University of Stuttgart
Insititute of Navigation

GEOENGINE

Master Thesis

Temperature Dependency of a Low-cost IMU

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Table of Contents

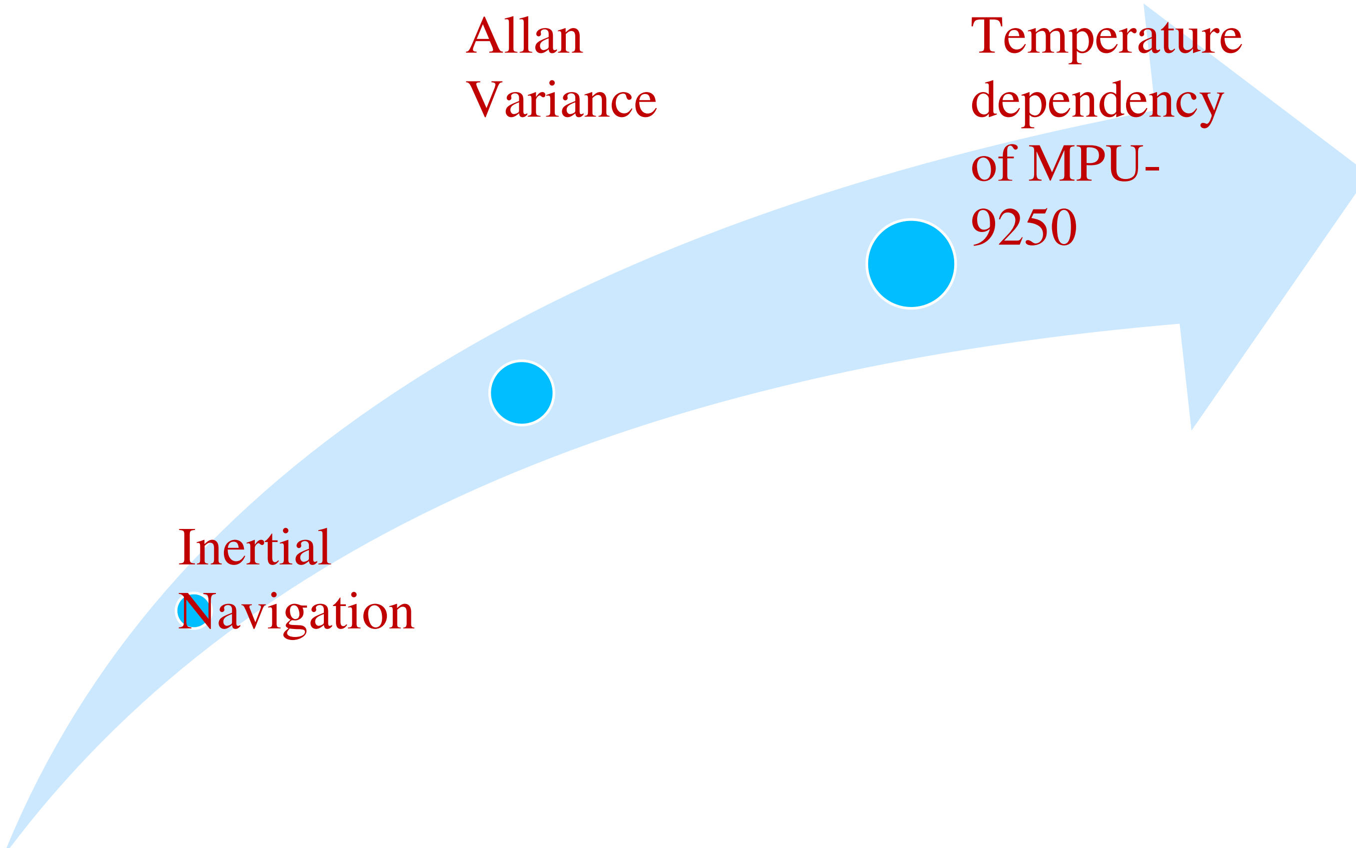
Table of Contents

p **Introduction**

Background

- Navigation plays very important role from past to now on for people.
- Inertial Navigation System is an important modern navigation method.
- MEMS (Micro-Electro-Mechanical-Systems) technology enables IMUs to be manufactured smaller, lighter and cheaper.
- MEMS IMUs have become very widely used.
- MEMS IMUs are still far less accurate than some traditional high accuracy IMUs at present.
- Temperature influences the performance of MEMS IMUs differently from device to device.

Objectives


Allan Variance
Temperature dependency of MPU-9250
Inertial Navigation

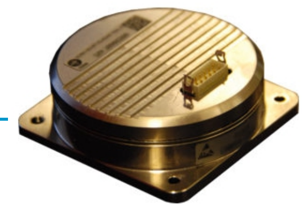
p **Inertial Navigation**

Types of Gyroscope

Gyroscope

Mechanical

Source:[1]



Optical

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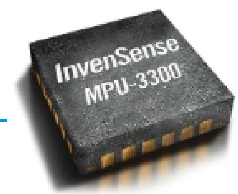


MEMS

Source:[3]

Types of Accelerometer

Accelerometer


Source:[4]

Mechanical


Source:[5]

Optical

Source:[3]

MEMS

MEMS Inertial Sensor

- **Advantages**
  - Small size
  - Low weight
  - Rugged construction
  - Low power consumption
  - Short start-up time
  - Inexpensive to produce
  - High reliability
  - Low maintenance
- **Disadvantage**
  - Less accurate than some conventional high accuracy IMUs at present.

