AIRFRAME HEALTH MONITORING SYSTEM

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Introduction

Problem statement: Design an Unmanned Aerial Vehicle (UAV) health monitoring system that autonomously alerts ground operators of failure predictions to the UAV based on continuous measurements.

Motivation: UAVs operating functionally in our airspaces present minimal threat, but a UAV subject to failure (a crash) presents significant safety, cost, and operational risk.

Success Criteria

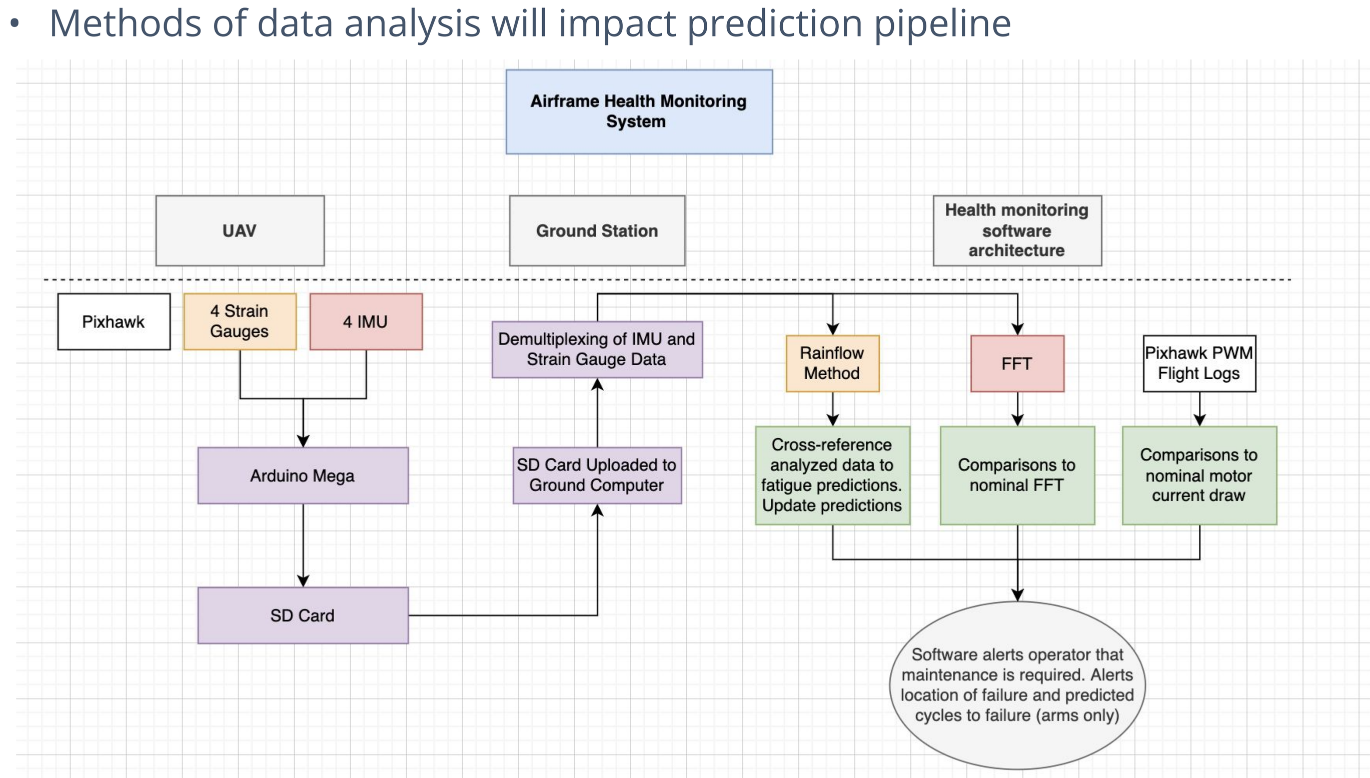
- Integrated an autonomous Health Monitoring System on an off the shelf drone that successfully predicts failures based on 2 or more failure modes to a ground station
- Predicted failures are identified to a high level of accuracy shown through rigorous testing
- Identified and pinpointed two or more specific components that are at risk of failure as shown through continuous test data

