

Background

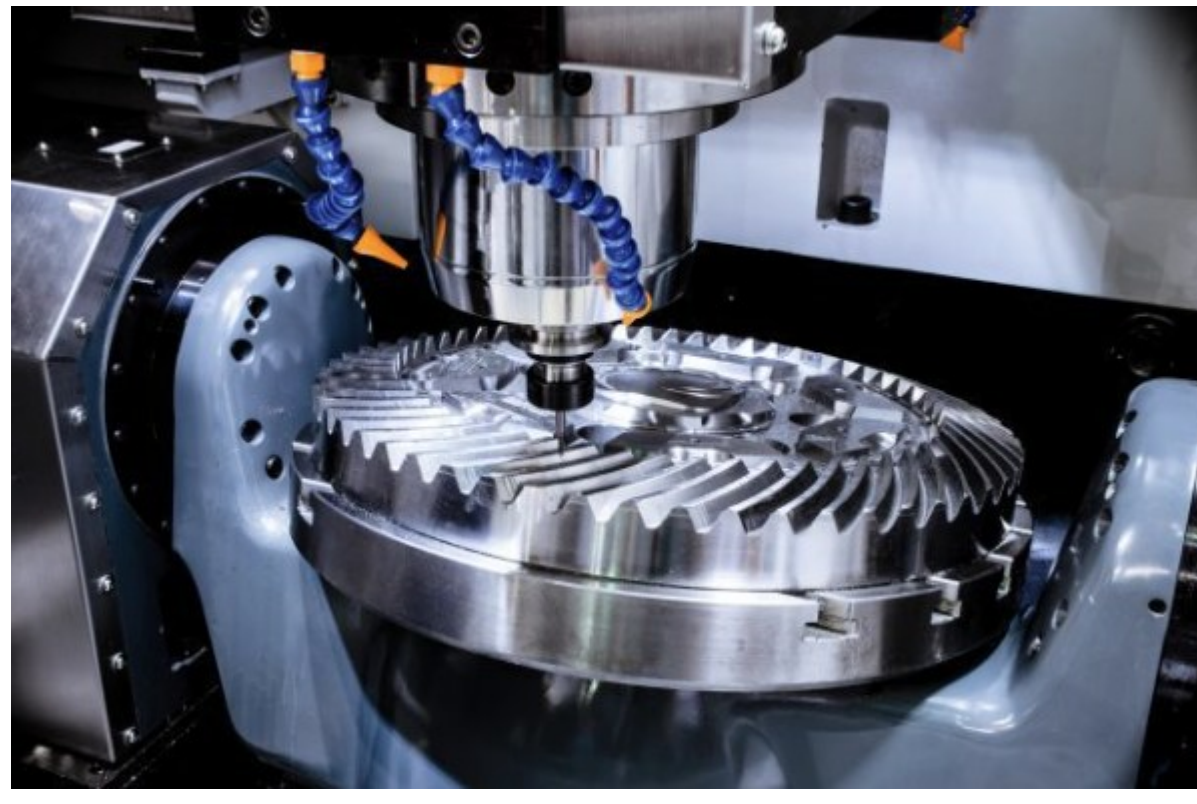


Fig. 1 5 axis Computer Numerical Control machine cutting cogwheel

- CNC machines are computer-controlled tools that cut and shape materials by moving a spindle and cutting tool precisely along programmed paths.
- Unexpected tool wear and breakage causes downtime, scrap and safety risks.
- Tool health monitoring systems use a variety of sensors to evaluate a cutting tools health.

- High-end tool health monitoring systems exist and work but are costly and disruptive to integrate for small- and medium-sized enterprises.
- A low cost Inertial Measurement Unit (IMU) paired with machine learning may offer a plug and play route to basic tool condition monitoring.

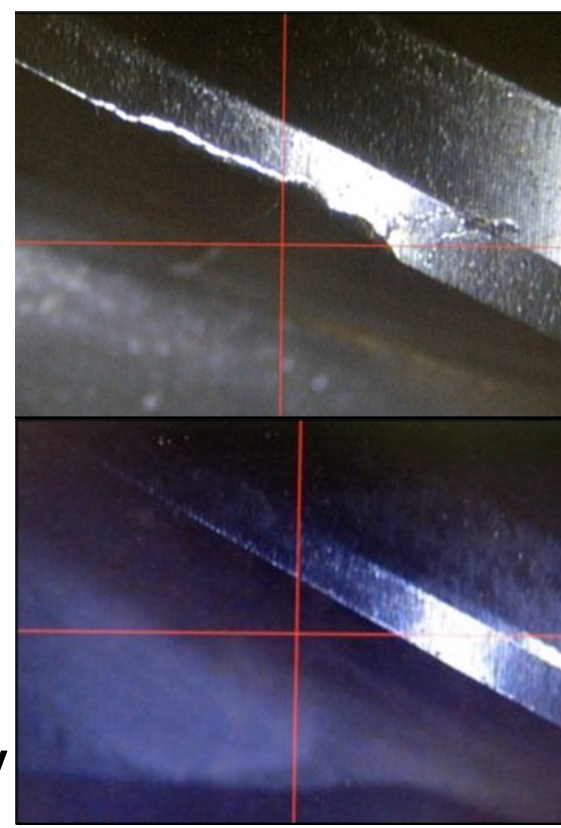


Fig. 2 No tool wear vs. excessive tool wear.