Growing Market for MEMS Inertial Sensor

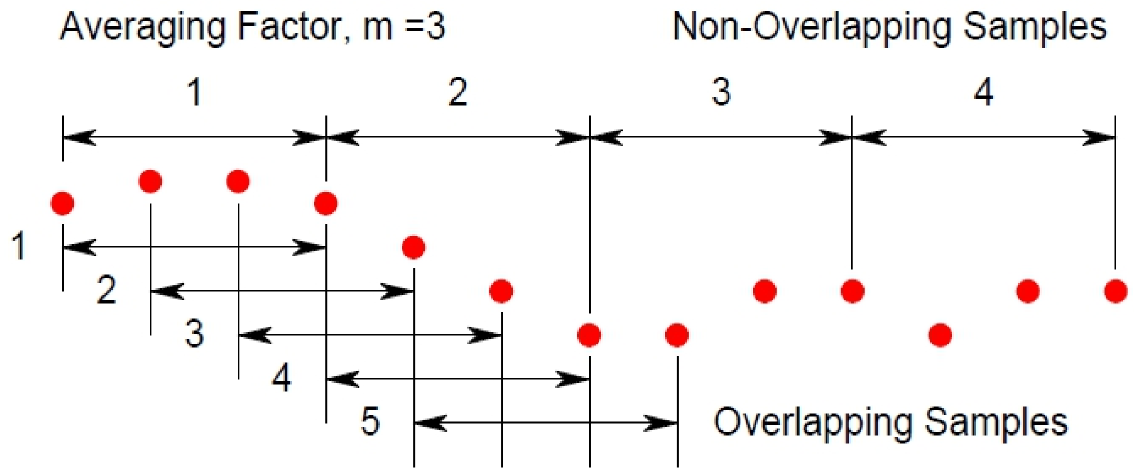
Source:[6]

p **Allan Variance**

Allan Variance

- Allan Variance was proposed by David W. Allan in 1996.
- An important method of analyzing a sequence of data in the time domain.
- One of the most popular methods for identifying and quantifying the different noise terms that exist in inertial sensor data.
- The Allan Variance analysis consists of computing its Allan Deviation and then analyzing the characteristic regions and log-log scale slopes of Allan Deviation curves to identify the different noise terms.

Allan Variance



Source:[7]

Non-Overlapped Allan Variance: Stride = τ = averaging period = $m \cdot \tau_0$

$$\sigma_y^2(\tau) = \frac{1}{2(M-1)} \sum_{i=1}^{M-1} \left(y_{i+1} - y_i\right)^2$$

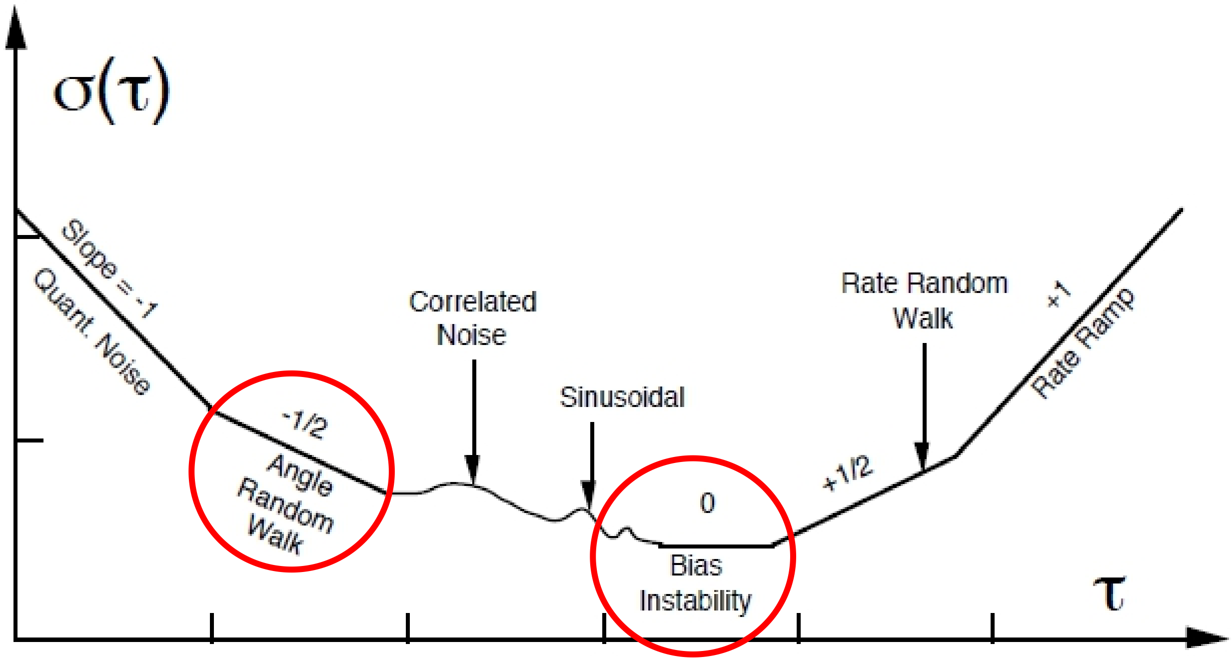
ith of M fractional frequency values averaged over τ

Overlapped Allan Variance: Stride = τ_0 = sample period

$$\sigma_y^2(\tau) = \frac{1}{2m^2(M-2m+1)} \sum_{j=1}^{M-2m+1} \sum_{i=j}^{j+m-1} \left(y_{i+m} - y_i\right)^2$$

