A virtual platform for real-time performance analysis of EM tracking systems for surgical navigation

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DEI Doctoral Research Seminar - 2022

Research objectives

- Develop a EM system to guide the surgeon during interventions
- Improve its working volume to overcome the state-of-the-art
- Realtime analysis of system components and configurations

Outline

- State-of-the-art
- System architecture
- Virtual platform for system analysis
- Test and results: simulated and experimental

Minimally Invasive Surgery

Traditional surgery

- Large incisions
- High trauma
- High risk of infections
- Long recovery time
- High stress
- **Depends on surgeon's skills**

Minimally-invasive surgery

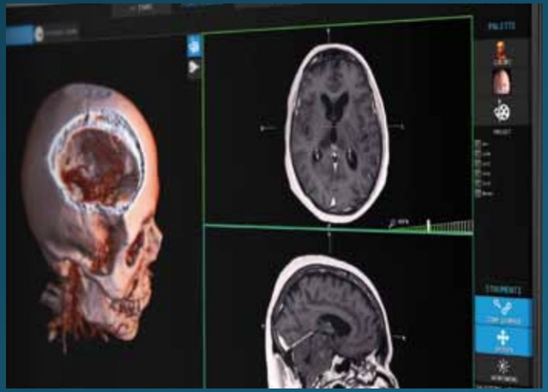
- Small incisions
- Reduced trauma
- Medical images, endoscopes, tracking systems
- **Precision surgery**

