Audio Signal Analysis as a Tool in Preventive Maintenance and System Diagnosis

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ABSTRACT: The sound a machine makes can be used to generate an audio profile of the machine's nominal performance. By analyzing the properties of the audio signal, it is possible to determine the expected behavior of the equipment, allowing for anomalies to be identified and diagnosed before they cause significant problems. By constantly monitoring the performance of assets, it is possible for maintenance to be proactive rather than reactive. As a preliminary investigation into the usage of spectral descriptors to predict mechanical failure, multiple pieces of equipment in the John Mica Engineering and Aerospace Innovation Complex were recorded. Trends were determined, and profiles of these machines were constructed. More than 24 hours of audio were recorded and analyzed, taken throughout the operation cycles of the machines. The da Vinci Super by XYZPrinting, a large format 3D printer, was monitored extensively; a failure to correctly print a part was successfully identified and predicted through audio signal processing before a visual inspection of the part confirmed the results of the algorithm.

Background

Vibration data has been studied in the past as a method of nondestructive evaluation [1, 2]. However, this research asserts that another waveform ought to be considered for this analysis—audio signals and their characteristics can be monitored to evaluate system health. The following parameters were considered:

$$\mu_1 = \frac{\sum_{n=b_1}^{b_2} f_n s_n}{\sum_{n=b_1}^{b_2} s_n}$$ Centroid

$$\mu_2 = \sqrt{\frac{\sum_{n=b_1}^{b_2} (f_n - \mu_1)^2 s_n}{\sum_{n=b_1}^{b_2} s_n}}$$ Spread

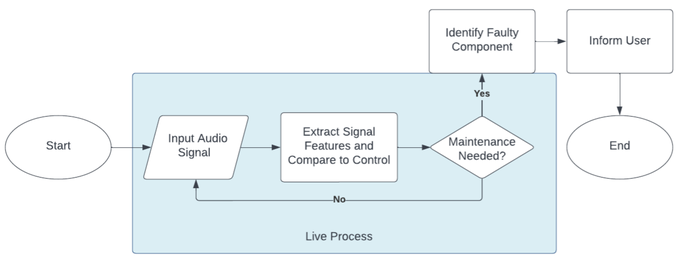
$$\mu_3 = \frac{\sum_{n=b_1}^{b_2} (f_n - \mu_1)^3 s_n}{\mu_2^3 \sum_{n=b_1}^{b_2} s_n}$$ Skew

$$\mu_4 = \frac{\sum_{n=b_1}^{b_2} (f_n - \mu_1)^4 s_n}{\mu_2^4 \sum_{n=b_1}^{b_2} s_n}$$ Kurtosis

$$S = \frac{-\sum_{n=b_1}^{b_2} s_n \log(s_n)}{\log(b_2 - b_1)}$$ Entropy

$$\sum_{n=b_1}^{i} |s_n| = 0.95 \times \sum_{n=b_1}^{b_2} s_n$$ Rolloff Point

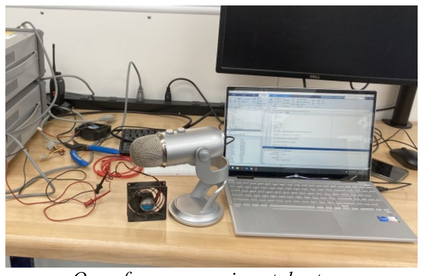
Methodology



Making use of the MATLAB Audio Toolbox, the spectral parameters were analyzed and patterns began to emerge when multiple different sound sources were considered. A preliminary pattern recognition algorithm was developed to detect when a system was under some form of stress, utilizing relationships between the various parameters, as seen above.

Results & Discussion

A preliminary investigation was completed using various sources of audio—systems under known stress conditions were considered. The following observations were made:



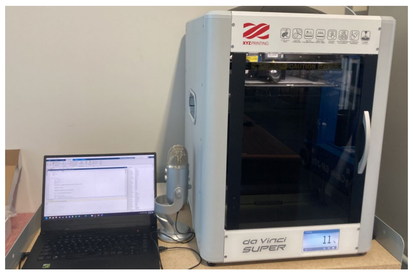
One of many experimental setups

1. Spectral centroid is an indicator of system performance, as is spectral spread.
2. Spectral skewness and rolloff point are indications of ambient speech in the signal.
3. Spectral kurtosis and entropy indicate suddenness of changes in the signal.

Next, the da Vinci Super, a large format 3D printer was monitored extensively throughout its operation. The printer was in use practically 24/7 by ADAMUS Laboratory in the MicaPlex, an was monitored for several weeks. As the system was monitored, system stress was accurately detected.

Parameter	Minimum	Maximum	Mean
μ_1	214.8 Hz	1031.6 Hz	521.2 Hz
μ_2	166.2 Hz	1145.2 Hz	647.3 Hz
μ_3	-1.5730	15.55	6.916
μ_4	1.1176	319.3	95.53
S	0.1308	0.7331	0.4080
i	233.3 Hz	3000 Hz	1456.0 Hz

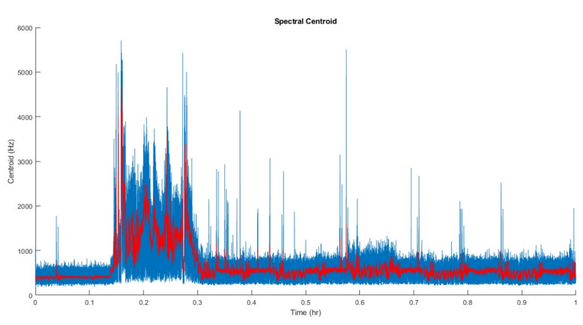
Nominal performance for da Vinci Super

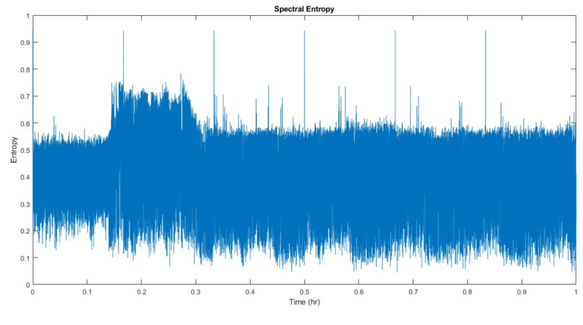


Experimental setup

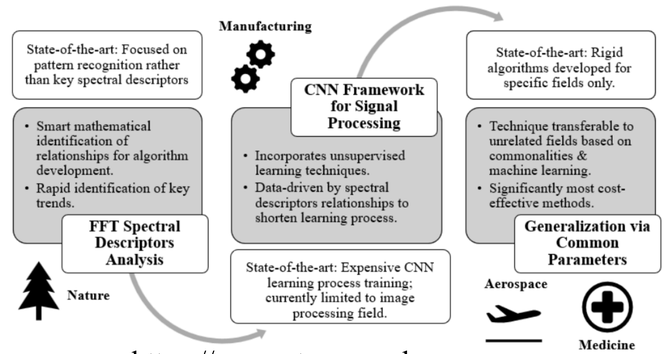
Failed print—operational stress

Under stress, a marked increase in the spectral centroid is visible. During the same timeframe, so is an increase in entropy entropy—an indication of sudden, "acute" stress on the system.





Future Research



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