Analytical developments on 6C computation inspired by navigation algorithms

Baptiste Pinot, Frederic Guattari, Joachin Honthaas, and David Mimoun

Summary

- Rotation sensors in seismology ?
- What does a rotation sensor measure ?
- How to use a rotation sensor ?
- Comparison with lab tests by F. Bernauer
- Algorithm and simulations !

isae
Institut Supérieur de l'Aéronautique et de l'Espace
SUPAERO

Rotation sensors in seismology ?

A quick introduction

Rotation sensors in seismology ?

- They allow to measure ground rotational motion
- Some, like the FOGs (typically the BlueSeis3A) are insensitive to ground translational motion

Tilt correction

- OBS (Crawford and Webb, 2000)
- Wind noise (Lin et al, 2022)
- Strong motion (Bernauer et al, 2020)

Back azimuth measurements

Seismic array with one station

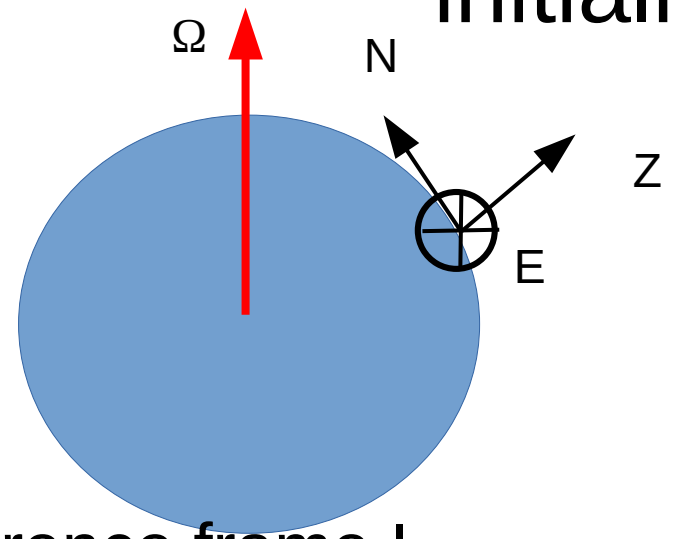
Planetology ! (Bernauer et al, 2020b)

What does a rotation sensor measure ?

Initialisation of the sensor heading

What does a rotation sensor measure ?

- It measures a rotation rate along its sensitivity axes
- It means it measures the Earth rotation – you can initialise the heading !



Inertial reference frame I

Earth reference frame E

Navigation (ENZ) reference frame N

Body (XYZ) reference frame B

Heading = difference between Y axis of Body frame and North

What does a rotation sensor measure ?

Initialisation of

- Earth → Navigation (locally level)
- Navigation → Body (rotation sensors)

But also

- Rotation sensors → seismometer

How to use a rotation sensor ?

Integration and linear algebra !

How to use a rotation sensor ?

- The solution of this equation is the orientation of the sensors in the Navigation frame. Several approximations can be done :

$$\dot{C}_B^N = C_B^N [\omega_{IB}^B \times] - [\omega_{IE}^N \times] C_B^N$$

"direct" integration

(+ coning compensation)

Earth projection

Comparison with lab tests

Tests conducted by Bernauer et al, published in 2020

Bernauer, F., Wassermann, J., & Igel, H. (2020). Dynamic tilt correction using direct rotational motion measurements. Seismological Research Letters, 91(5), 2872-2880.

