Calibrating MEMS Accelerometers

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for
Sofia University – Application of mathematics for modelling real processes

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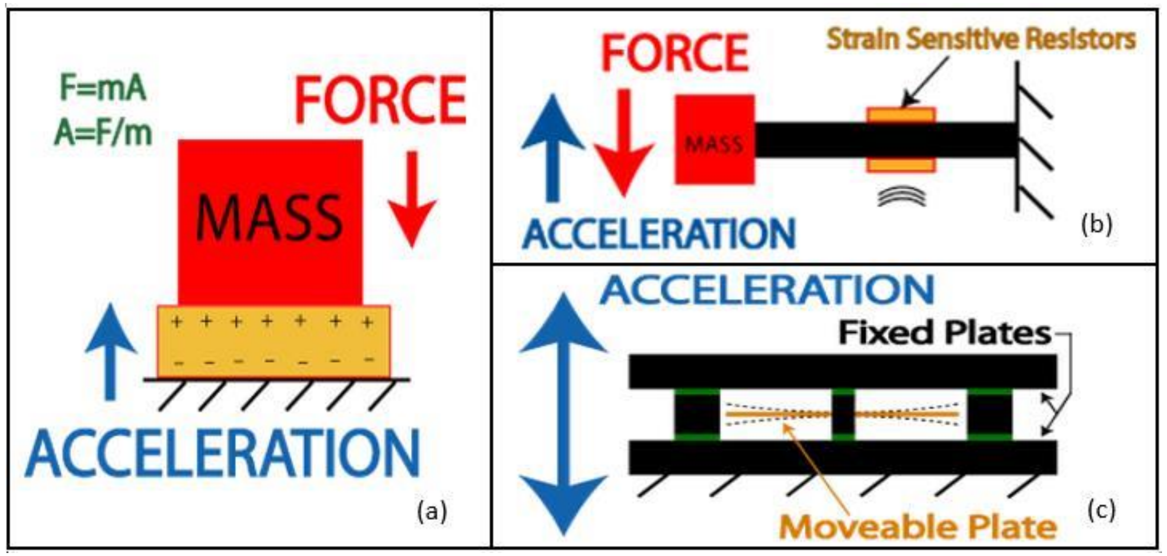
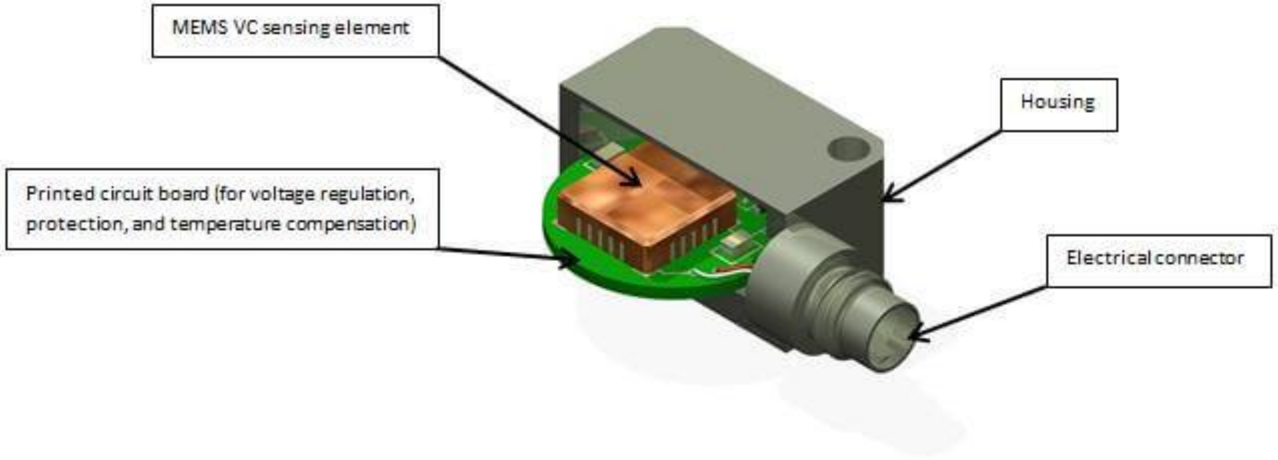
- Introduction to accelerometers
- MEMS Accelerometers
- Calibration Errors
- Solution
- Future project development.