Number of samples

Noise Characterization

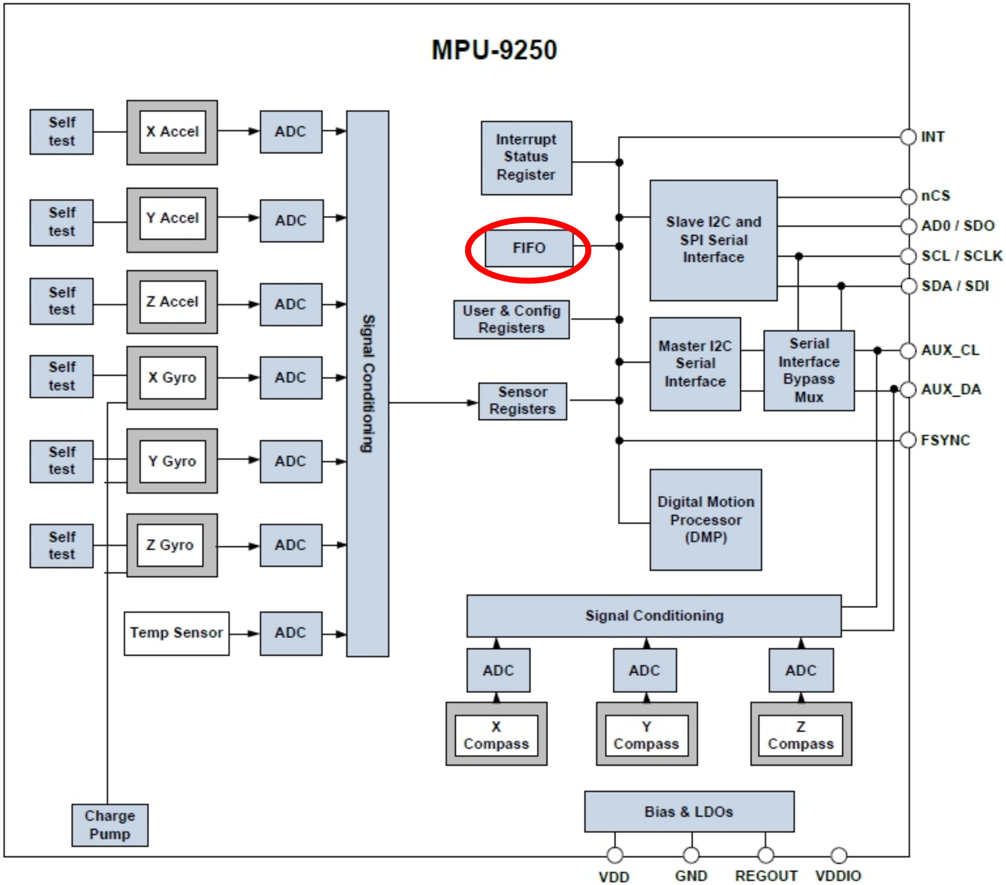


Source: [8]

- **ARW/VRW** (Angle/Velocity Random Walk) describes the average deviation or error that will occur when integrating the signal.
- **BI** (Bias Instability) can be defined as how much deviation or drift the sensor has from its mean value of the output rate.

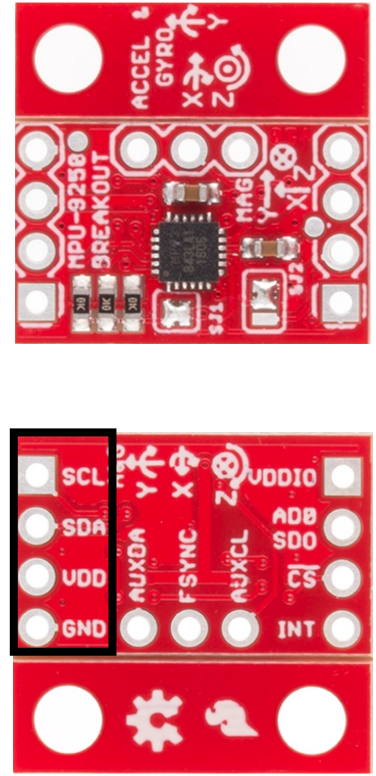
- **Hardware Implementation**

MEMS IMU



Block Diagram

Source: [10]



Source: [9]

Single Board Computer

p Raspberry Pi 3 Model B+

ü Broadcom BCM2837B0, Cortex-A53 (ARMv8) 64-bit SoC @ 1.4GHz

ü 5V/2.5A DC power input

ü 1GB LPDDR2 SDRAM

ü Raspbian OS (Linux core)

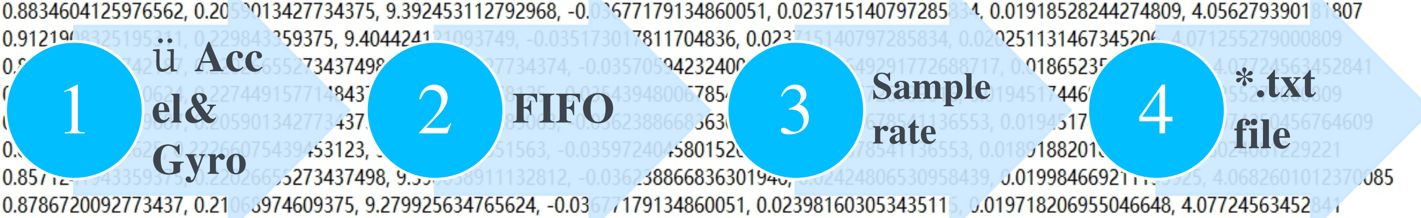
ü Extended 40-pin GPIO header

ü Support I²C and SPI communication

ü Cost: ≤40€

Source: [11]

