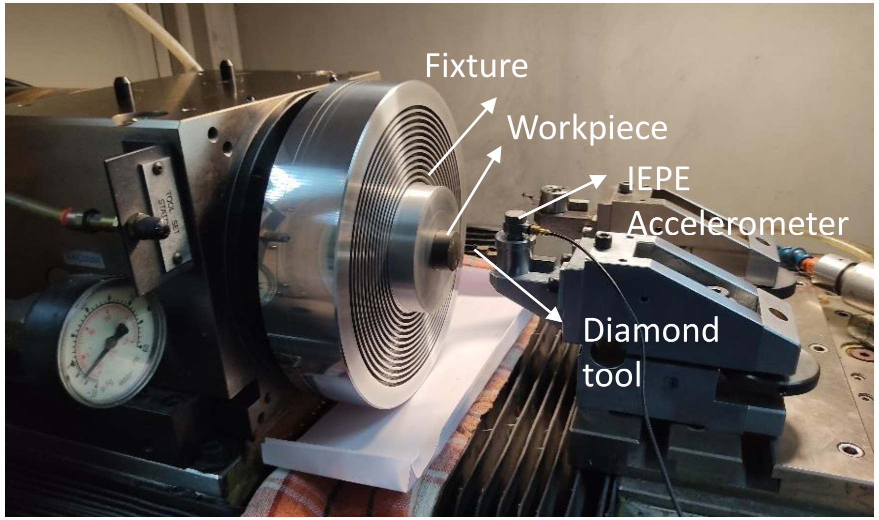
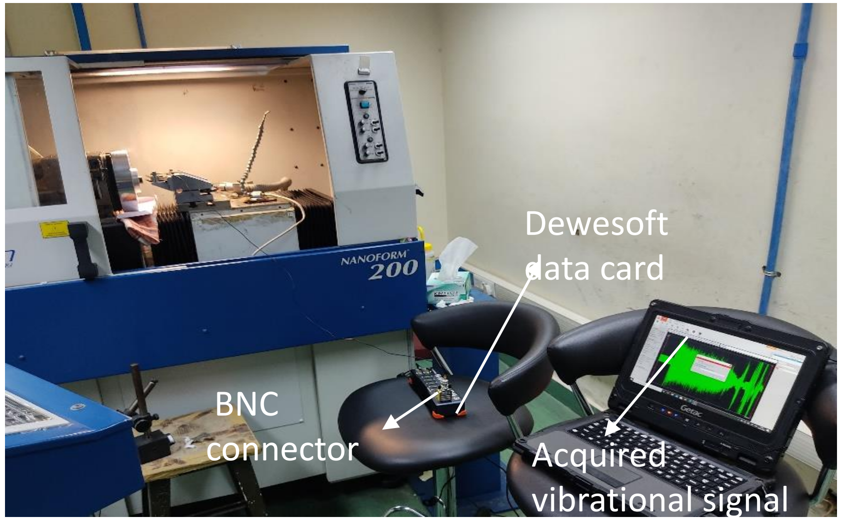
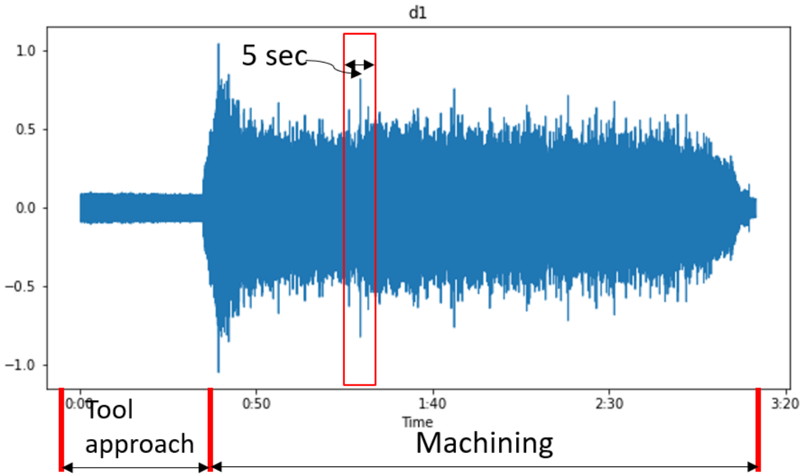
EXPERIMENTAL SETUP