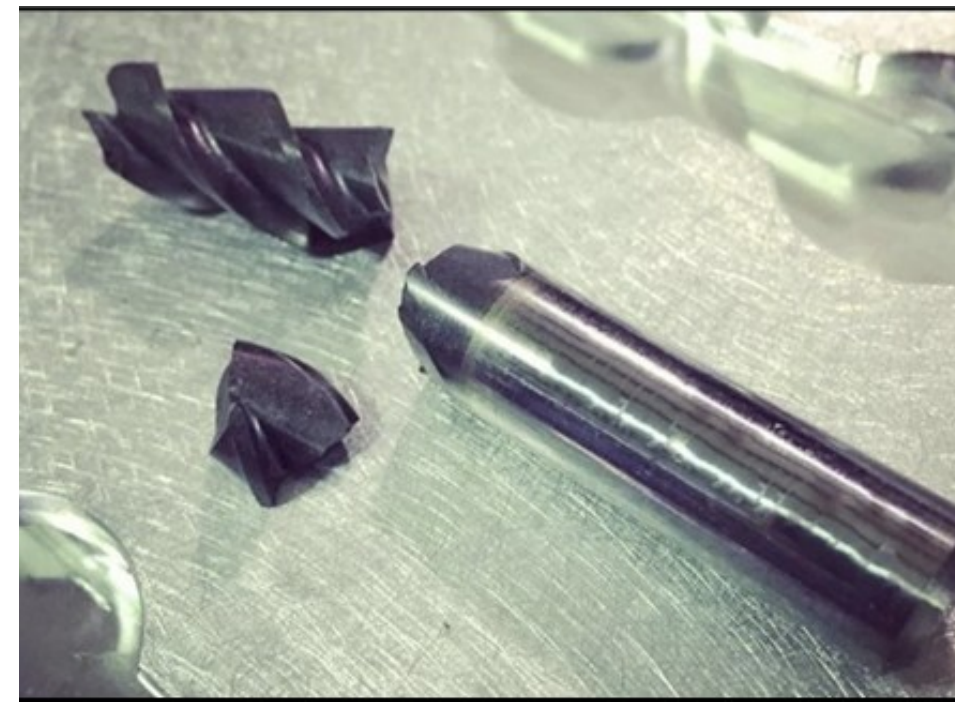


Fig. 3 Fractured end mill cutting tool.

Aims

- Test whether a single low-cost IMU is sufficient for reliable state classification.
- Separate core machine states: idle, spindle spinning, travelling, cutting.
- Build a full data acquisition and processing pipeline that produces clean, labelled windows suitable for future training of a machine learning model.



Fig. 4 Inertial Measurement Unit.

Achieving these aims will determine whether a low-cost IMU sensor is a viable method for tool condition monitoring. A pipeline will standardise data capture and preprocessing, apply consistent state labelling, and output reusable, ready-to-train datasets that support threshold-based monitoring now and straightforward model training later.

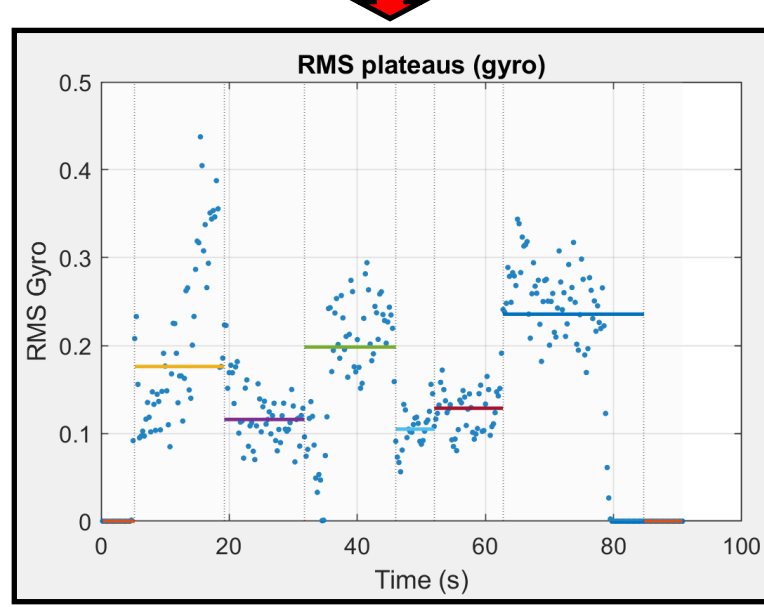
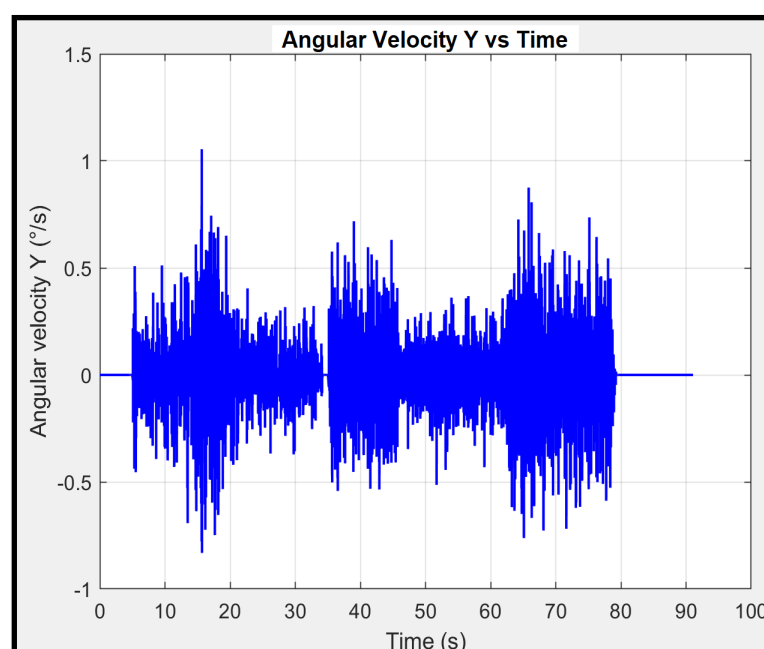


Fig. 5 Aim to signal process data.



Fig. 6 Hurco VM10 CNC machine used for testing.

