Monitoring Fused Deposition Modeling 3D Printers with Acoustic Emission

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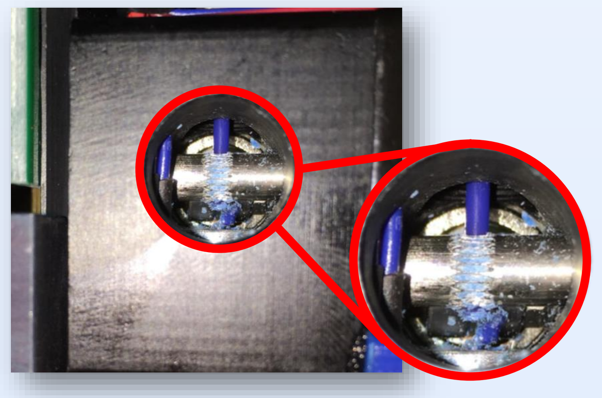
Introduction

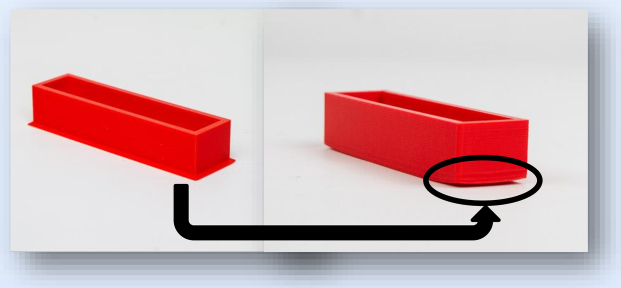
Fused deposition modeling (**FDM**) is a mainstream additive manufacturing process commercially available to consumers. This form of additive manufacturing deposits sequential layers of polymer (ABS, PLA, etc.) in sliced profiles to create complex geometries with a single machining setup. Though a versatile manufacturing method, the process has inherent disadvantages that include poor reliability and inconsistent part production.

Common FDM Printer Problems

Filament jams occur due to broken or bent filament in the extruder



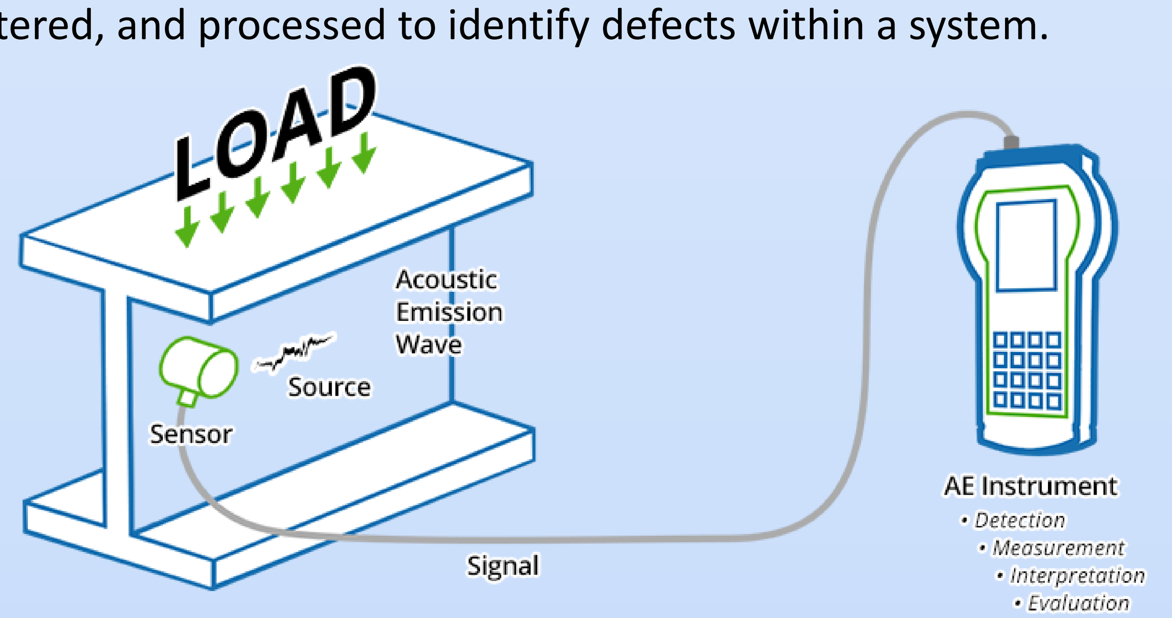
Typical part deformations that cause the model to begin peeling off the bed