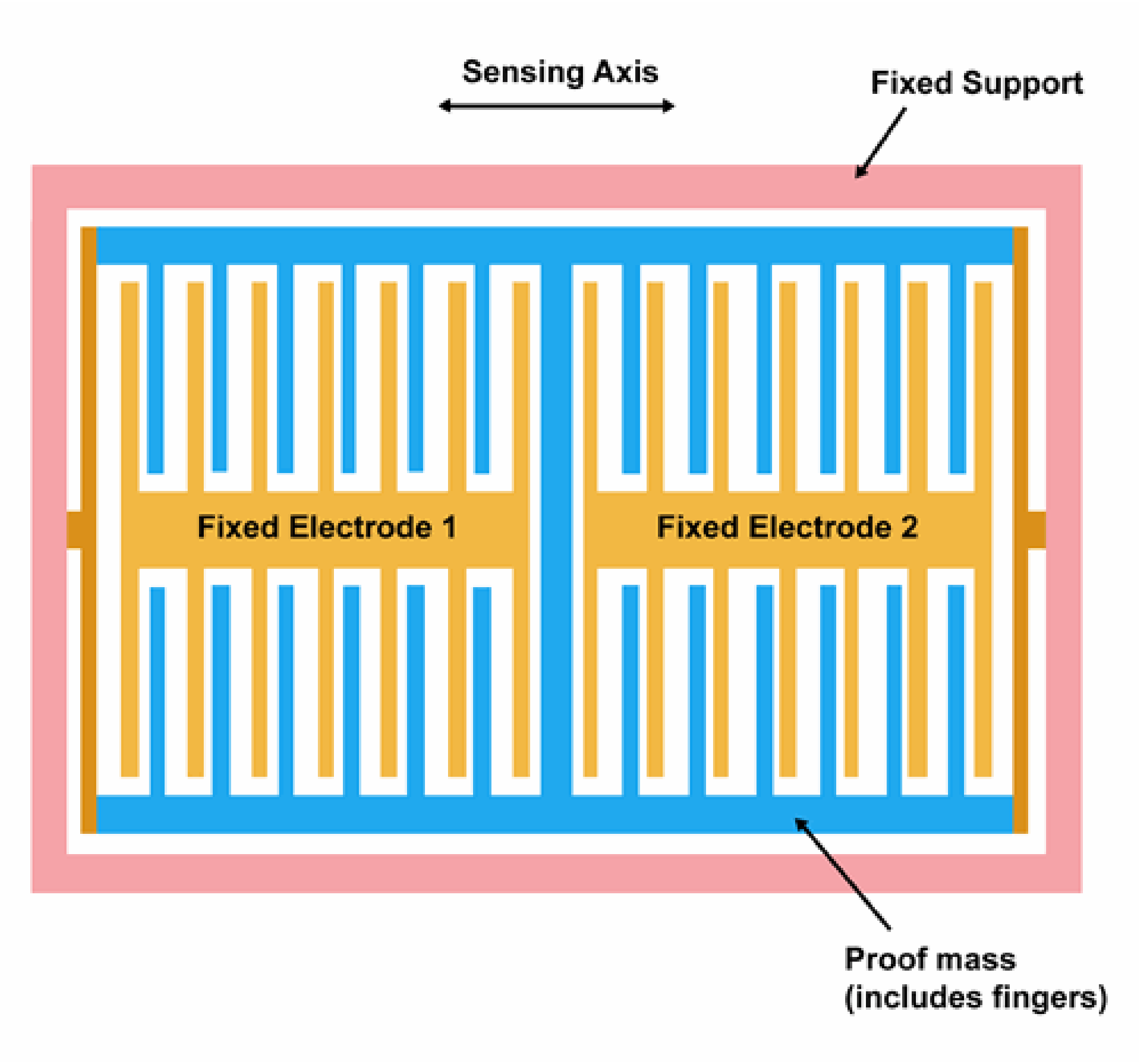
Introduction to accelerometers

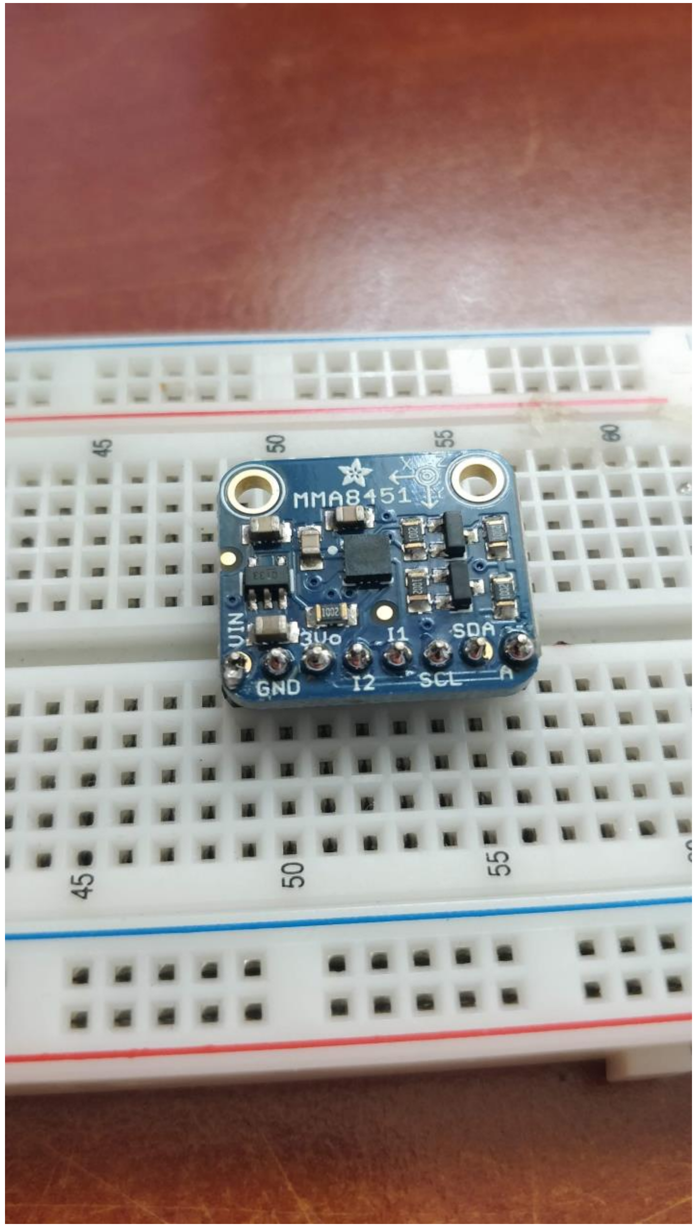
- **MEMS**
- Piezoelectric
- Piezoresistive
- Capacitive





MEMS Accelerometers





Calibration Errors

- Constant Bias
- Scaling Errors
- Errors due to the non-orthogonality of the axes
- Thermo-Mechanical White Noise / Velocity Random Walk
- Flicker Noise / Bias Stability
- Temperature Effects

What do we expect from the sensor?

Uncalibrated		
X	Y	Z
0.686143985	9.693013241	0.146230973
0.307313184	-9.555131822	0.121707371
10.20588166	0.146627372	0.293913142
-9.235730337	0.149835656	-0.153514714

Norms Before Calibration
9.71837
9.56085
10.2112
9.23822
9.72837

Details about data calibration

- $$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \underbrace{\begin{pmatrix} M_{xx} & M_{xy} & M_{xz} \\ M_{yx} & M_{yy} & M_{yz} \\ M_{zx} & M_{zy} & M_{zz} \end{pmatrix}}_{M} . \begin{pmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{pmatrix} + \underbrace{\begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix}}_{B}$$

- We can say that the sensor data is calibrated when (the norm of the acceleration vector) – $g^2 \approx 0$.