Software Design



mpu_accel_1[m/^2], mpu_accel_2[m/^2], mpu_accel_3[m/^2], mpu_gyro_1[rad/s], mpu_gyro_2[rad/s], mpu_gyro_3[rad/s], temp[degC]
0.8786720092773437, 0.19632453613281248, 9.344569079589844, -0.03677179134860051, 0.022649291772688717, 0.01891882018659881, 4.062269745709408
0.8810662109374999, 0.22026655273437498, 9.363722692871093, -0.036238866836301946, 0.023182216284987275, 0.01945174469889737, 4.074250456764609
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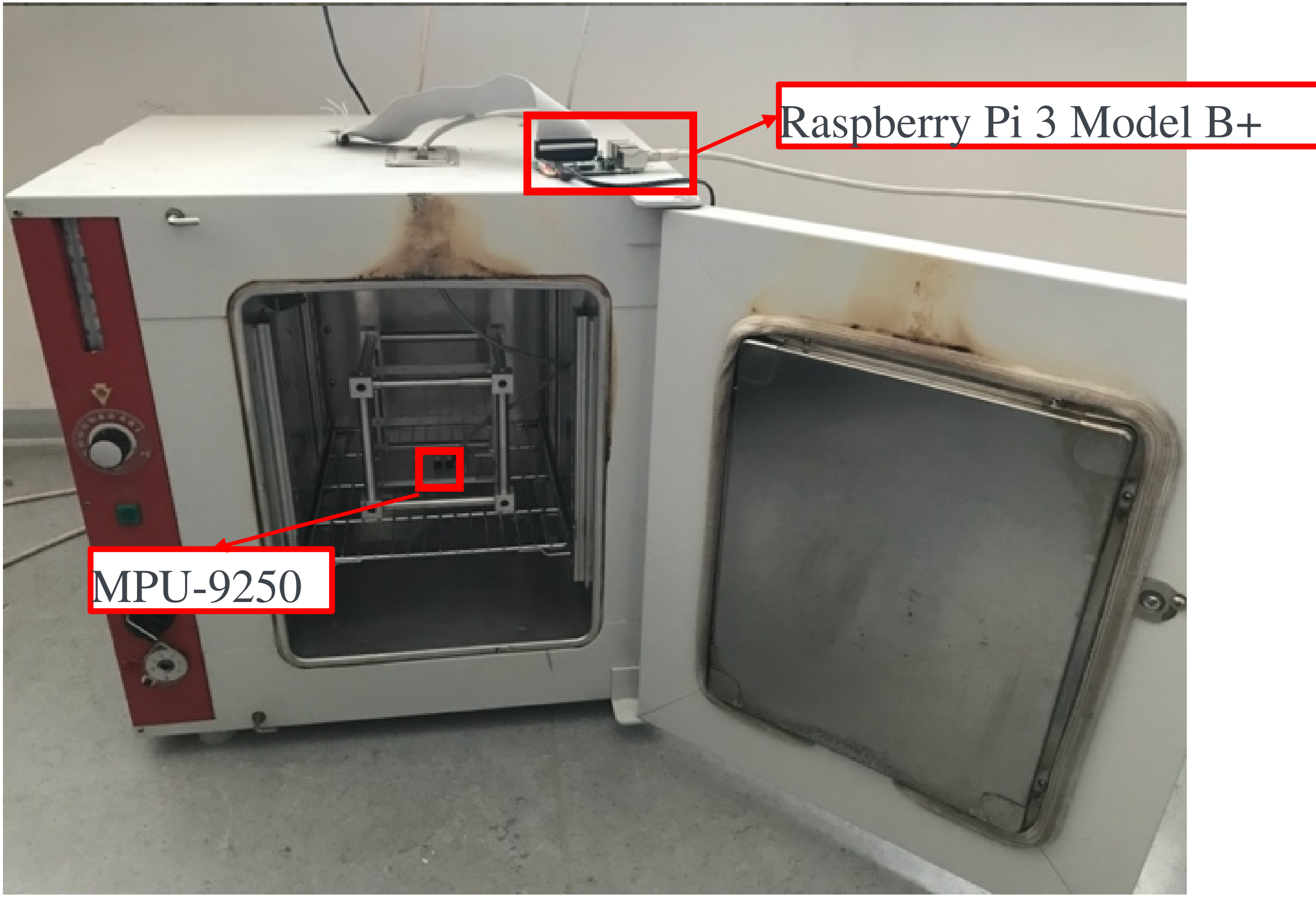
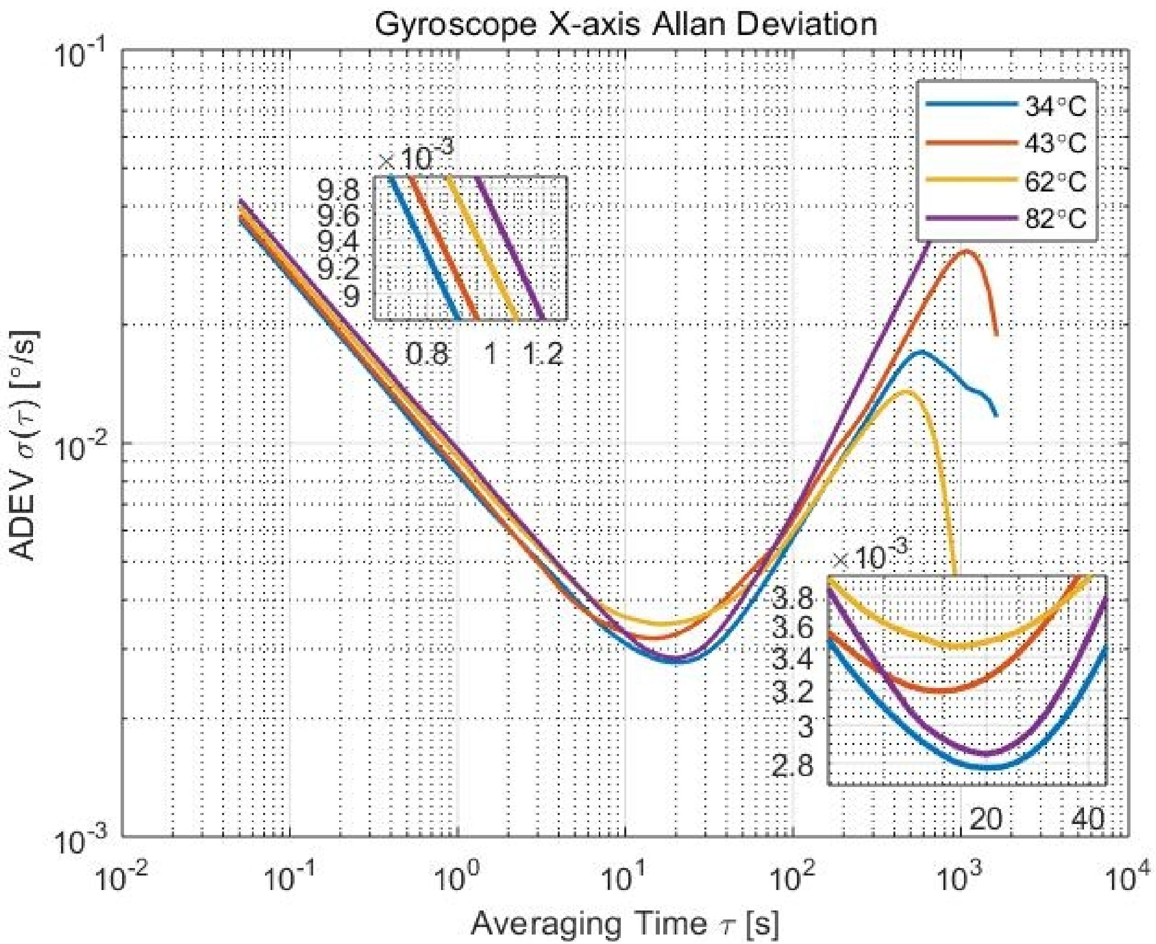
- Python 3.7
- Linux