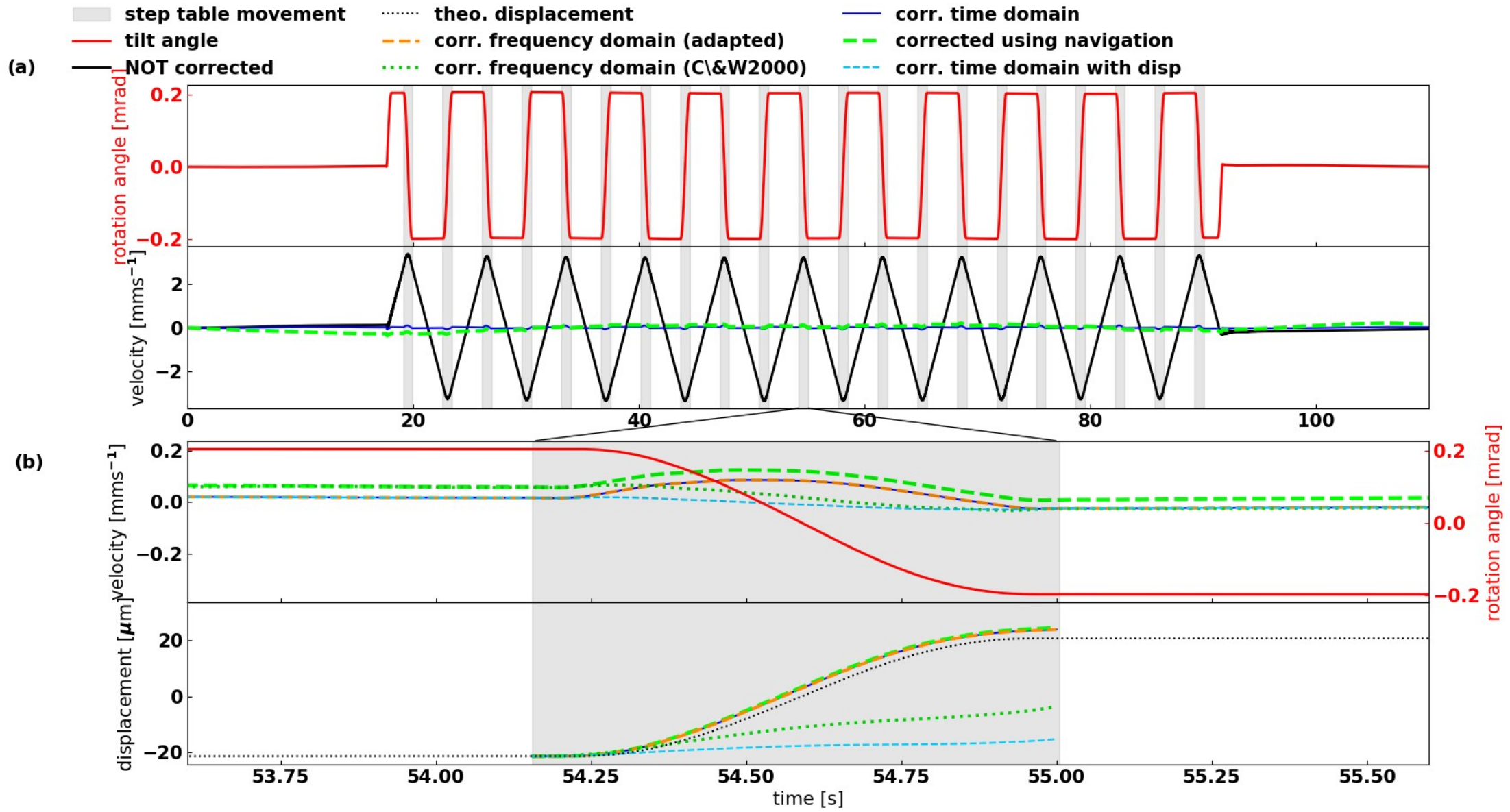
Comparison with lab tests

- Tilt table with BlueSeis3A and Trillium Compact, rotated around East axis

- 3 methods in Bernauer et al to remove tilt
  - Frequency method (Crawford & Webb 2000)
  - Adapted frequency method
  - Time domain

- « Navigation » method with rotation matrix added

Comparison with lab tests



Comparison with lab tests

- Same results with new method
- Advantages : real time method
- But main advantages not seen in this experiment :
  - Easy rotation when data on several FOG axes
  - Gravity projection ! Here only rotation on East axis...

Algorithm and simulations

Algorithm and simulations

$$\dot{C}_B^N = C_B^N [\omega_{IB}^B \times] - [\omega_{IE}^N \times] C_B^N$$

This equation is good analytically but is flawed numerically because of the integration. Numerical methods have been developped to mitigate numerical errors and non-orthogonality. They use the rotation vector formalism.