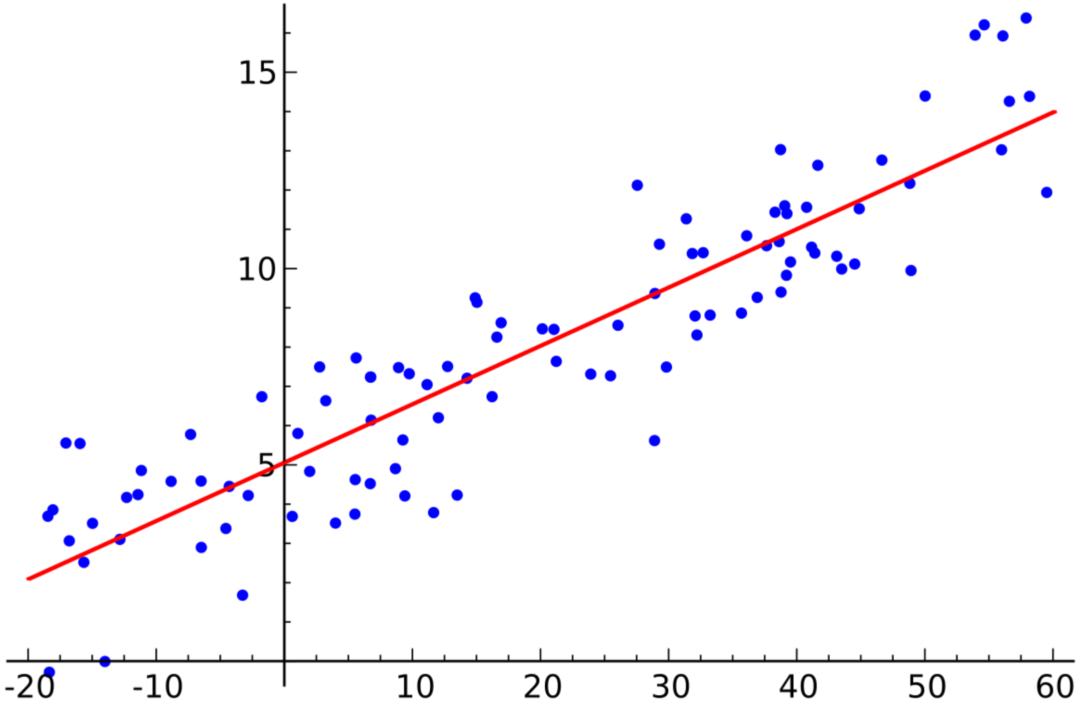
- We need to find for which $M_{xx}, M_{xy}, M_{xz}, M_{yx}, M_{yy}, M_{yz}, M_{zx}, M_{zy}, M_{zz}$ and B_x, B_y, B_z we have the smallest error.

$$Err(M,B) = \sum_{i=1}^{n} (M_{xx}x_i + M_{xy}y_i + M_{xz}z_i + B_x)^2 + (M_{yx}x_i + M_{yy}y_i + M_{yz}z_i + B_y)^2 + (M_{zx}x_i + M_{zy}y_i + M_{xz}z_i + B_z)^2 - g^2$$

Data calibration methods

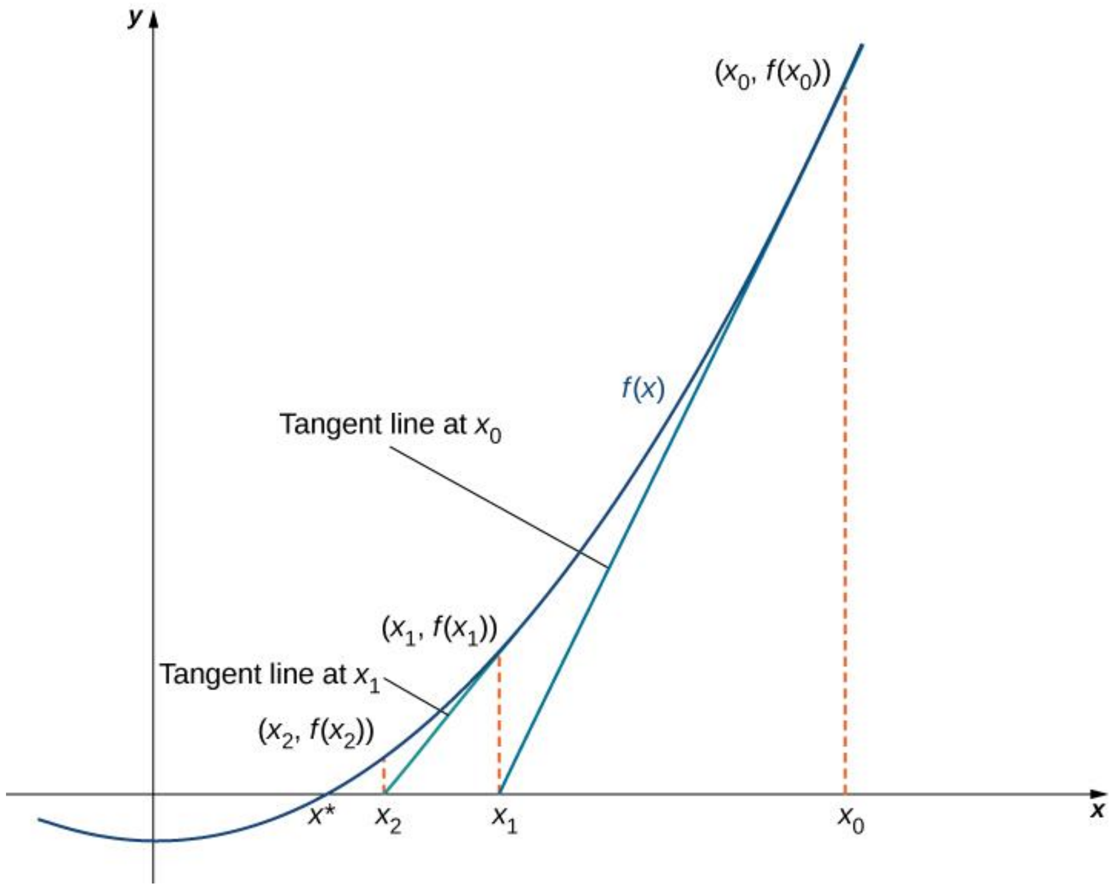
I use the least squares method in order to find for which $M_{xx}, M_{xy}, M_{xz}, M_{yx}, M_{yy}, M_{yz}, M_{zx}, M_{zy}, M_{zz}$ and B_x, B_y, B_z I have the smallest error for the given data.