Hardware Setup

Sensor: DFRobot serial 6-axis Inertial Movement Unit, ± 16 g and $\pm 2000^\circ/s$, 0.1 to 200 Hz.

Mount: 3D-printed with magnets, attached to Hurco VM10 3 axis CNC machine.

Cutting Tool: 12mm Aluminium Carbide End Mill. 3 flutes.

Logger: Arduino Uno R3 with Python capture, Excel and MATLAB for analysis.



Fig. 7 Position of IMU on spindle

The IMU collects measurements at 200 samples per second and sends them to the Arduino, which transmits the data to a computer. Python formats the incoming data into an Excel file, and MATLAB is then used for signal processing and analysis.

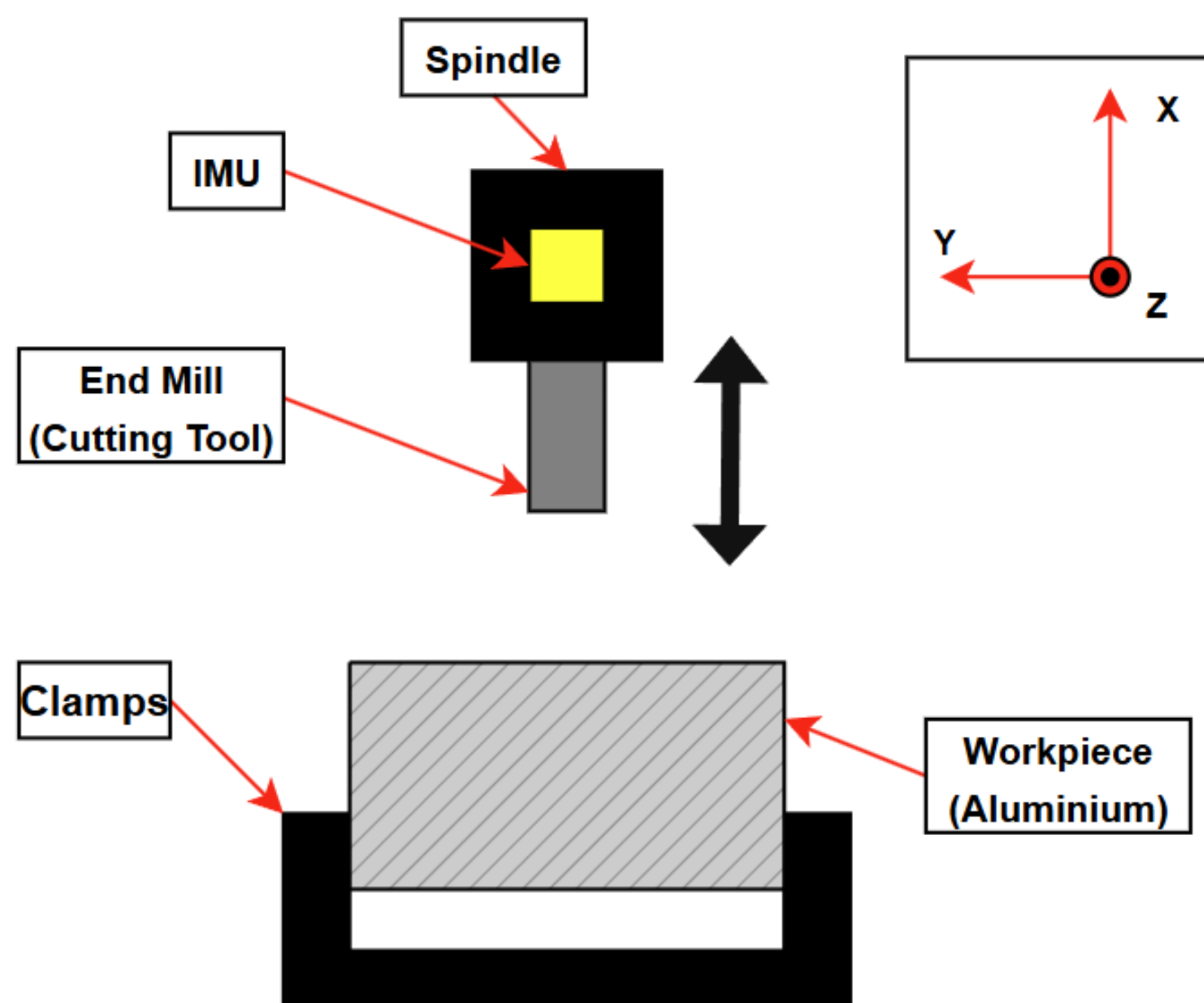


Fig. 8 Diagram of testing setup

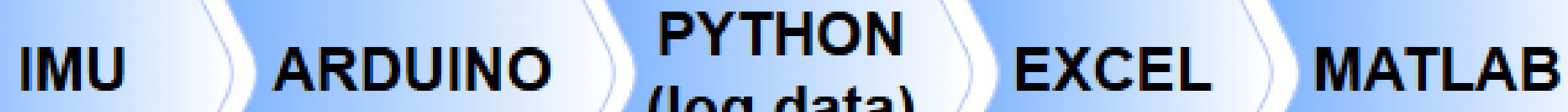


Fig. 9 Data acquisition pipeline

Data Acquisition

- Baseline:** Machine powered down, no motion, single run.
- Linear workpiece motion:** Workpiece moves 100 mm on y-axis, 3 runs.
- Fast vertical travel:** Home \rightarrow P1 \rightarrow P2 \rightarrow P1 \rightarrow Home, feeds 1500 and 3000 mm/min, 3 + 3 runs.
- Spindle speed holds:** 0 \rightarrow 10000 \rightarrow 8500 \rightarrow 6000 \rightarrow 5000 \rightarrow 2500 \rightarrow 0 rpm, 3 runs. No movement.
- Cutting passes:** Straight cuts at 1, 2 and 3 mm depth. 1 run per depth.