Navigation systems

Medical imaging techinques

CT, MR

3D anatomical model



Pre-operative planning

System registration

Surgery navigation

Tracking system

Tracking systems

Optical

- (+) high resolution
  large volume

- (-) direct line-of-sight
  No intra-corporeal interventions

Electromagnetic

- (+) No direct line-of-sight
  Small sensor inside the instrument

Tracking systems

Electromagnetic

- (+) No direct line-of-sight

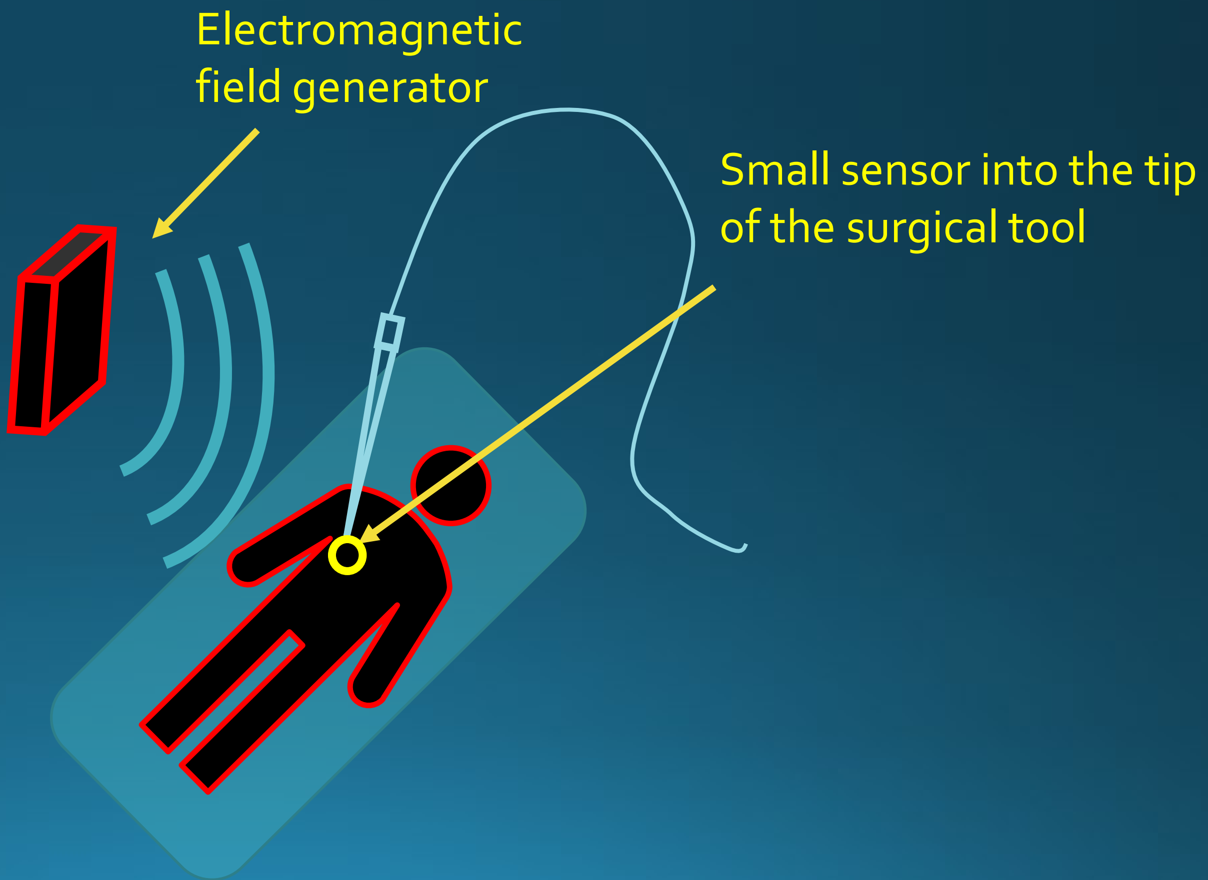
  Small sensor inside the instrument

- (-) Sensitivity to EM interferences

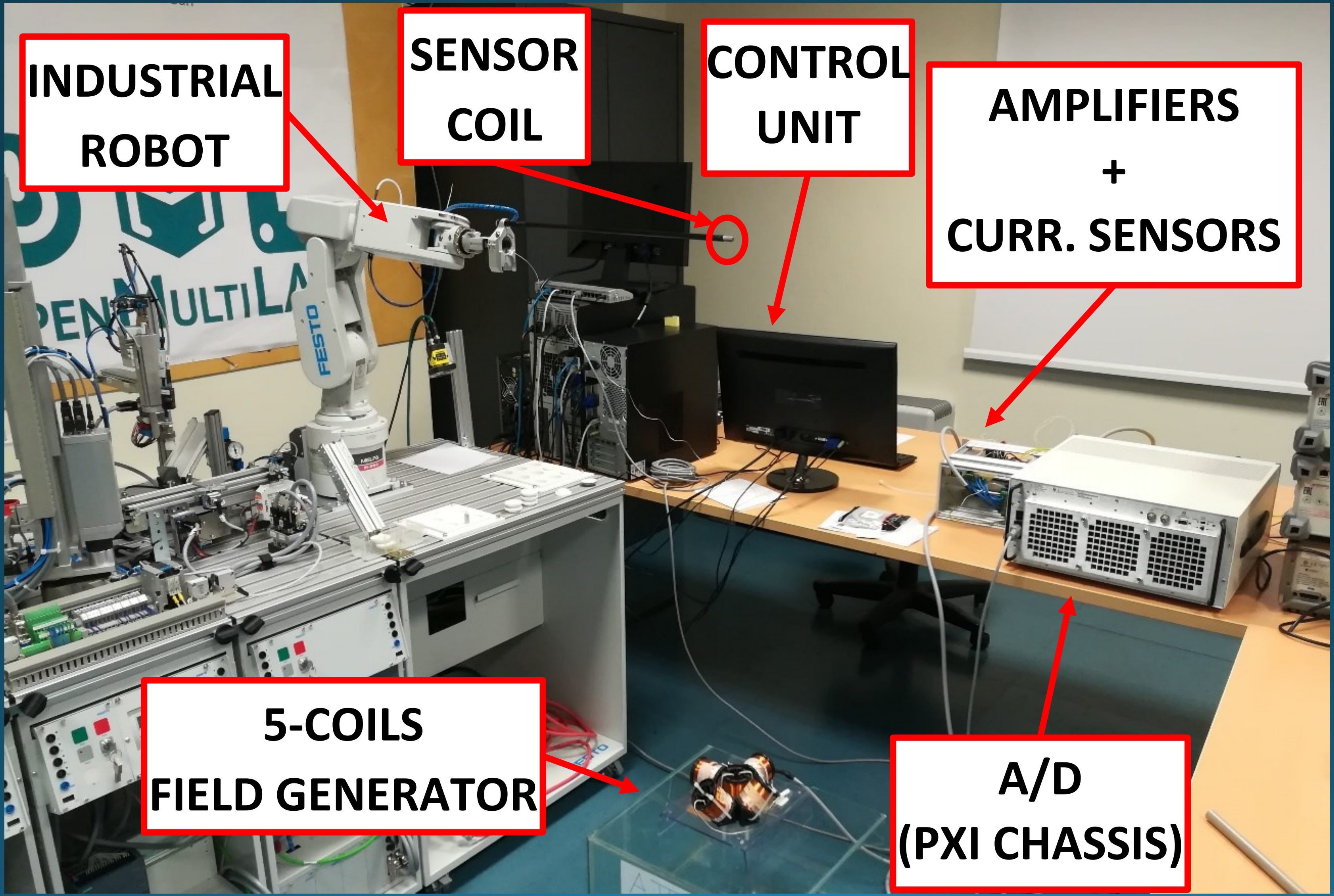
  Short range: **< 0.5 m**

  Generator near to the patient

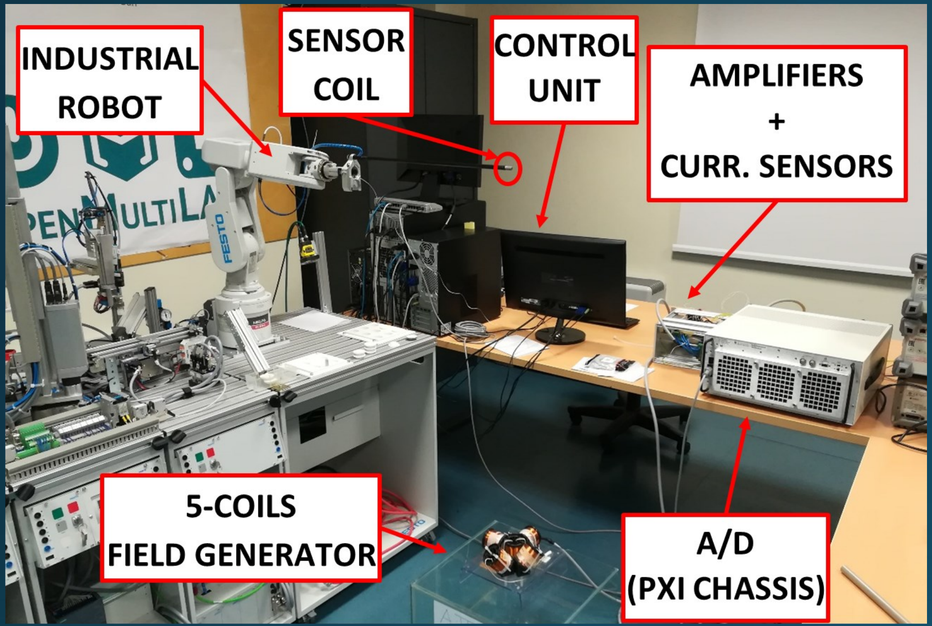
  ⇒ impediment for the surgeon!