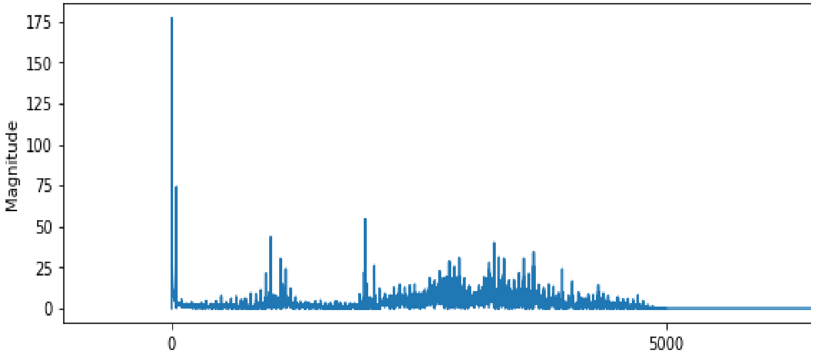


Parameter	Value
Workpiece material	SLM Ti6Al4V alloy
Workpiece dimensions	25mm X 10 mm
Tool	Diamond tool
Tool nose radius	1.495 mm
Sensor	B&J 4533-B (IEPE)
Data logger	Dewesoft DAQ

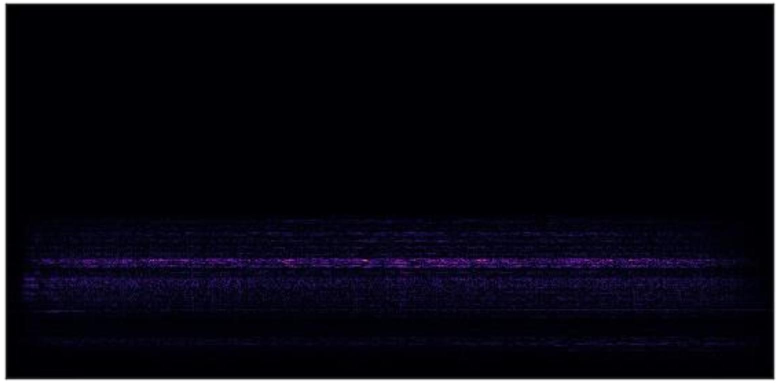
Signal Acquisition setup in UPM



Time domain signal