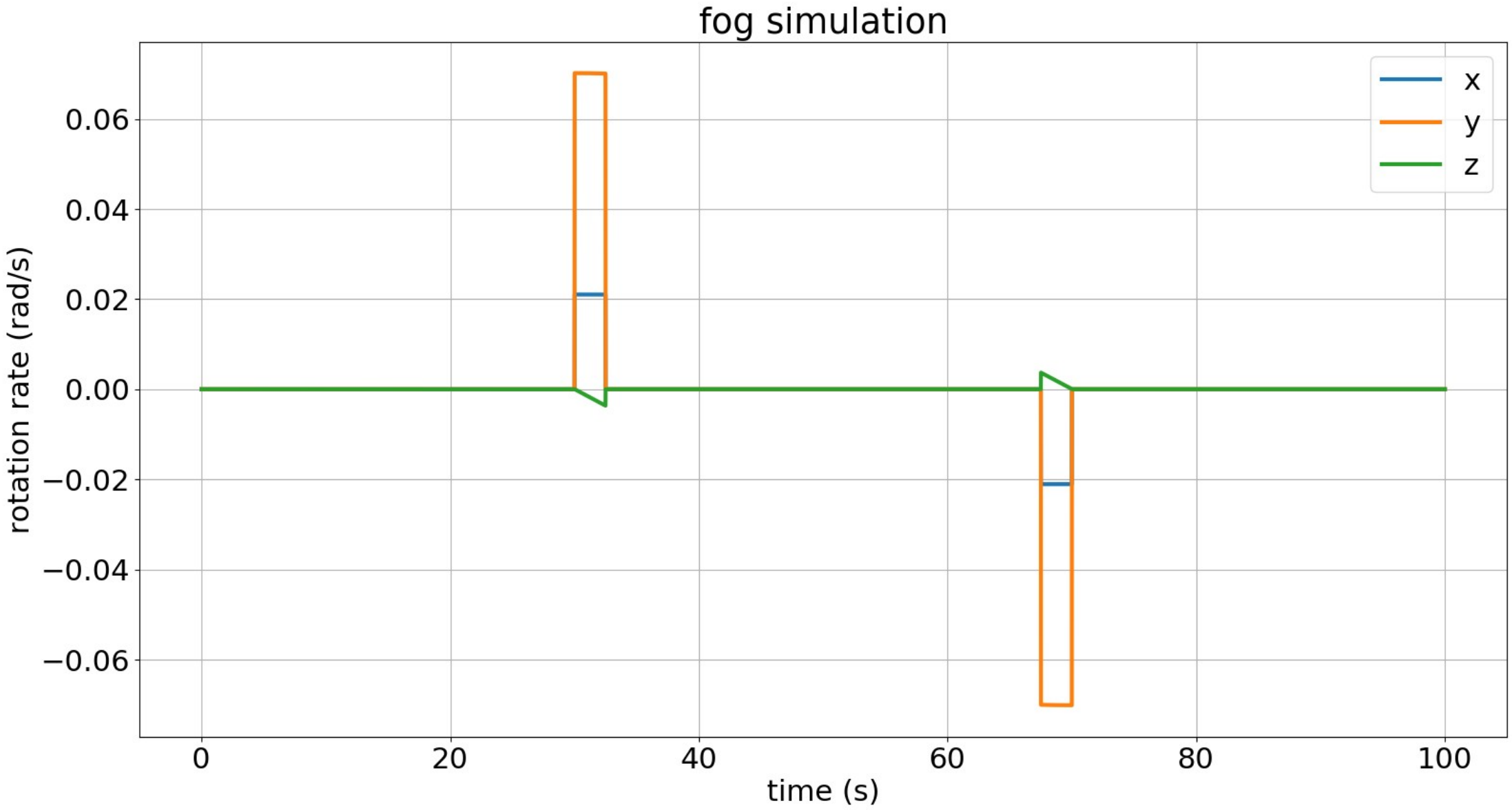
Simulation:

- roll and pitch angles applied
- Simulation of FOGs
- Retrieval of input angles from FOGs