$$M = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \qquad B = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$



Newtons Method

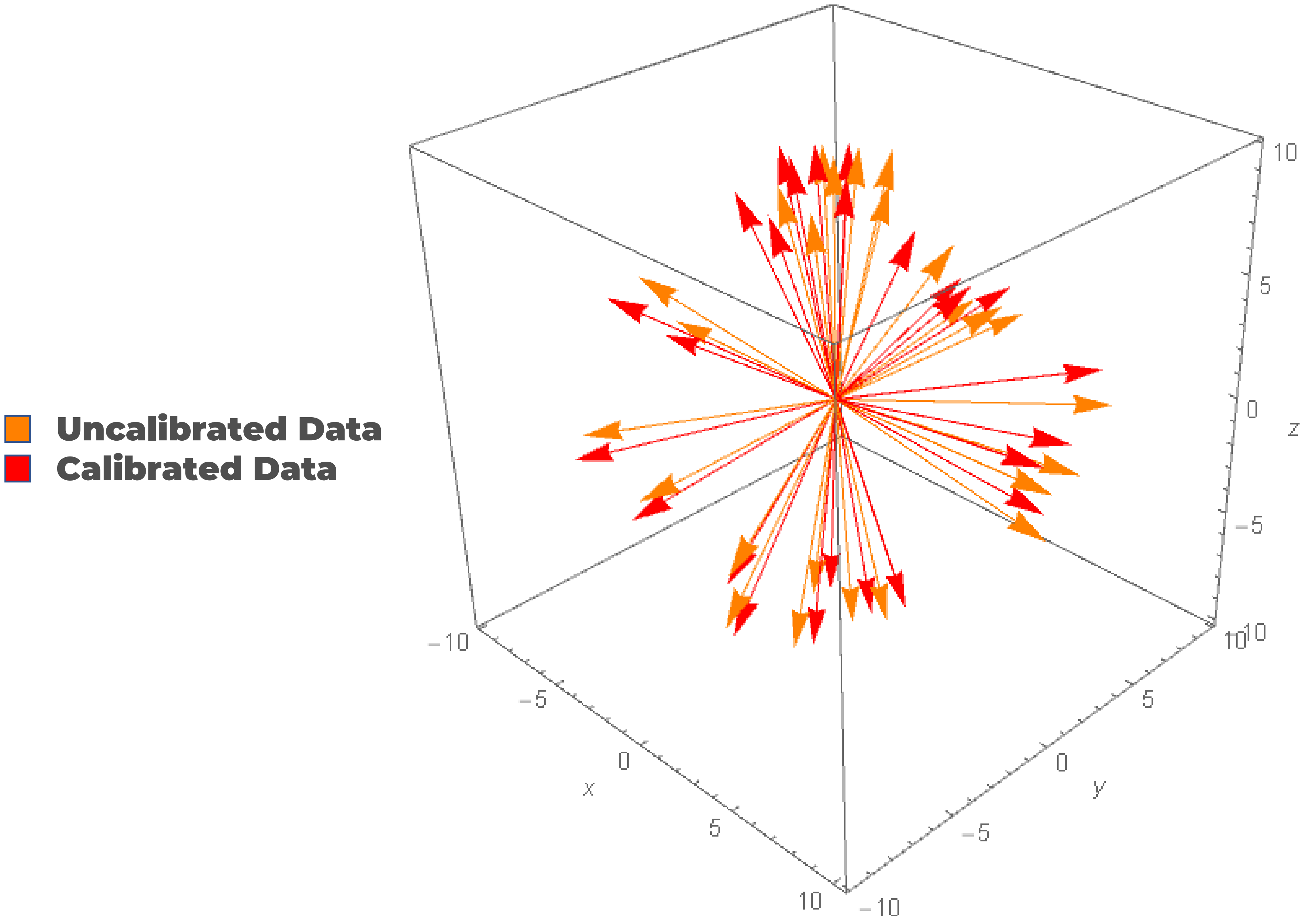
- Popular minimization method
- Partial Derivatives
- Using it for a system of 12 equations