Frequency domain signal



STFT

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TIME-FREQUENCY ANALYSIS FOR ANOMALY DETECTION

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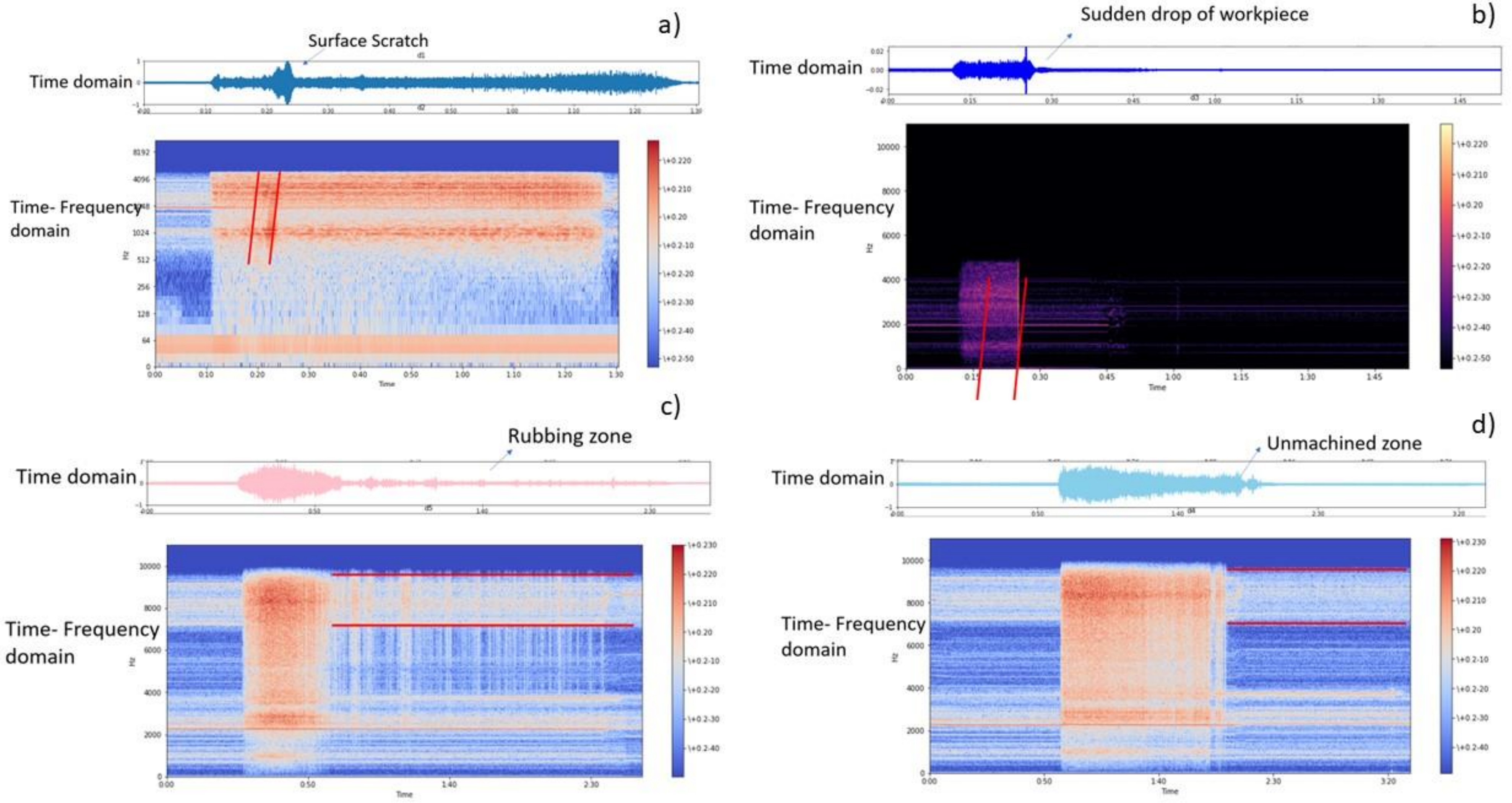
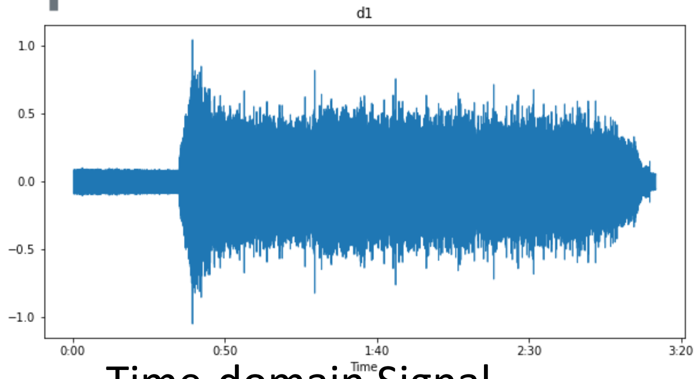
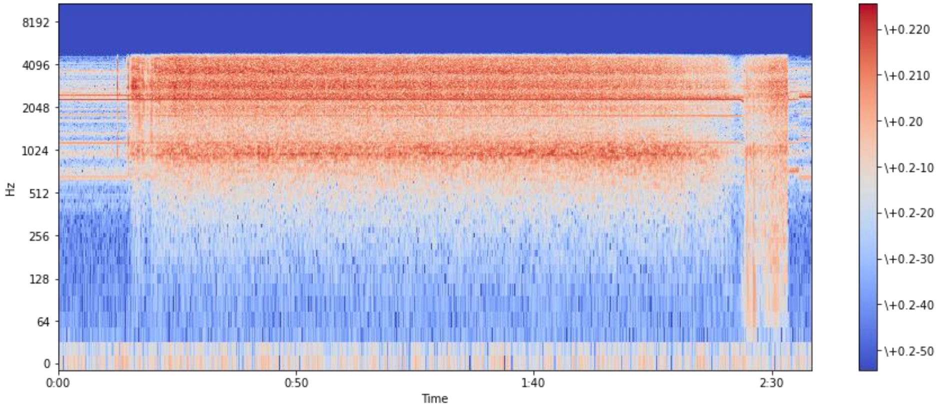