Feeder jams occur during the loading process

Acoustic Emission

Acoustic Emission (**AE**) is a non-destructive testing (NDT) method that is used to detect elastic stress waves generated from the source of emission. The source of emission can consist of cracks, deformations, friction, etc. An AE sensor is typically a piezoelectric transducer that converts mechanical energy into electrical signals. These collected signals are further amplified, filtered, and processed to identify defects within a system.

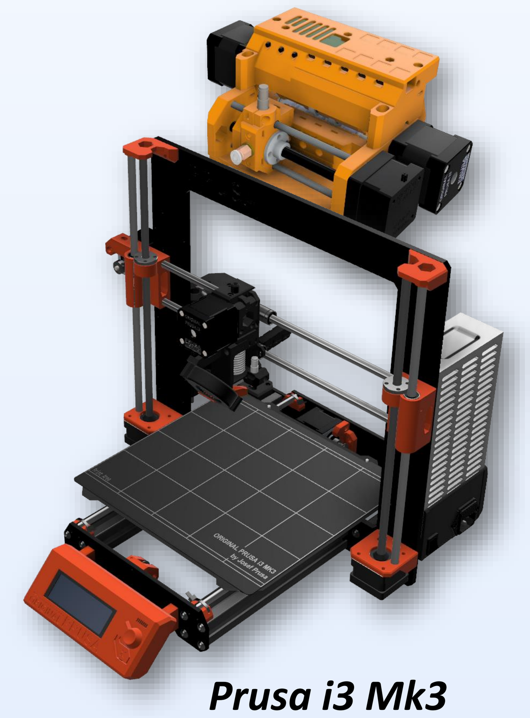


Project Goal

The goal is to address the inherent disadvantages of FDM printers using acoustic emission monitoring techniques. This involves developing a cost-effective and efficient **closed-loop system** that provides **sensory feedback** to monitor machine states. The system should increase reliability and repeatability via self-check protocols.

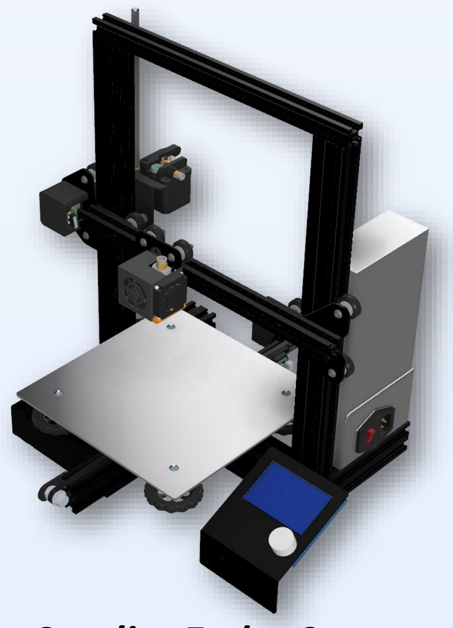
Technical Approach

FDM 3D Printers



Prusa i3 Mk3
Multi-Material Upgrade (MMU)