Experimental Setup



p **Result**

Allan Deviation Plot



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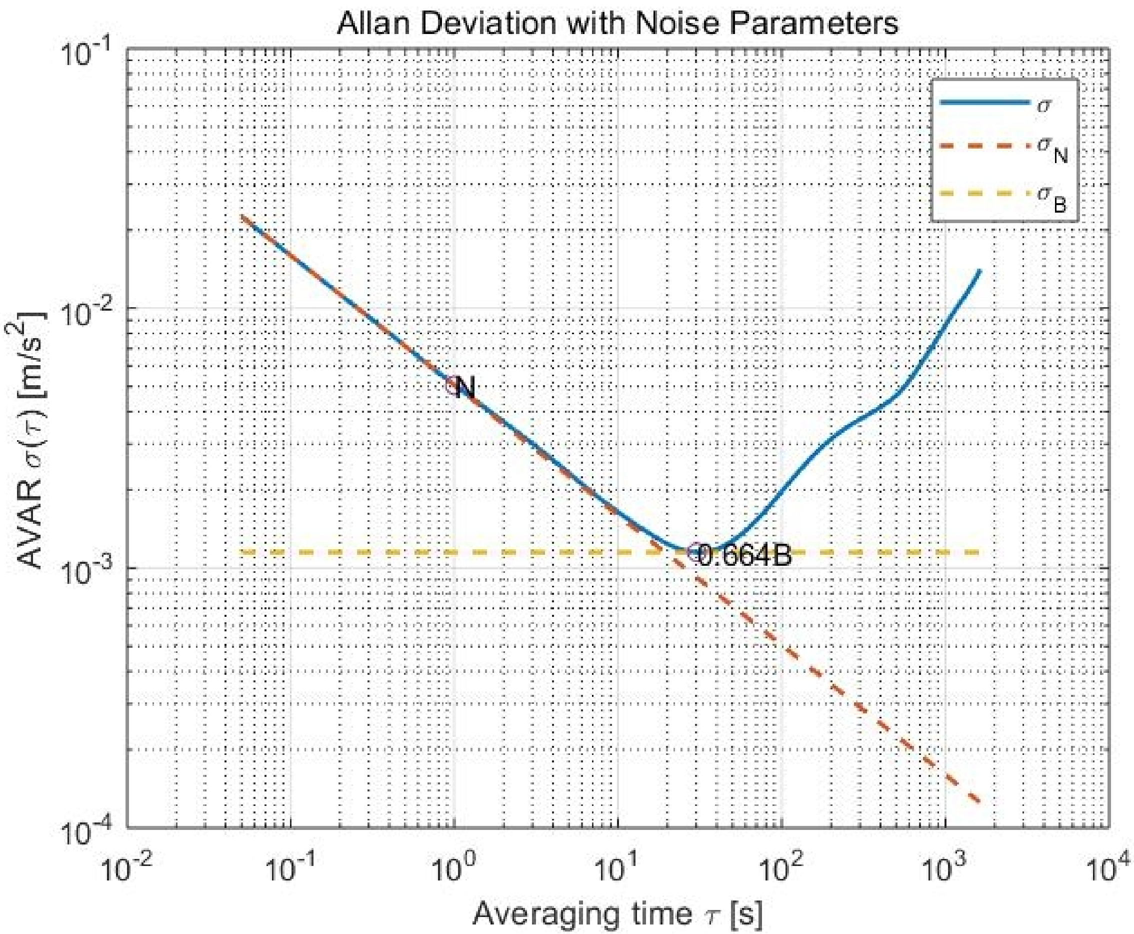
Noise Parameters



Accelerometer Noise Parameters

Velocity Random Walk ($m/s^2/\sqrt{s}$)				
	34°C	43°C	62°C	82°C
Accel X	0.0046	0.0049	0.0049	0.0051
Accel Y	0.0045	0.0049	0.0049	0.0050
Accel Z	0.0072	0.0076	0.0078	0.0083

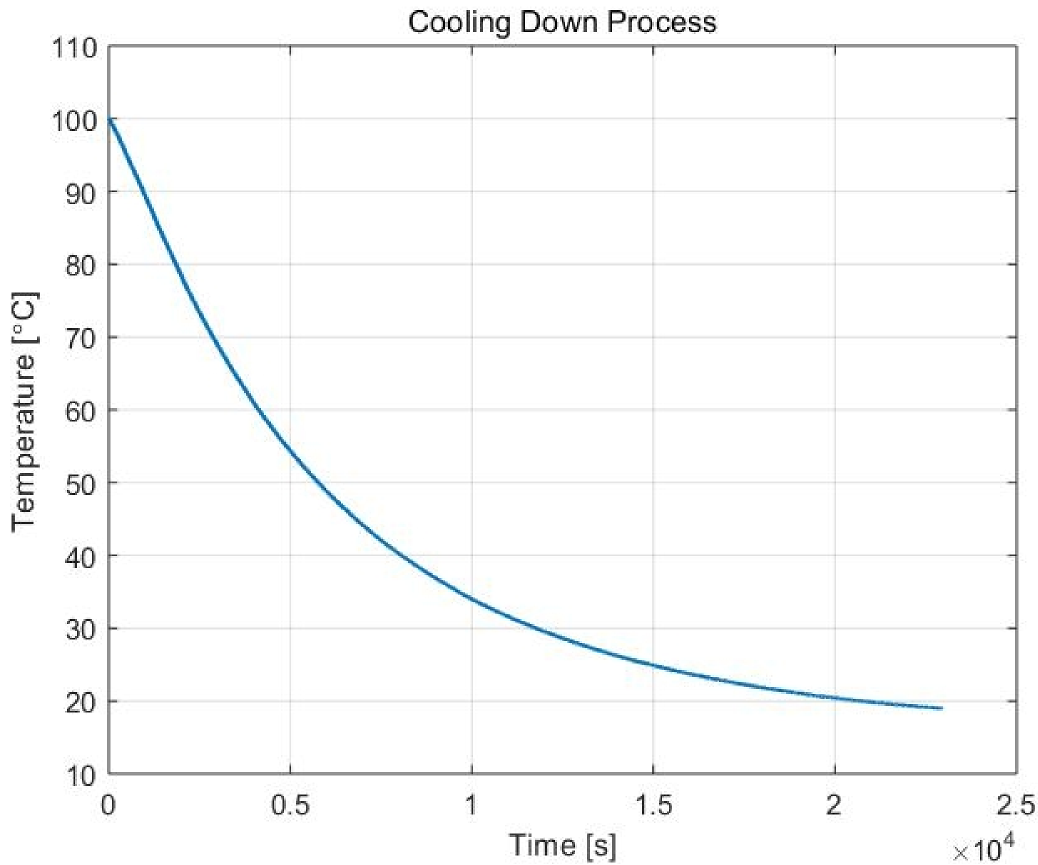
Accel Bias Instability (m/s^2)				
	34°C	43°C	62°C	82°C
Accel X	0.0016 (at 46.1s)	0.0018 (at 37.4s)	0.0020 (at 24.6s)	0.0017 (at 30.3s)
Accel Y	0.0015 (at 37.4s)	0.0018 (at 30.3s)	0.0018 (at 41.6s)	0.0017 (at 46.1s)
Accel Z	0.0016 (at 86.6s)	0.0017 (at 96.2s)	0.0024 (at 33.7s)	0.0023 (at 41.6s)