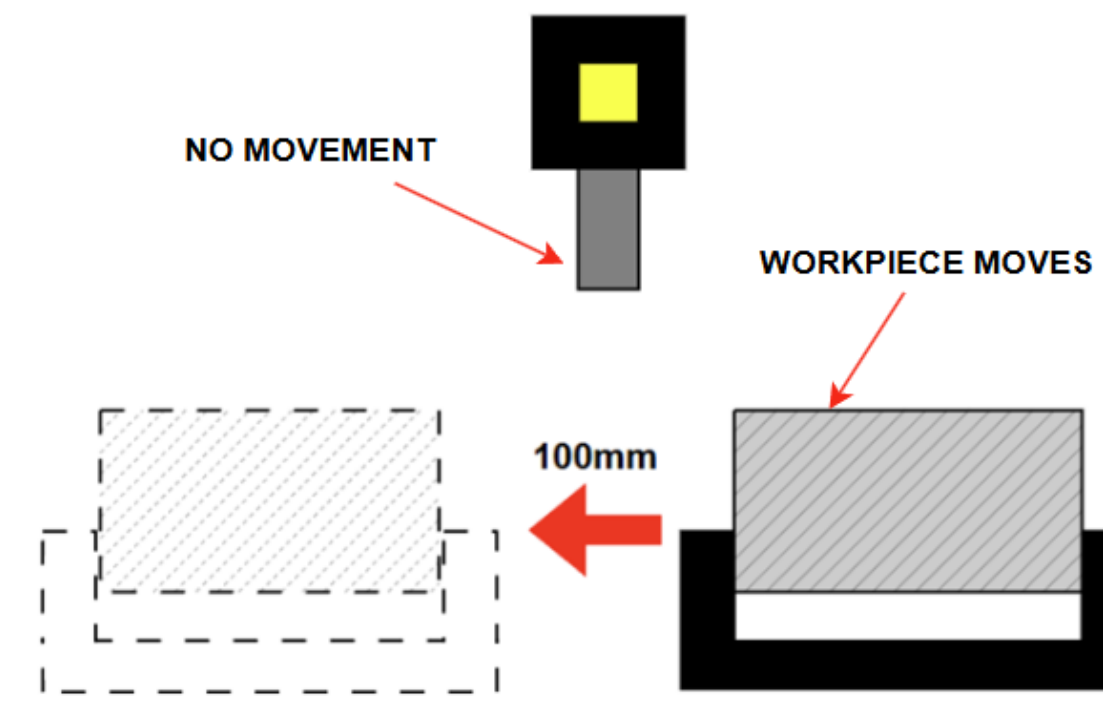


Fig. 10 Workpiece movement test.

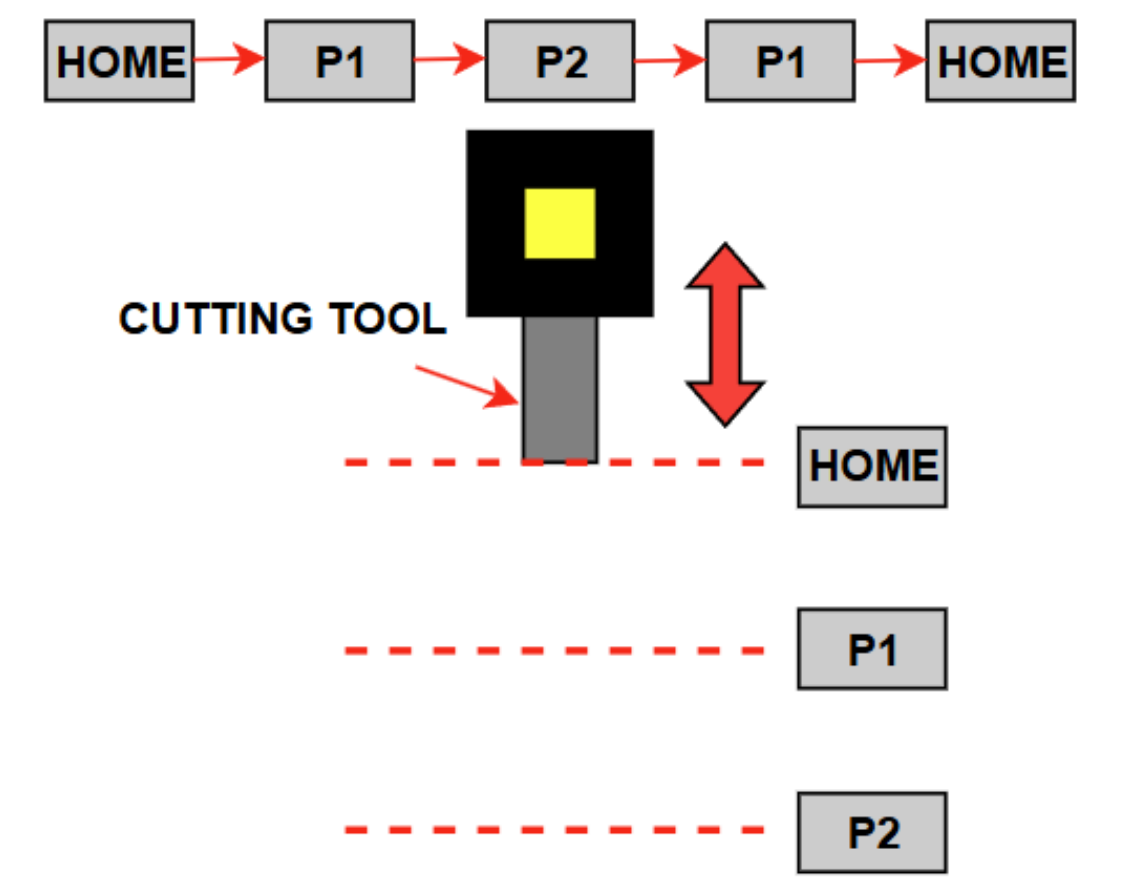


Fig. 11 Vertical travel of the spindle test.