Time-frequency domain log-spectrogram analysis for monitoring various process anomalies a) surface scratch b) Work piece drop c) Rubbing or ploughing b) unmachined zones.

IN-PROCESS MONITORING



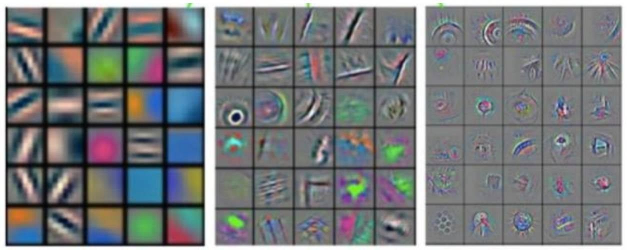
Time-domain Signal

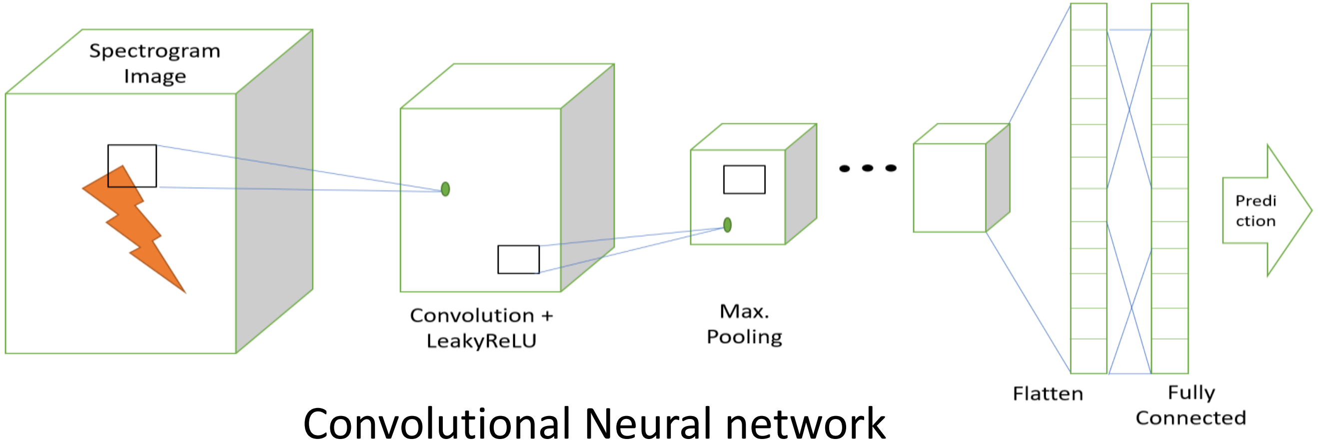


Log-Spectrogram

colab

TensorFlow





Convolutional Neural network

Classification

Normal Machining

Abnormal Machining

CONCLUSIONS

- In this paper an attempt is made for monitoring the machining status using time-frequency analysis. By using log-spectrum analysis has shown very relevant information pertaining the machining process.
- This study is especially relevant when considering the trend towards flexible manufacturing. The main contributions of this paper are as follows:
    - In-process monitoring using a single-direction accelerometer during ultraprecision machining has been discussed. The signals analyzed using CWT reflected the changes during the cutting mechanism.
    - Time-frequency based status analysis further increases the transparency and shortened quality feedback laying the foundation for optimizing the cutting parameters.

FUTURE SCOPE

- This idea can likely be extended to other complex manufacturing process monitoring using transfer learning.
- The focus can be made on exploring transfer learning capabilities by taking advantage of the computational support from the TensorFlow hub using various networks available.

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I still have lot to unlearn and learn

Thank you