Gyroscope Noise Parameters

Angle Random Walk ($°/\sqrt{s}$)				
	34°C	43°C	62°C	82°C
Gyro X	0.0084	0.0086	0.0092	0.0097
Gyro Y	0.0087	0.0087	0.0090	0.0096
Gyro Z	0.0088	0.0094	0.0096	0.0100

Bias Instability (°/s)				
	34°C	43°C	62°C	82°C
Gyro X	0.0042 ~~(at 19.9s)~~	0.0048 (at 14.6s)	0.0052 (at 16.2s)	0.0043 (at 19.9s)
Gyro Y	0.0036 ~~(at 33.7s)~~	0.0037 (at 22.1s)	0.0049 (at 18.0s)	0.0047 (at 18.0s)
Gyro Z	0.0041 ~~(at 27.3s)~~	0.0042 (at 22.1s)	0.0049 (at 14.6s)	0.0051 (at 19.9s)

Cooling Down Process Temperature Change



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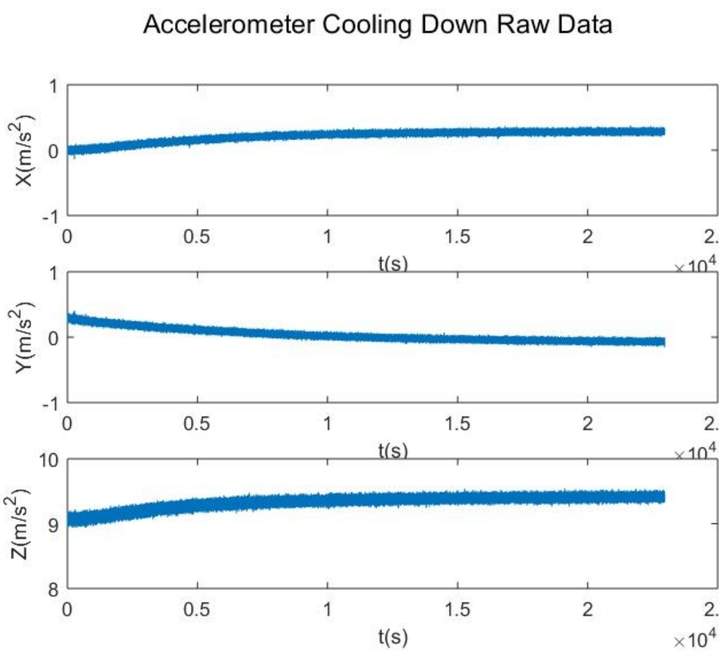
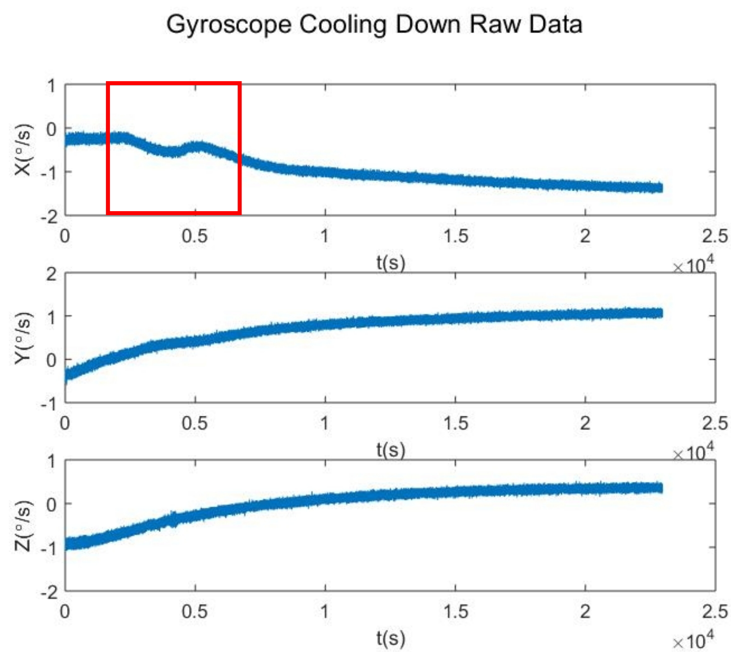
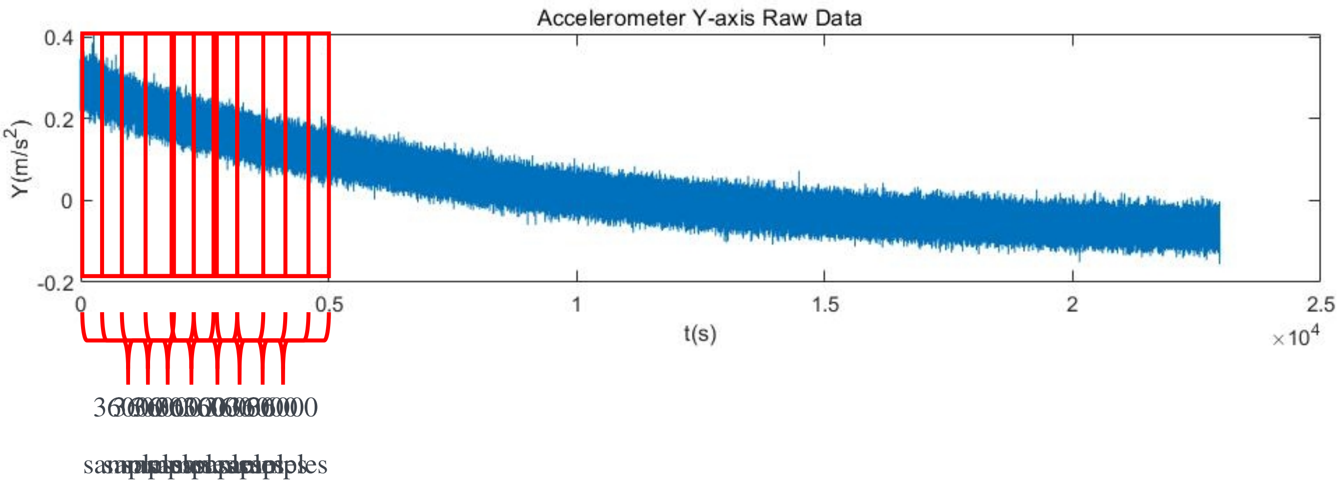
Cooling Down Process Raw Data

