LOW COST MEMS IMU CALIBRATION 
FOR 
AEROSPACE STUDENT ACTIVITIES 
Aureliano Rivolta 
Mattia Giurato 
Francescodario Cuzzocrea 
Federico Rovere 
Stefano Farí
• Skyward Experimental Rocketry
• MEMS IMU in student sounding rockets
• MEMS IMU error model
• Calibration platform
• Calibration platform sequence
• Hierarchical calibration procedure
• Accelerometer calibration
• Gyroscope calibration
• Tested IMUs
• Calibration results
• Temperature sensitivity
Skyward Experimental Rocketry

Student association since 2012
Design, testing realization & launching of experimental sounding rockets
More than 50 members since 2013
Company-like organization

I launch [nov 2013]
Parachute failure

II & III launch [jun 2014]
No Failures
MEMS IMU in student sounding rockets
MEMS IMU error model

\[ a_b = R_{mis} T_a S_{aam} + b_a + n_a \]

- **IMU placement attitude errors**
- **Non orthogonality of three axis IMU**
  \[ T_a = \begin{bmatrix} 1 & -\beta_{yz} & \beta_{zy} \\ \beta_{xz} & 1 & -\beta_{zx} \\ -\beta_{xy} & \beta_{yx} & 1 \end{bmatrix} \]
- **Scale factor**
- **Bias**
- **Sensor noise**
- **Configuration dependent**
- **Long term error performance neglected**
- **High Temperature sensitivity**
- **Principal concern for aerospace vehicle control**
Calibration platform
Calibration platform sequence

Platform joints

Accelerometers reference

Velocity rates

Gyroscope reference
Hierarchical calibration procedure

Step - 1
- Time shift
- Bias
- Scale

Step – i
- Increasing complexity
  (fixed registration)

Final Step
- All parameters

Check the goodness of each iteration by comparison with the previous
Accelerometer calibration

Preliminary calibration

- Time delay

Fix registration

Calibration of all parameters

- Also: misalignment & orthogonality

Non linear data fitting (Levenberg-Marquardt)

Time shift determined at first iteration (also for gyroscope)

Preliminary estimated scale & biases used as first guess for the second calibration
Gyroscope calibration

Main motion identification

Motion identification
Integration
Scale factor & bias identification
Final calibration

Gyroscope calibration
Motion
identification
Integration
Scale factor & bias identification
Final calibration
Calibration results

Comparison after calibration

\begin{align*}
\text{Comparison after calibration} & \\
\text{Comparison after calibration} & \\
\text{Comparison after calibration} & \\
\text{Comparison after calibration} & \\
\end{align*}
Temperature sensitivity

Temperature affects the biases. Many trials are needed to model the variation. For on-board applications temperature compensation or active temperature regulation may be necessary depending on the use of the measurements.
Conclusion

• A hierarchical and instructive calibration procedure has been devised,
• an experimental set-up has been prepared,
• experiments were made by students,
• technical requirements have been investigated.

The calibration procedure has produced good and coherent results.
Open problems and future activity

- IMU position on the platform induces non-modeled accelerations
- Gyroscope g-sensitivity has not yet been tested
- More tests required to characterize temperature influence
- Calibration improvement

- Identify a procedure for on-board compensation [digital/analog]
- Identify requirement for filtering of IMU data for control purpose
Thank you for your attention.

Questions?

http://www.skywarder.eu