- Spindle speed holds:** 0 \rightarrow 10000 \rightarrow 8500 \rightarrow 6000 \rightarrow 5000 \rightarrow 2500 \rightarrow 0 rpm, 3 runs. No movement.
- Cutting passes:** Straight cuts at 1, 2 and 3 mm depth. 1 run per depth.



Fig. 12 Aluminium workpiece after 3mm depth cut.

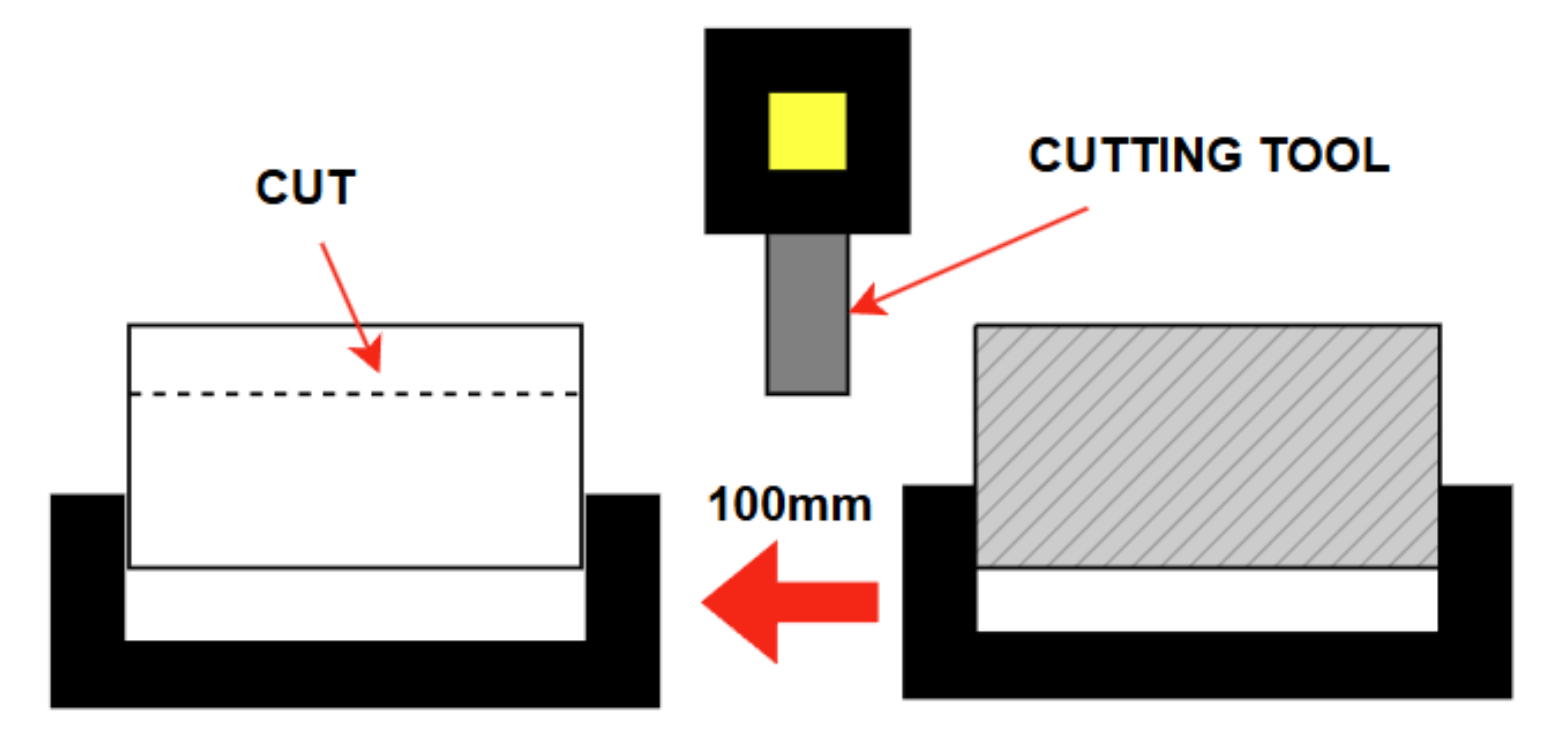


Fig. 13 Cutting the workpiece test.

Results

1. Baseline and preprocessing

Electric noise produces jitter, this steady bias causes integration drift. Bias removal stabilised the signal.

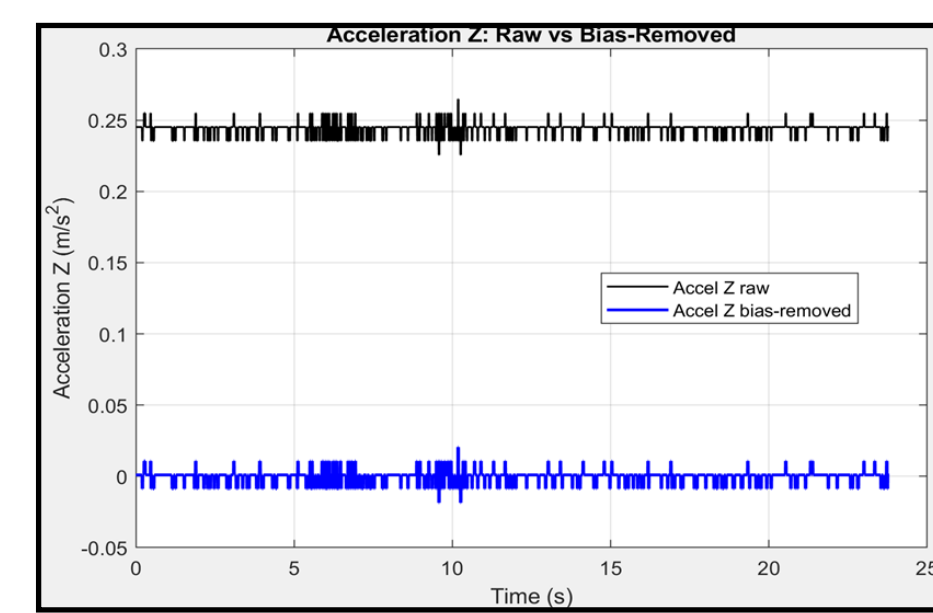


Fig. 14 Signal with and without bias removal.