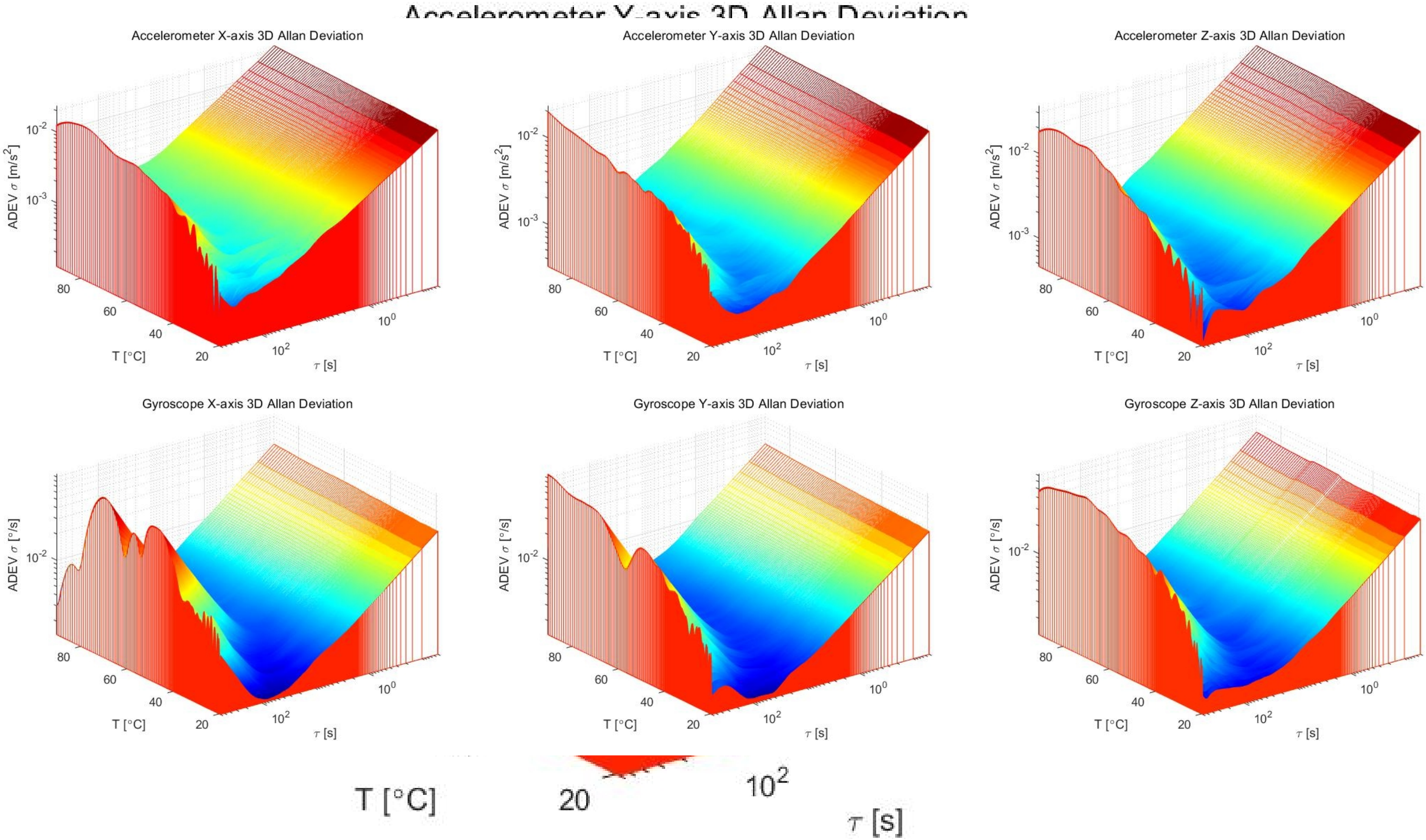




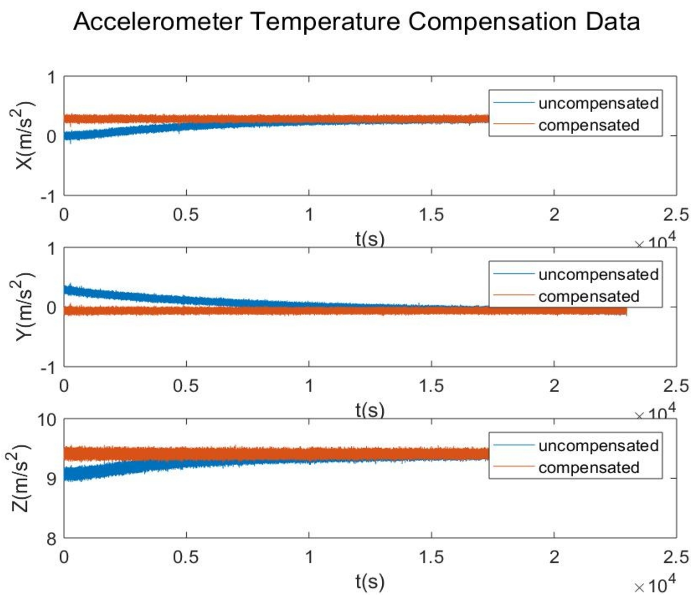
Cooling Down Process 3D ADEV Plot

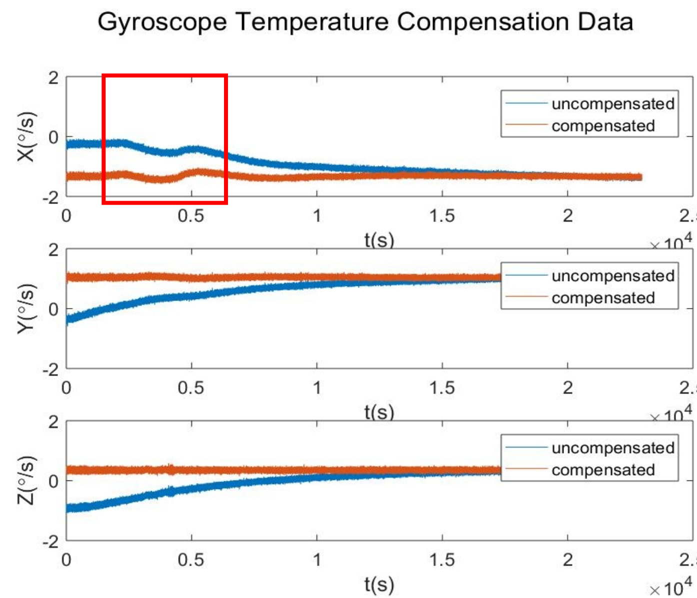


Cooling Down Process 3D ADEV Analysis



Temperature Compensation Test





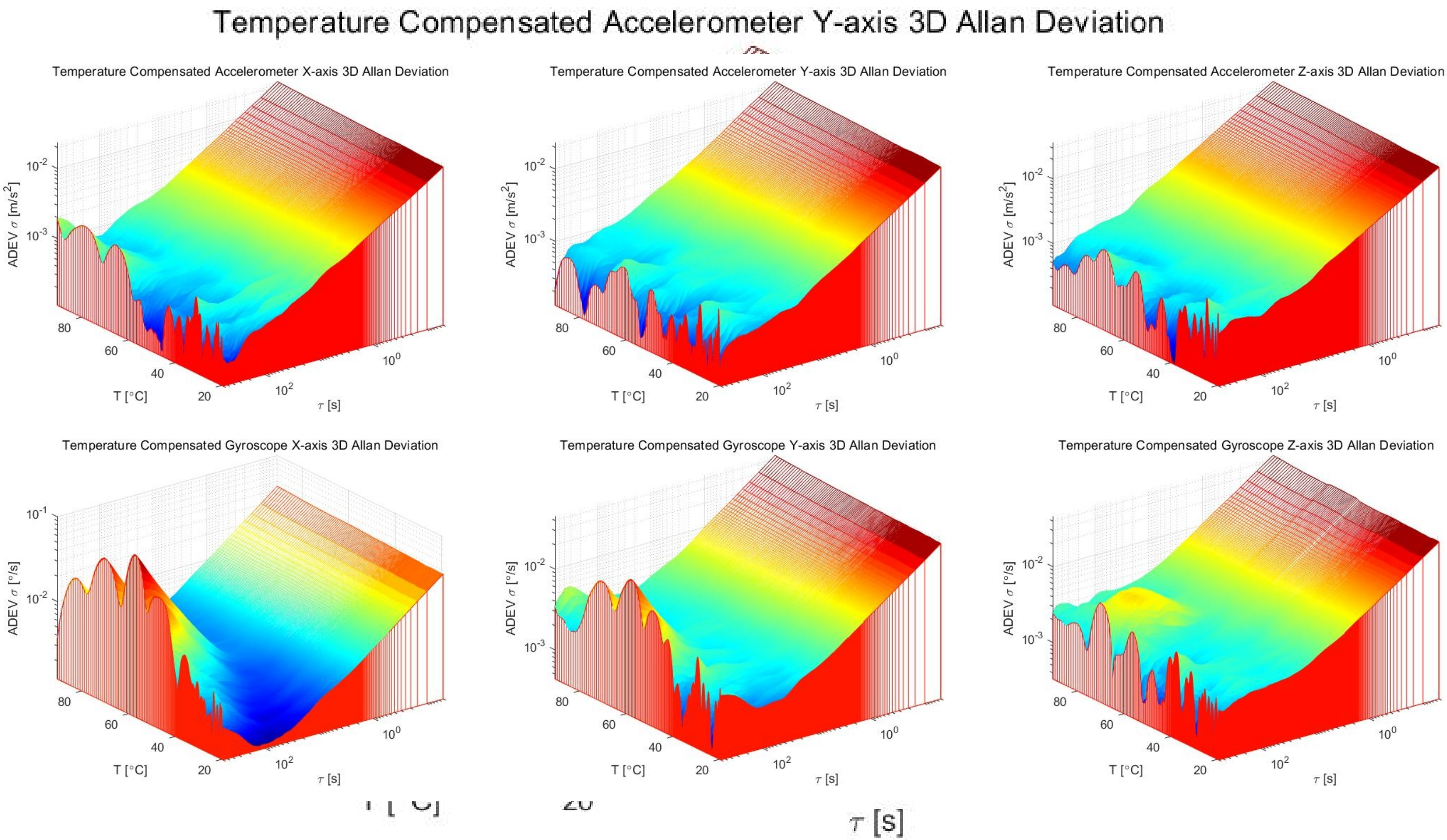
Polynomial coefficients

nth order polynomial

Temperature has no bias

```
p = double(polyfit(temp,x,n));
x_comp = x - (polyval(p,temp)-polyval(p,T_NB));
```

Temperature Compensation 3D ADEV Analysis



p Conclusion

Conclusion and Further Study

- **Conclusion**
  - Temperature influences the performance of MPU-9250.
  - Among four 1h temperature datasets, the performance at 34℃ is the best.
  - In the cooling down process, 3D ADEV plots show that the noises decrease as the temperature goes down from 100℃ to 20℃.
  - Polynomial temperature compensation model can reduce the noises for the high temperature part.
- **Further study**
  - Try out better temperature controller and evaluate at lower temperature.
  - Find out better temperature compensation model for MPU-9250.

References

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Thank you!

Any Questions?