Lulzbot TAZ 6
Dual Extruder



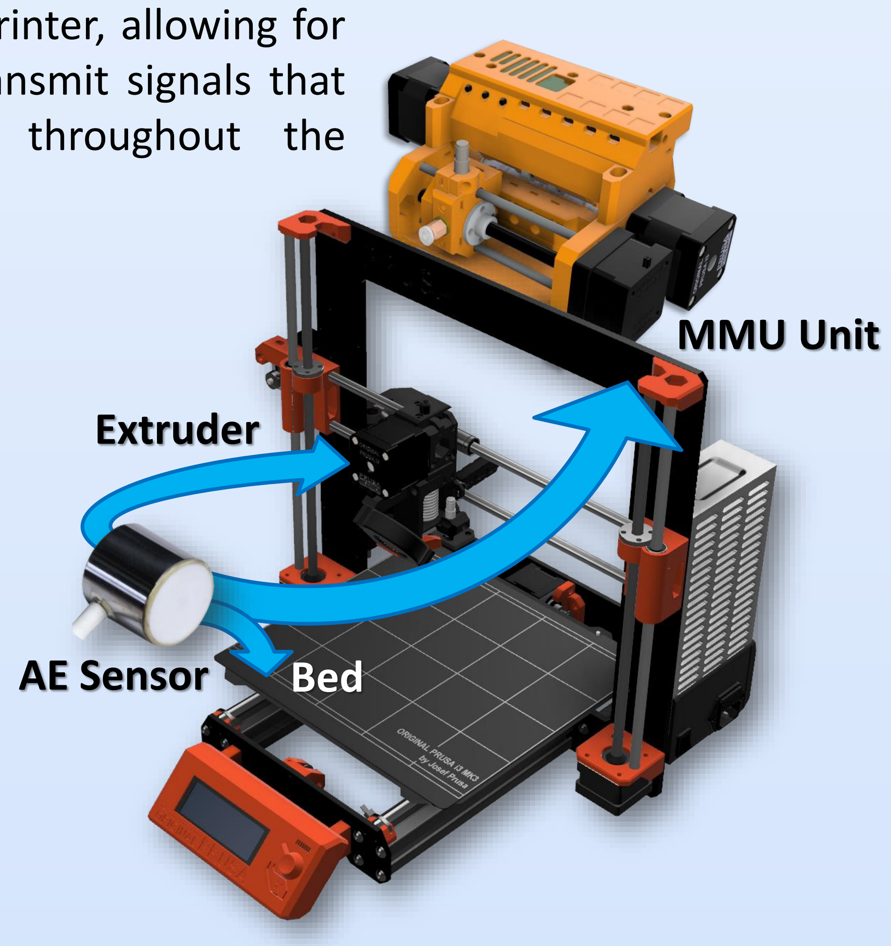
Creality Ender 3
Bowden Extruder

AE Sensor Instrumentation

Common errors are concentrated at specific sites on the printer, allowing for effective sensor instrumentation. The AE sensor would transmit signals that can be processed to identify the machine states throughout the manufacturing process.

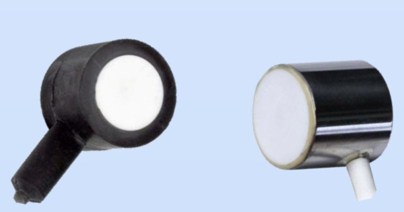
Machine States

Extruder	Bed	MMU Unit
▪ Filament jam ▪ Lack of material ▪ Filament grinding	▪ Part warping ▪ Stringing ▪ Part dislocation	▪ Feeder jams ▪ Filament grinding ▪ Filament not reaching extruder



The sensors transmit data to a DAQ unit that is capable of recognizing features within raw AE hits. The above conditions are intentionally created to acquire training data for a type of machine learning algorithm. This **support vector machine** (**SVM**) algorithm can associate new test data with the training data for real time classification.

AE + FDM Workflow



AE data from sensors

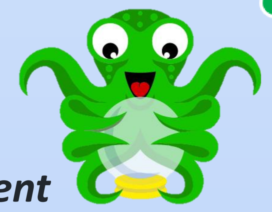
Windows Board

- NOESIS™ data processing
- Machine learning (SVM)
- Script to classify states
- Upload to cloud