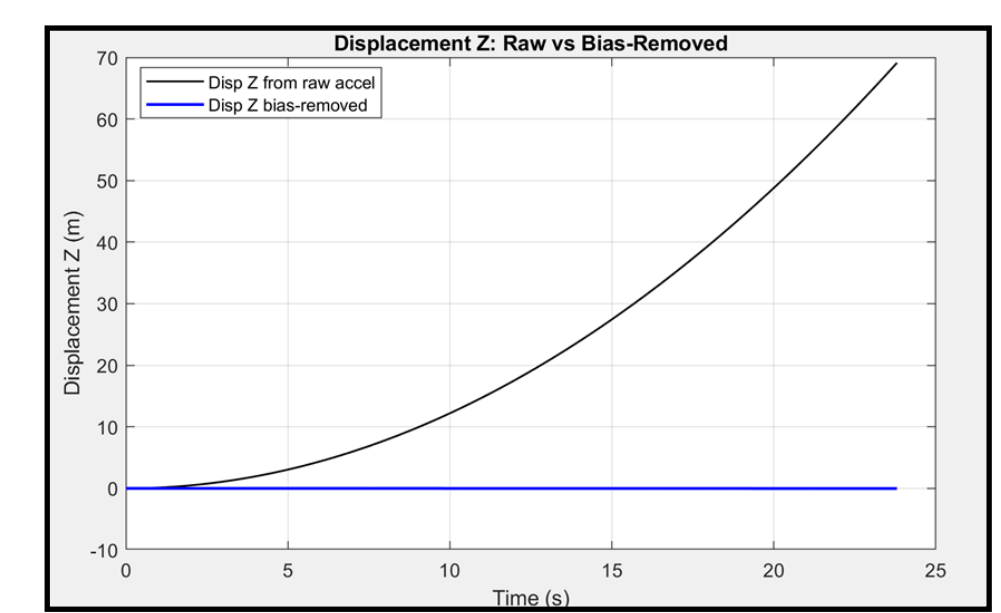


Fig. 15 Integration drift with and without bias removal.

2. Linear Workpiece motion

Linear table movement was not detectable with this signal and mount position.

3. Fast vertical travel

Clear acceleration, deceleration and jerk peaks. Feed 3000 showed higher peaks and approximately half the segment time compared with 1500. Cross-axis leakage confirms the IMU axes were not aligned exactly to machine axes.

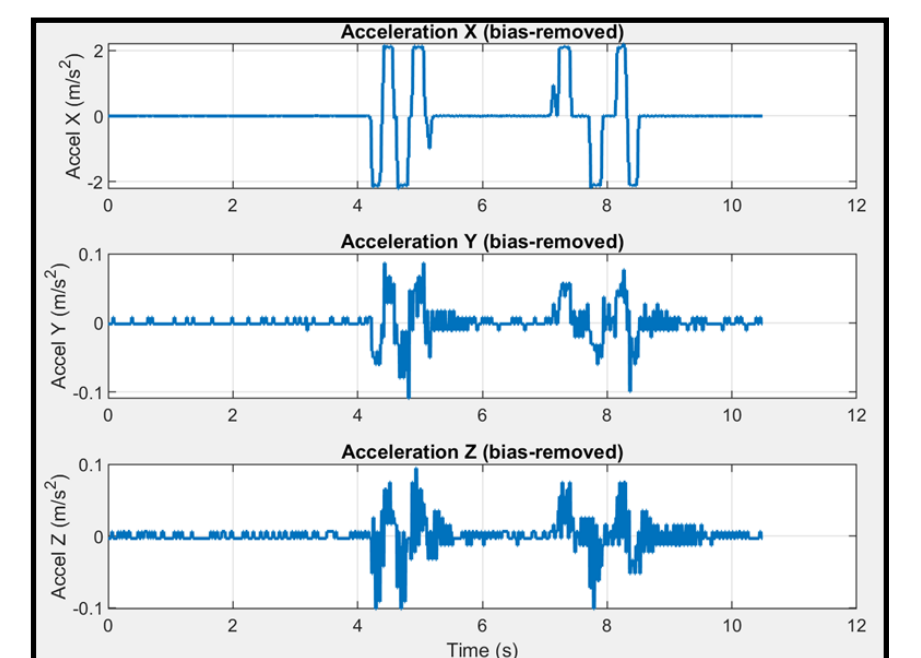


Fig. 16 Acceleration cross-axis leakage.

4. Spindle speed holds

After filtering (3Hz High Pass IIR) and windowing, plateau detection grouped steady rpm segments.

