**MGE-MSR-01 – Sensors and State Estimation**
WS 2020/2021

**Exercise 1: Inertial navigation**
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## 1 Learning objective

Understanding the construction and operating principle of inertial sensors; sensors advantages, disadvantages and error budgets; interaction of the sensors in a multi sensor system; inertial navigation; Strapdown integration

## 2 Description of the exercise

This exercise is about the determination of the trajectory of a moving platform by using inertial sensors. For this purpose a kinematic multi sensor system (MSS) is used, which is equipped with three fiber-optic gyroscopes and three servo accelerometers. Additionally, the MSS contains an accurate RTK-GPS (for a reference). The system is adapted to a trolley. However, it is also possible to adapt the system to a car or another moving vehicle. During the exercise real measurements are recorded at the Campus Poppelsdorf with the system. The goal is to determine the trajectory of the trolley via Strapdown integration by self-implemented algorithm using the observations of the accelerometers and the gyroscopes. The result of the Strapdown integration should then be analyzed in detail and compare to reference solutions as described in tasks in Section 5.

- **Execution:** group work with 2-3 students
- **Certification:** oral presentation (with slides)
- **Deadline:** submission of the presentation via eCampus until Tuesday, 16/12/2020
- **Examination:** Wednesday, 16/12/2020, 08:30 am, Zoom link

## 3 Prior knowledge

- MGE-MSR-01 – Sensors and State Estimation (Lectures: Sensors, Inertial navigation)

## 4 References


- Groves, P. D. (2013). *Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems*, 2nd edition. Artech House, Boston, London, ISBN: 978-1-60807-005-3.
- Groves, P. D. (2015). Navigation Using Inertial Sensors. University College London, United Kingdom, IEEE A&E Systems Magazine, February 2015, Part II of II.
- Titterton, D. H., Weston, J. L. (2004): *Strapdown Inertial Navigation Technology*, 2nd edition. The Institute of Electrical Engineers, ISBN: 978-0-86341-358-2.
- Teunissen, P. J. G. & Montenbruck, O. (Hrsg.) (2017). *Springer Handbook of Global Navigation Satellite Systems*. Springer Verlag, Berlin, ISBN: 978-3-319-42926-7.


## 5 Description of the tasks

1. **Describe the components of the MSS** used for the trajectory determination of the trolley. Explain how the different absolute (RTK-GPS) and relative sensors (accelerometers, gyroscopes) work, i.e. the construction, the operating principle as well as the observation. What are the advantages and disadvantages of the different sensors and what error budget do they have (random and systematic errors)? How can be sensors separated by accuracy/price range and in which category fall the instruments used in this exercise? What are the advantages of using a MSS instead of using single sensors? (End of the task 1.)

2. **Describe the principles of Strapdown integration**. How does the algorithm work and what are the input and output variables? For which effects the observations have to be corrected and which corrections can be neglected in small areas? The algorithm requires initial values for the position, the orientation and the velocity. How can they be generated? (End of the task 2.)

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**General task:** Determine the trajectory of the trolley at the Campus Poppelsdorf on the basis of the simplified Strapdown integration as shown in the supplementary document. Utilize the observations of the accelerometers and gyroscopes of the MSS. Visualize your results and discuss them.

3. **Analyzing 2D trajectory (2D position) and attitude:** Compare the trajectory of your own simplified implementation with: **A)** the results of the strict implementation by Paul Groves (see provided ".txt" file & comparison script) and **B)** with the accurate RTK-GPS position provided by MSS (reference). What is the maximal difference between trajectories and where does it occur? Calculate the differences between both Strapdown realizations (own & by Paul Groves) and the RTK-GPS positions in different time points (2D distances in meters). Visualize differences against time and analyze them. Calculate the average difference per time (e.g. cm/s or m/min). Analyze attitudes (roll, pitch and yaw separately). Compare the results of own implementation against implementation by Paul Groves and by attitude information provided by MSS. Visualize differences against time and analyze them. Do you observe notable differences and where? (End of the task 3.)

4. **Analyzing heights and velocities:** Calculate own Strapdown solution again. However, this time replace the mathematically (theoretically) calculated $g_b^n$ with measured $g_b^n$ using accelerometer measurements while the trolley was standing still (average of n measurements) – see supplementary material. Compare heights against time for: **A)** your own implementation (old), **B)** your own implementation (new), **C)** RTK-GPS height (reference), **D)** implementation by Paul Groves. Visualize differences against time and analyze them. What are maximal differences, average differences per time (e.g. cm/s or m/min). Analyze the velocity over time for all three directions (north, east, down) for both own implementations and implementation by Paul Groves. Visualize the differences against time and analyze them. (End of the task 4.)

**Remarks**

- It is strongly recommended to utilize Python or Matlab/Octave for the implementations and calculations (only in this case we can offer help)
- The Strapdown integration algorithm must be done by utilizing own source code. The use of existing source code and algorithms is not permitted!
- All plots/figures needs to have readable axis labels and units in presentations and you must be able to discuss the results you are presenting