Post-Flight Anomaly Detection in Simulated Rocket Sensor Data

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1 Abstract

This project implements a post-flight anomaly detection system for a two-stage rocket using simulated sensor data. We use a Kalman Filter to estimate altitude and detect anomalies by analyzing the residuals between estimated and measured values.

2 Introduction

Modern rockets rely on sensor fusion and anomaly detection systems to ensure mission success and post-flight diagnostics. This project simulates a rocket flight, generates synthetic sensor data, applies a Kalman Filter for state estimation, and detects anomalies using statistical residual analysis.

3 System Overview

The system is implemented in Python and consists of the following components:

- Rocket flight simulator
- Sensor data simulator (barometer, accelerometer)
- Kalman filter with residual computation
- Anomaly detection via residual thresholding
- Data logging and visualization

4 Rocket and Sensor Simulation

A custom flight profile models the two-stage ascent and descent. Sensor data is generated with Gaussian noise.

4.1 Rocket Model

The rocket follows a staged acceleration pattern. Key equations for velocity and altitude use numerical integration of acceleration:

$$v(t) = \sum a(t) \cdot \Delta t$$
$$h(t) = \sum v(t) \cdot \Delta t$$

4.2 Sensors

Barometric pressure is converted to altitude using:

$$h = 44330 \cdot \left(1 - \left(\frac{P}{P_0}\right)^{\frac{1}{5.255}}\right)$$

Accelerometers are simulated with additive Gaussian noise.

5 Kalman Filter

We apply a discrete-time Kalman filter to estimate altitude from accelerometer data and barometric readings. State vector:

$$x = \begin{bmatrix} \text{altitude} \\ \text{velocity} \end{bmatrix}$$

System and measurement models:

$$A = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix}, \qquad B = \begin{bmatrix} 0.5\Delta t^2 \\ \Delta t \end{bmatrix}, \qquad H = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

6 Anomaly Detection

Residuals are computed as:

$$y_k = z_k - Hx_k$$

Anomalies are highlighted if:

$$|y_k - \mu| > 3\sigma$$

7 Results

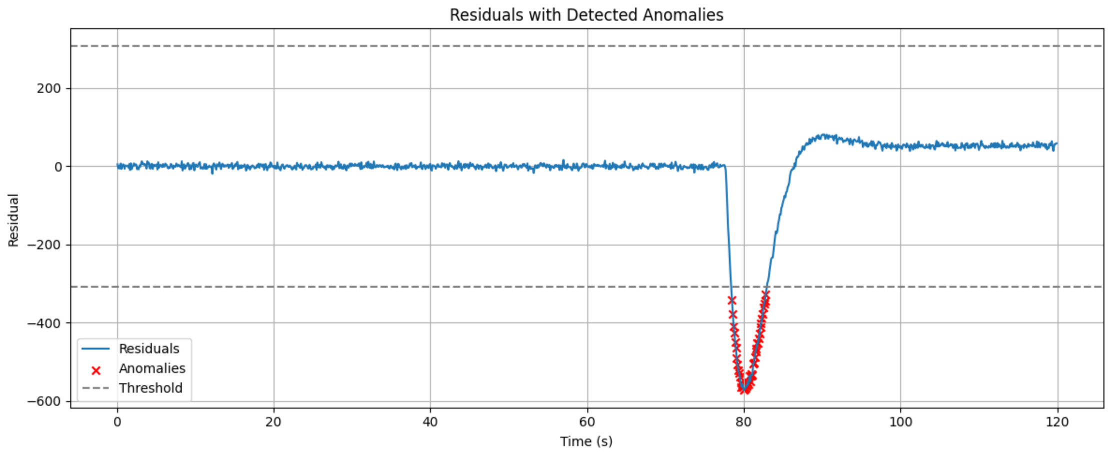

Figure 1: Residuals and detected anomalies

Table 1: Sample Anomaly Log

Time (s)	Barometer Altitude (m)	Residual
28.1	1345.3	78.5
55.2	1845.6	-82.1
...	...	...

8 Files Submitted

- `Anomaly_detection.py`, `phase4_anomaly.py`: Source code
- `sensor_data.csv`: Full flight and sensor data
- `anomaly_report.csv`: Anomaly log
- `altitude_estimation.png`, `residual.png`: Plot image
- Report PDF (this document)

9 Conclusion

The project demonstrates how sensor fusion and statistical residuals can detect anomalies in a simulated rocket flight. The use of a Kalman filter enables robust state estimation even with noisy sensor data.