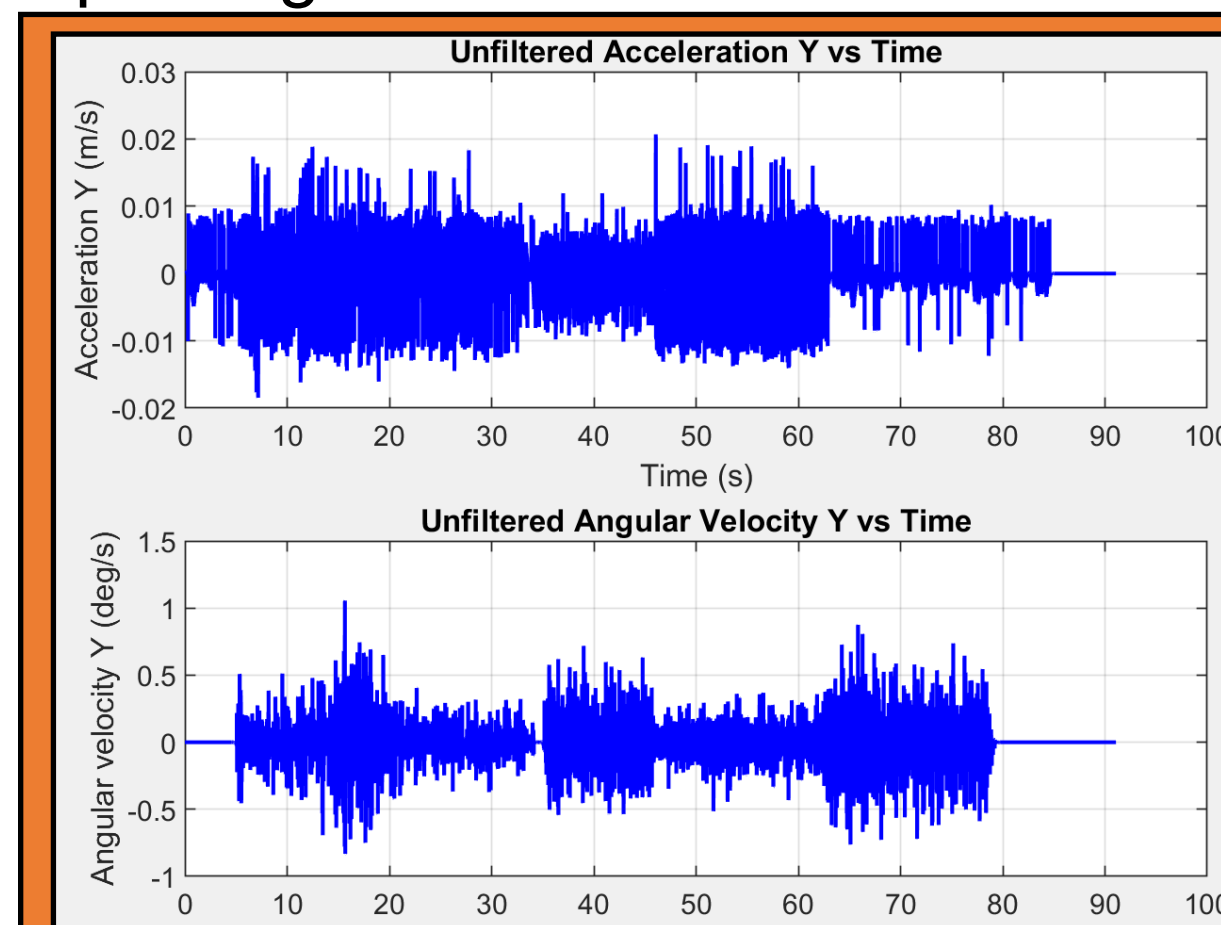


Fig. 17 Unfiltered acceleration and gyro (angular velocity) signal.