Result Comparison

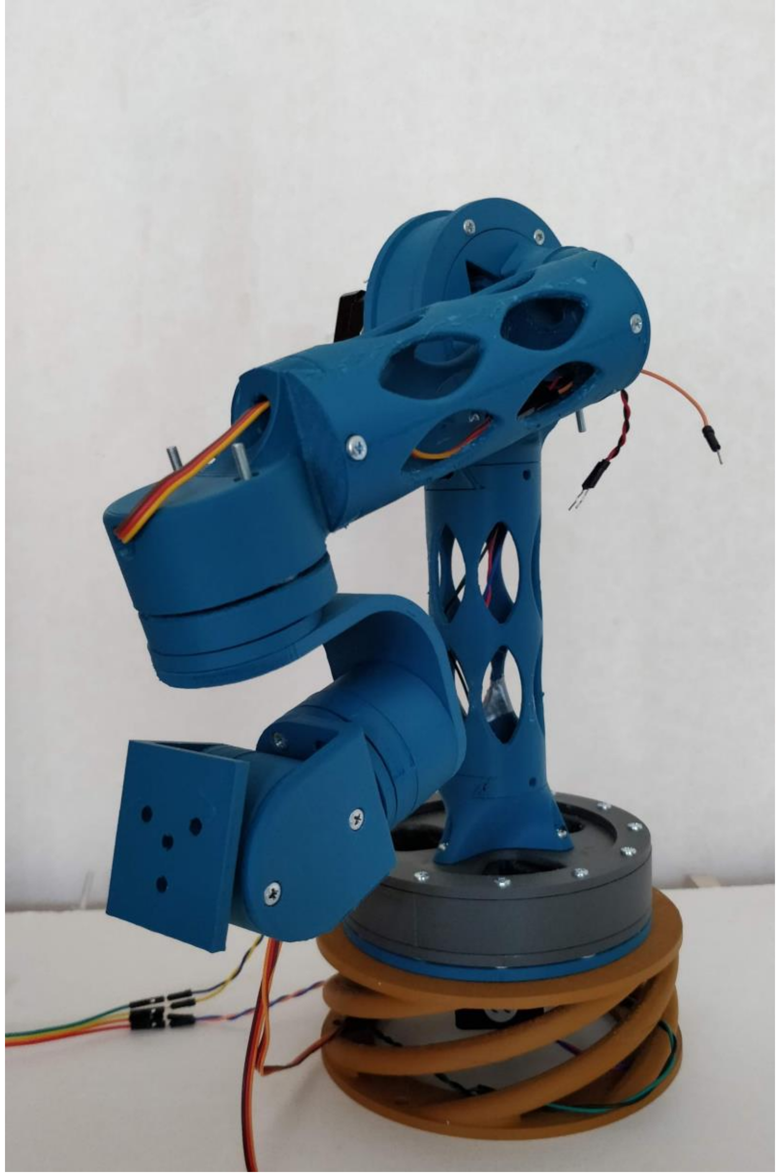
Uncalibrated				Calibrated		
X	Y	Z		X	Y	Z
0.686143985	9.693013241	0.146230973	>	-0.21872	9.78756	0.393097
0.307313184	-9.555131822	0.121707371		0.23227	-9.79228	-0.00413996
10.20588166	0.146627372	0.293913142		9.7752	0.458216	0.448614
-9.235730337	0.149835656	-0.153514714		-9.79133	-0.299772	-0.18428

Norms Before Calibration		Norms After Calibration
9.71837	>	9.79789
9.56085		9.79504
10.2112		9.79621
9.23822		9.79765
9.72837		9.78336


Uncalibrated Data
Calibrated Data
x
y
z
-10
-5
0
5
10

Practical Applications

- Sensing applications in industrial settings.
- Robotics
- Drones/Aircraft



Demo

- <Work in progress>

Thank you for the attention!