Integration and Interfaces of Subsystems

Structures & Avionics
- Sensors mounted on each arm of drone (3D printed mounts)
  - Strain Gauge and Accelerometer
- Inducing failure modes mechanically leads to off-nominal sensor readings

Avionics & Software
- Microcontroller programmed to read sensors and log data to SD card
- Sampling rate will impact results in data analysis

Software & Data Analysis
- Data logged in a file on the SD card is accessed in a Python script
- Methods of data analysis will impact prediction pipeline

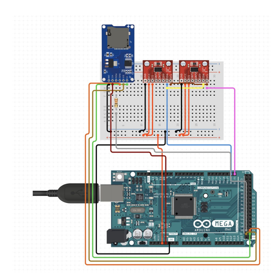


Off-Nominal Motor Failure

Methodology
- Vibration data is collected from sensors placed beneath each motor
- Nominal vibration data is collected to be used as a baseline
- Ground tests using broken props provide off-nominal data
- Varying damage is induced to distinguish severity of failure in prediction pipeline

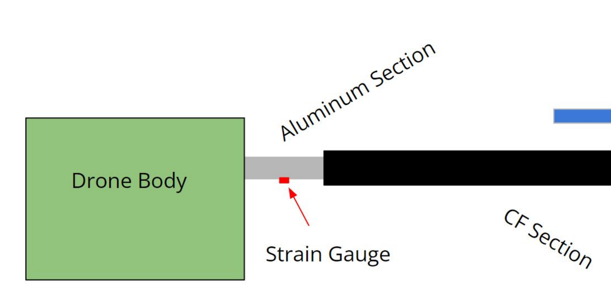
Data Collection
- ADXL345 digital accelerometers are mounted beneath the motor
- Communication between microcontroller and accelerometers is via I2C protocol
- Accelerometer x, y, and z axial readings are sampled at 100 Hz

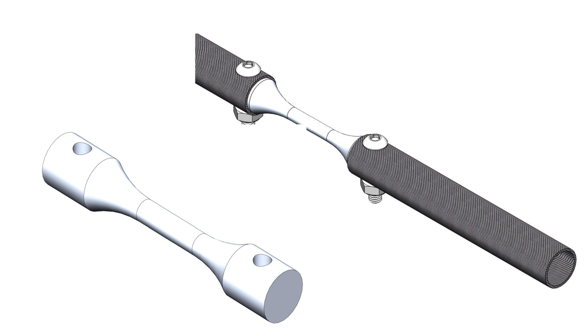
Prediction
- Data is filtered through Butterworth filter to reduce noise
- A power spectral density analysis is performed on the data
- A comparison is made between the nominal data and the to-be-categorized data
  - comparison between the top 10 highest PSD magnitudes
  - comparison between the top 10 highest PSD frequencies



Arm Structural Failure

Methodology
- Create aluminum 6061-T6 arm inserts to eliminate anisotropic properties of carbon fiber arms and more easily induce failure
- Strain gauges attached to the aluminum segment on each arm monitor bending strain
- Python script uses the strain data to make fatigue life and yield predictions





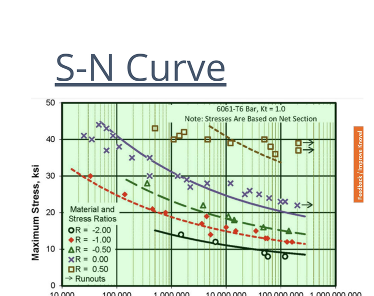
Data Collection
1. Strain gauge as variable resistor in Wheatstone Bridge
2. Wheatstone Amplifier Shield powers and amplifies voltage measurements
3. Microcontroller processes data via ADC

Prediction
- Categorize flight types with known damage accumulation, backcalculate flights possible