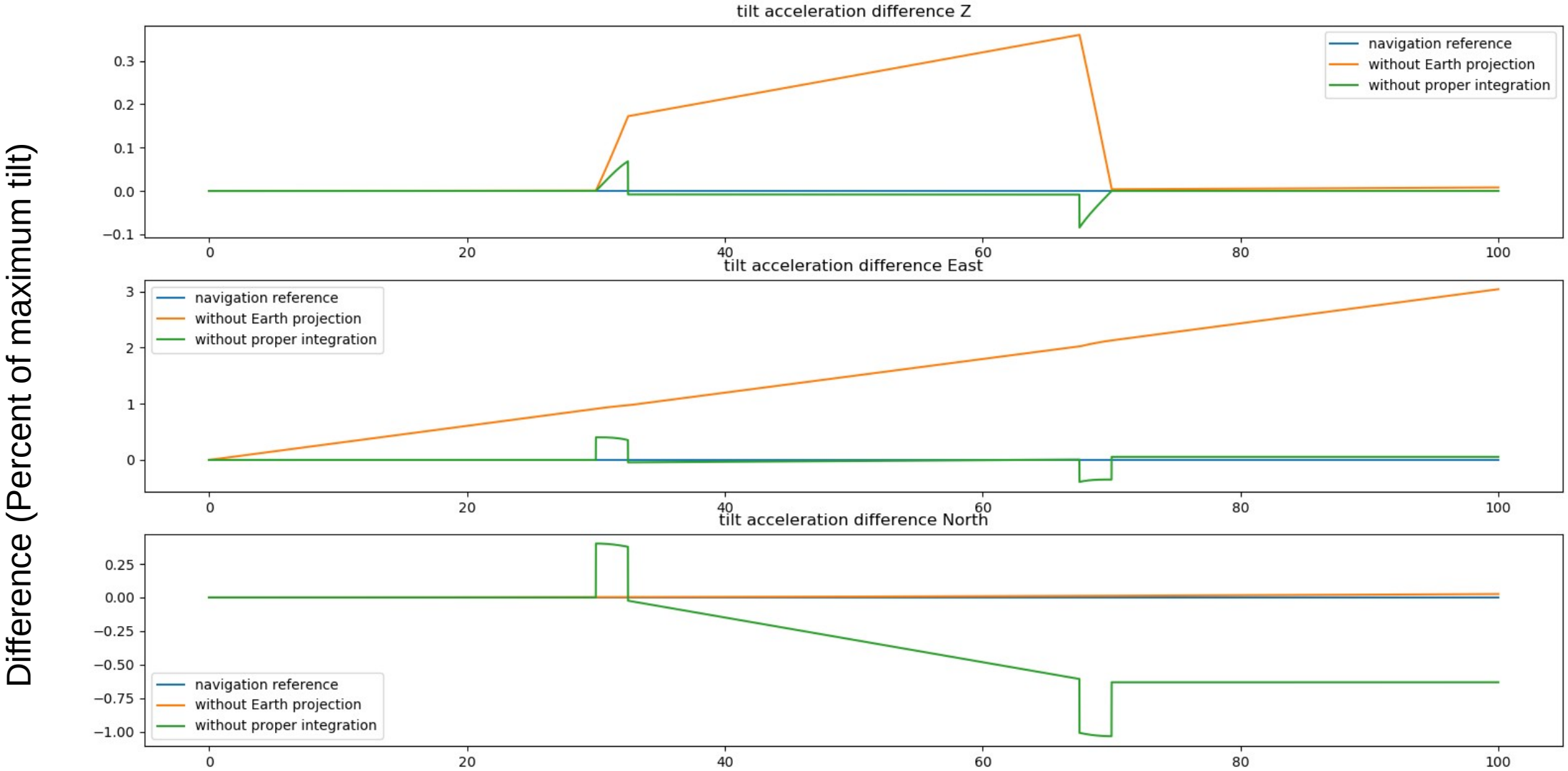
3 methods are tested to retrieve the angles:

- “direct” method
- “Without gravity”
- navigation

Algorithm and simulations



Algorithm and simulations



Conclusion

Conclusion

INPUTS

- Rotation sensors measurements
- Position of station
- Initial “verticality” of rotation sensors

OUTPUTS

- Heading
- Pitch
- Roll at every time

- Rotation vector at every time

\+ Attitude of seismometer → Tilt

Conclusion

- Always reliable, fewer hypothesis:
  - Can work for several axis rotation and complex rotations
  - No need to correlate to the seismometer output
  - Calculates Earth projection for large tilts
- Can be directly implemented as a FOG output
- Real time, no additional lowpass filtering needed for Earth projection

Thanks for your attention !