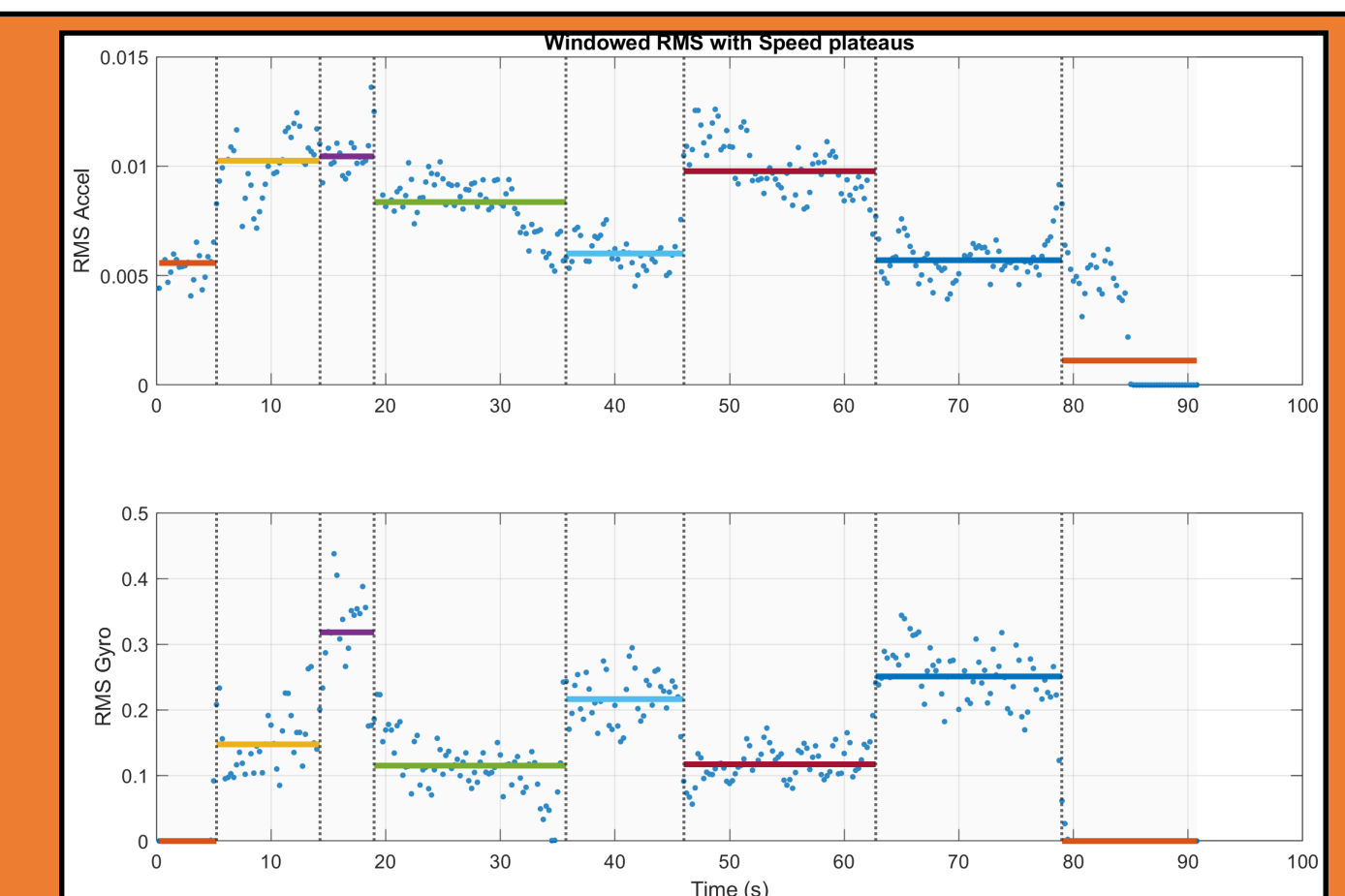
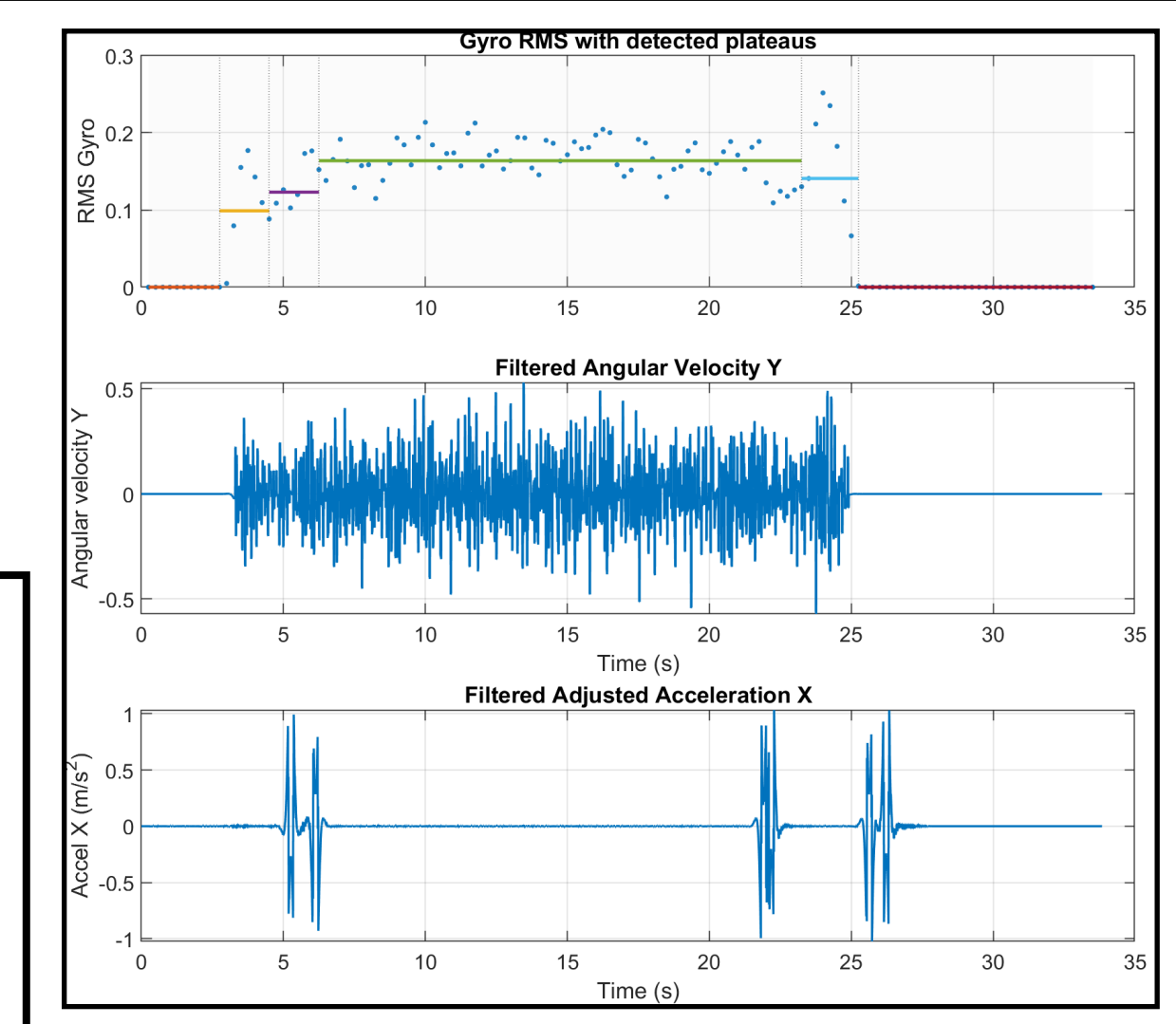


Fig. 18 Filtered acceleration and gyro with plateaus for areas of steady RPM.

5. Cutting passes

Angular velocity RMS content approximately separated initial spin up, air cut and metal cut but struggled with further separation.



Conclusion

- A single low cost IMU gave clear signals for simple movement and steady spindle.
- Air cut vs metal cut separation was not reliable; adding a second sensor on the table may improve separation. This would also improve table motion signal.
- Pipeline can be used to create a labelled dataset ready for training.

Fig. 1 fastems.com/cnc-machining/

Fig. 2 harveperformance.com/in-the-loope/avoiding-tool-wear/

Fig. 3 tormach.com/articles/how-to-avoid-4-major-types-of-tool-wear

Acknowledgements

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