Raspberry Pi 3

- Communication with OctoPrint
- Cloud-based printer control client

FDM Printer



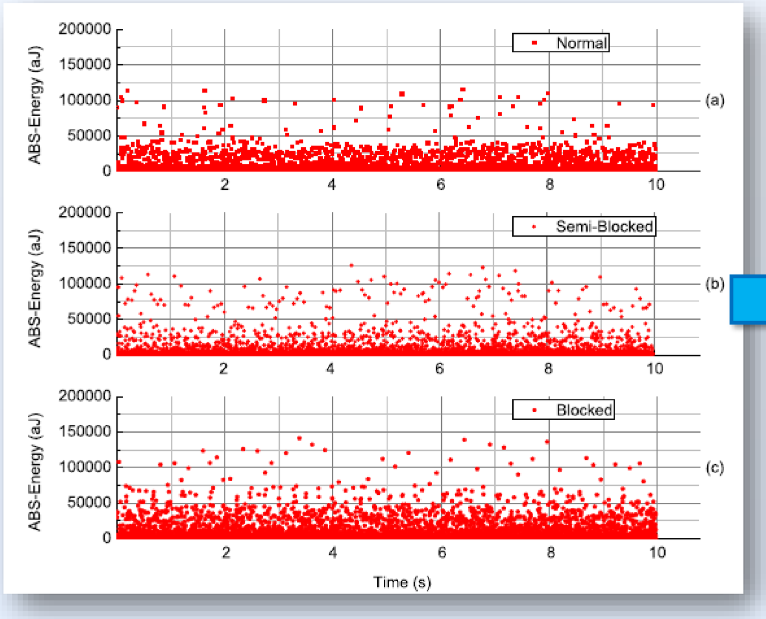
OctoPrint Client

The current setup allows for operational cloud control of the printer using the Raspberry Pi and OctoPrint configuration. Using the processed AE data from the SVM algorithm to identify defects, a respective solution can be implemented using a G-code input through OctoPrint.

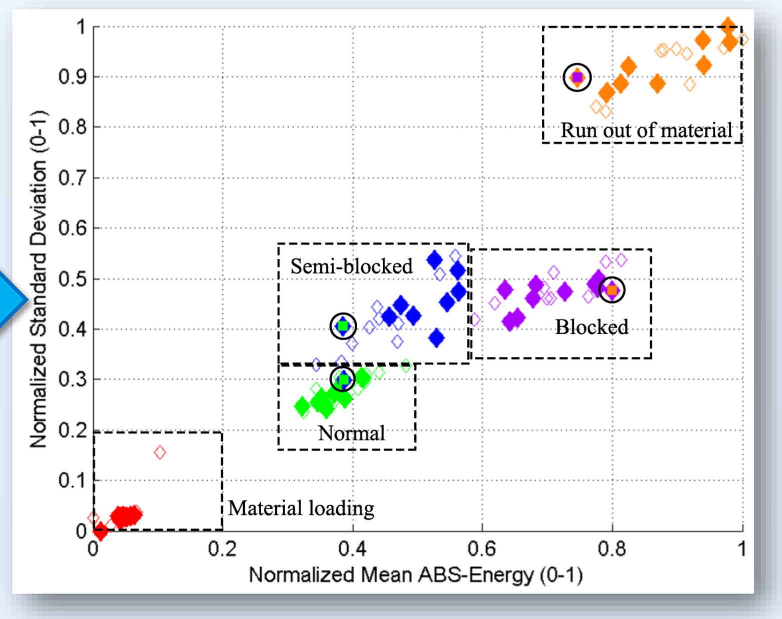
Results & Discussion

Based on the fundamental understanding from literature review, the instrumentation strategy detailed previously will be implemented to acquire data comparable to results shown below. This data represents state monitoring for extruder activity.

Raw AE Hits



Categorized State Data



Using NOESIS™, an AE data analysis software, training data can be processed to represent various machine states. Statistical pattern recognition formulas within the software can identify divisions between states using a form of machine learning. As seen in the graphs above, individual states are intentionally created to acquire training data for the SVM algorithm. This training data is categorized and cross-referenced with new testing data to ensure the AE sensor is correctly attributing hits with a predefined state.

This data for extruder state monitoring indicates that physical states of a system can be monitored via acoustic emission, thereby proving its viability for additional FDM component monitoring.

Future Work

With this preliminary understanding of the AE workflow in the context of FDM printers, a database can be created to represent the process critical machine states of a printer. The database can account for the printer's defects and will be later used to develop a closed-loop monitoring system.

This system would also incorporate a cloud-based printer control client can be used to identify the defects via acoustic emission, rewrite the G-code for the printer, and correct/eject the print in the next layer. The database would reflect potential rectifications for a given defect in the printing process, allowing for systematic correction to a process that is known to produce defective parts. This strategy will invite the possibility of automating a seemingly inconsistent and unreliable manufacturing process that produces usable parts.

References

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Acknowledgements

MISTRAS

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