Hooke's Law ➡ Rainflow Method ➡ S-N Curve ➡ Miner's Rule

$\sigma = E\varepsilon$

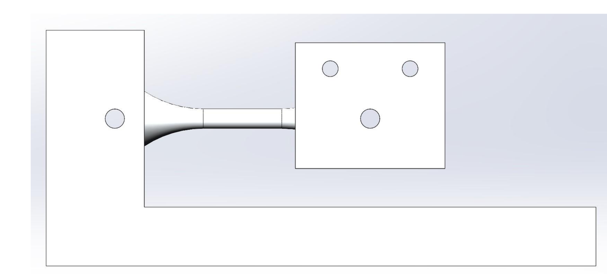
List([stress range, # of cycles],...)



$$damage = \sum_{m=1}^{k} \frac{n_m}{N_m}$$

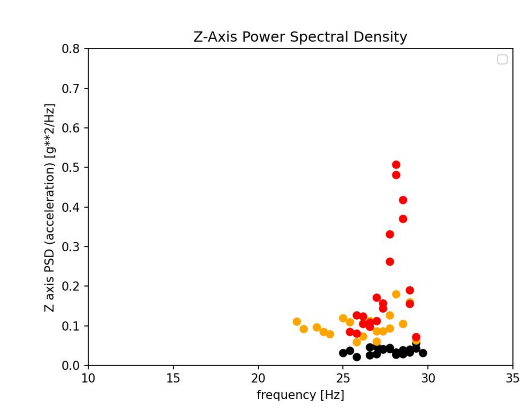
Testing and Results

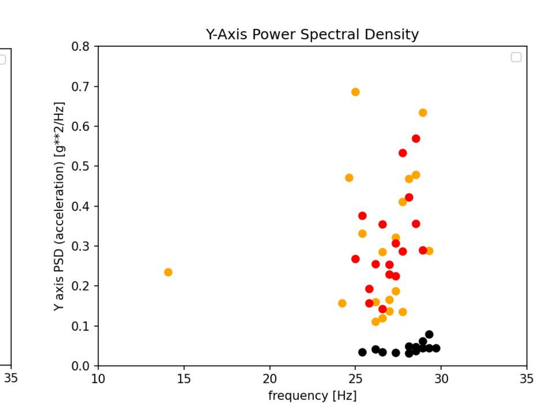
Ground Testing
- Drone bolted to ground and enclosed in a test box
  - Drone was held at ~75% thrust in nominal conditions for nominal data
  - Drone was held at ~75% thrust with 2 mm cut on one propellor
  - Drone was held at 75% thrust with 4 mm cut on one propellor
- Instron hydraulic load frame used to validate arm insert fatigue predictions

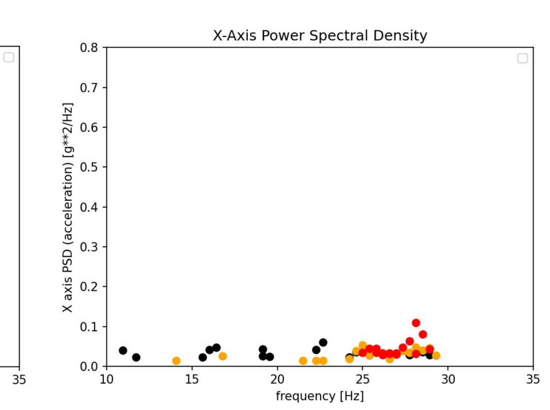


Flight Testing
- Fight worthiness - capability of flight and responding to autopilot mission plans
- Validation - capability of logging accelerometer data at 100 Hz and strain gauge data at 10 Hz

Results







- Note: X-axis ~ roll, Y-axis ~ pitch, Z-axis ~ yaw
- In-flight accelerometer data was also captured and reflected same PSD magnitude as ground testing nominal data
- Software capable of distinguishing between nominal and off nominal data

Conclusion and Future Work

This project has proven that airframe health can be detected and monitored via a backpack system. Our health monitoring system presents a first step risk mitigation solution for the future of drone operations in our airspaces. The future of this project can explore other failure modes such as fatigue in other materials and other parts of the airframe or add granularity to failure detection. We hope to see the groundwork laid out by our system help improve the safety of drone operations and aid drone pilots in their flights.

Acknowledgements

Thank you to our mentors for all their positive support and advice:
Faculty mentor: Dr. JK Yang
PhD student: James O'Neil
Industry mentor: Jon Braam, Rick Miller, Jonny Flowers

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