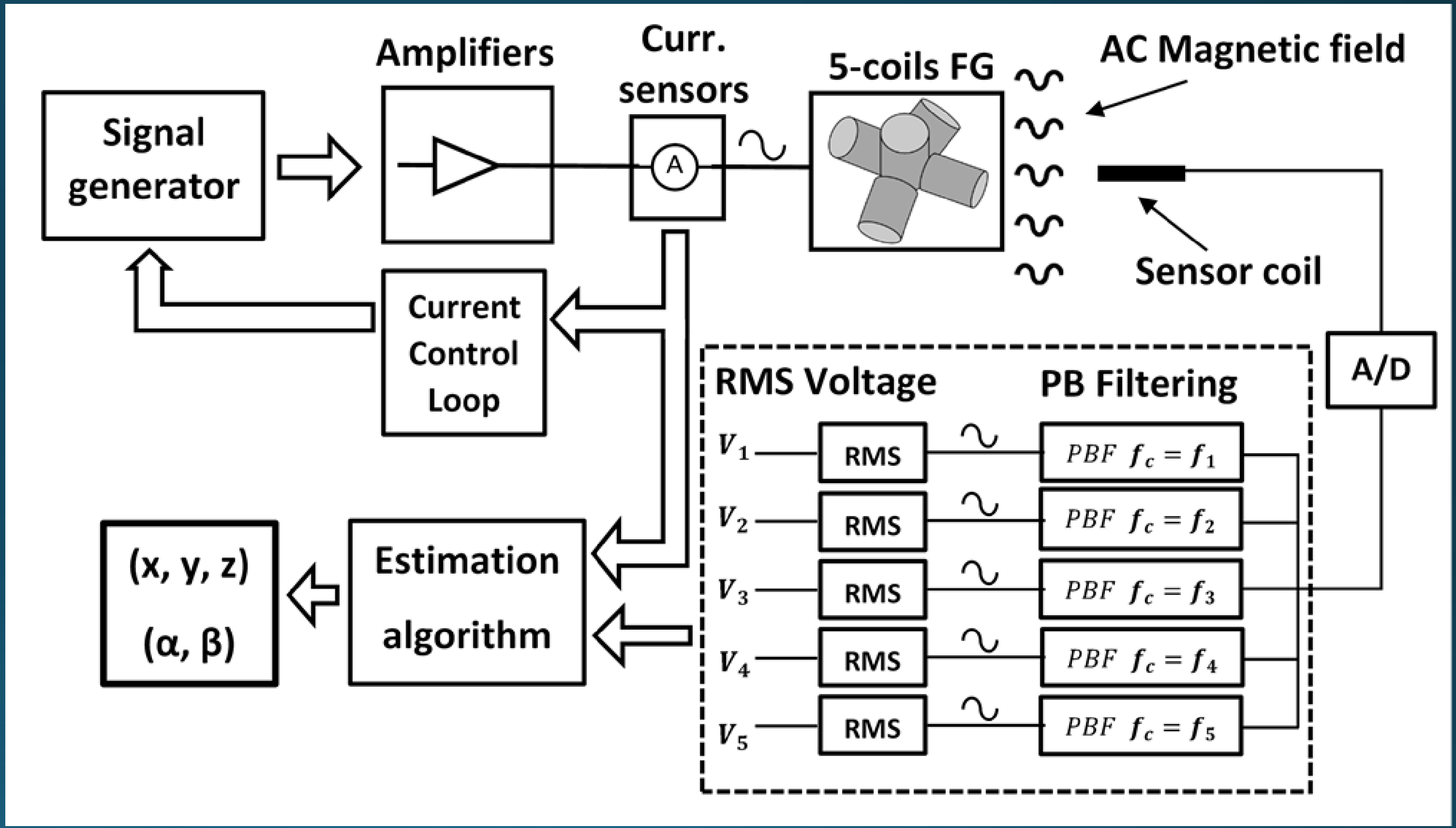


Experimental Setup

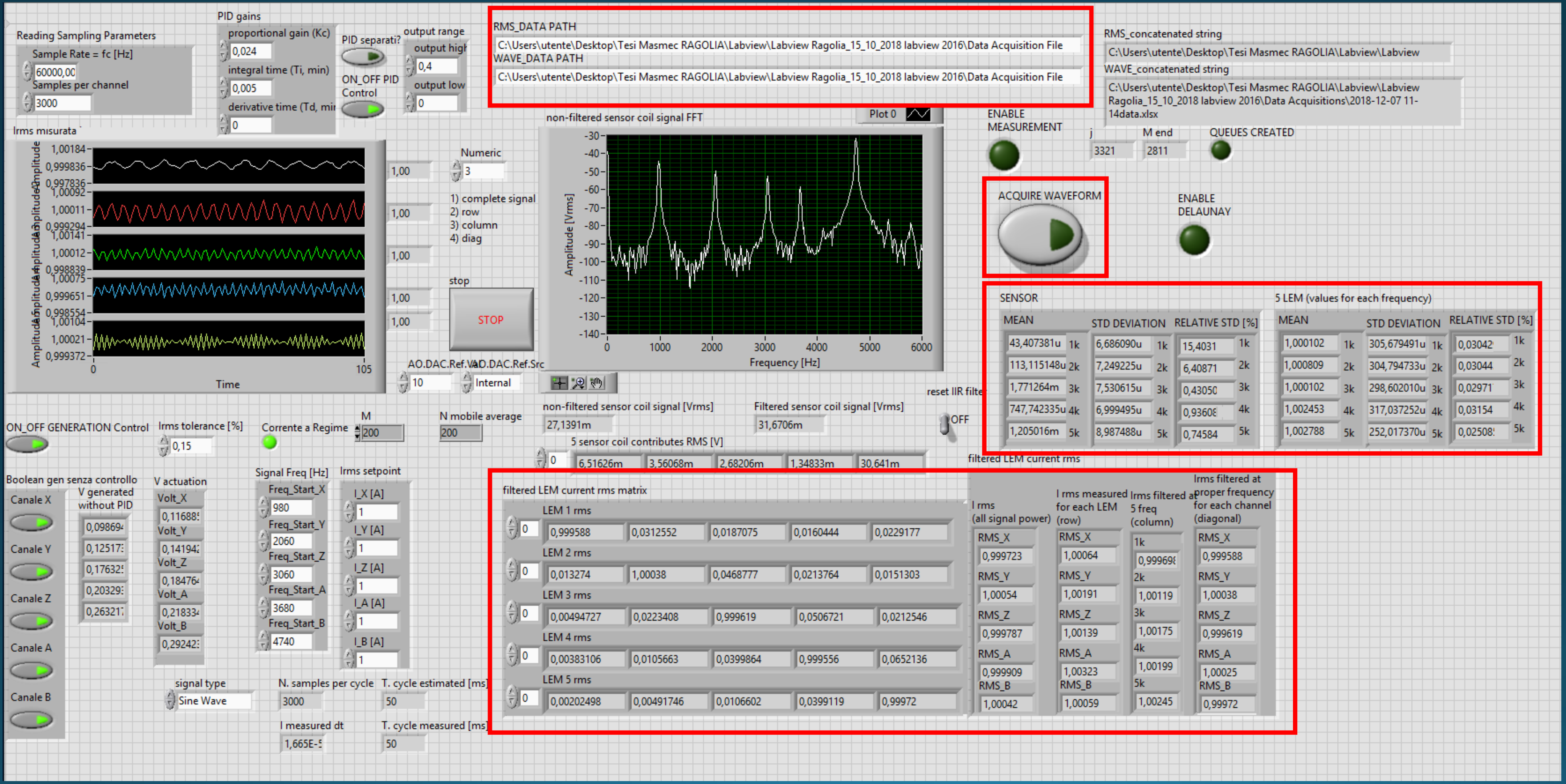


Experimental Setup

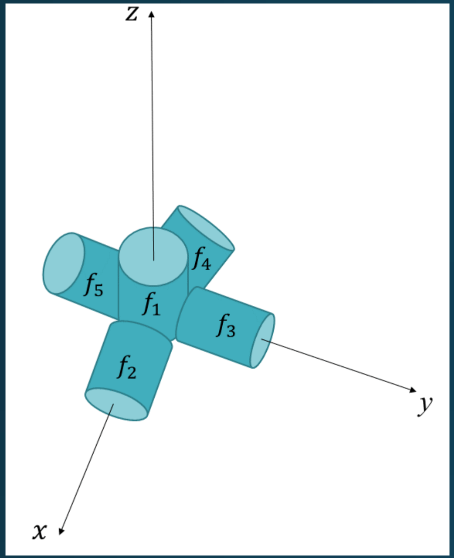


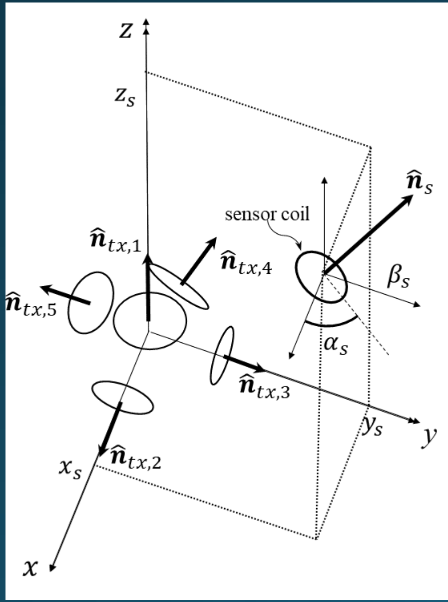


LABVIEW: control program



Magnetic dipole model





$$\boldsymbol{m}_{tx,i} = m_{tx,i}\,\hat{\boldsymbol{n}}_{tx,i},$$

$$m_{tx,i} = N_{tx,i}\,S_{tx,i}\,I_{ii}, \qquad S_{tx,i} = \pi\, r_{tx,i}^2$$

$$\mathbf{B}_i = \mathrm{B}_{i_x}\hat{\boldsymbol{x}} + \mathrm{B}_{i_y}\hat{\boldsymbol{y}} + \mathrm{B}_{i_z}\hat{\boldsymbol{z}} = \frac{\mu_0}{4\pi}\frac{m_{tx,i}}{d_i^3}\left[3(\hat{\boldsymbol{n}}_{tx,i}\cdot\hat{\boldsymbol{n}}_{d,i})\hat{\boldsymbol{n}}_{d,i} - \hat{\boldsymbol{n}}_{tx,i}\right]$$

$$\tilde{v}_i = 2\pi f_i\, N_s\, S_s\, \mathbf{B}_i \cdot \hat{\boldsymbol{n}}_s \qquad \hat{\boldsymbol{n}}_s = [cos(\alpha_s)cos(\beta_s),\ sin(\alpha_s)cos(\beta_s),\ sin(\beta_s)]^T$$

Double purpose:

Position reconstruction

$$F(\boldsymbol{\theta}, \boldsymbol{I}_{tx}) = \|\boldsymbol{v} - \tilde{\boldsymbol{v}}(\boldsymbol{\theta}, \boldsymbol{I}_{tx})\|_2^2$$

$$\hat{\boldsymbol{\theta}} = \arg\min F_2(\boldsymbol{\theta}, \boldsymbol{I}_{tx})$$

System analysis

$$\sigma_i \rightarrow \sigma_v \rightarrow e_p$$

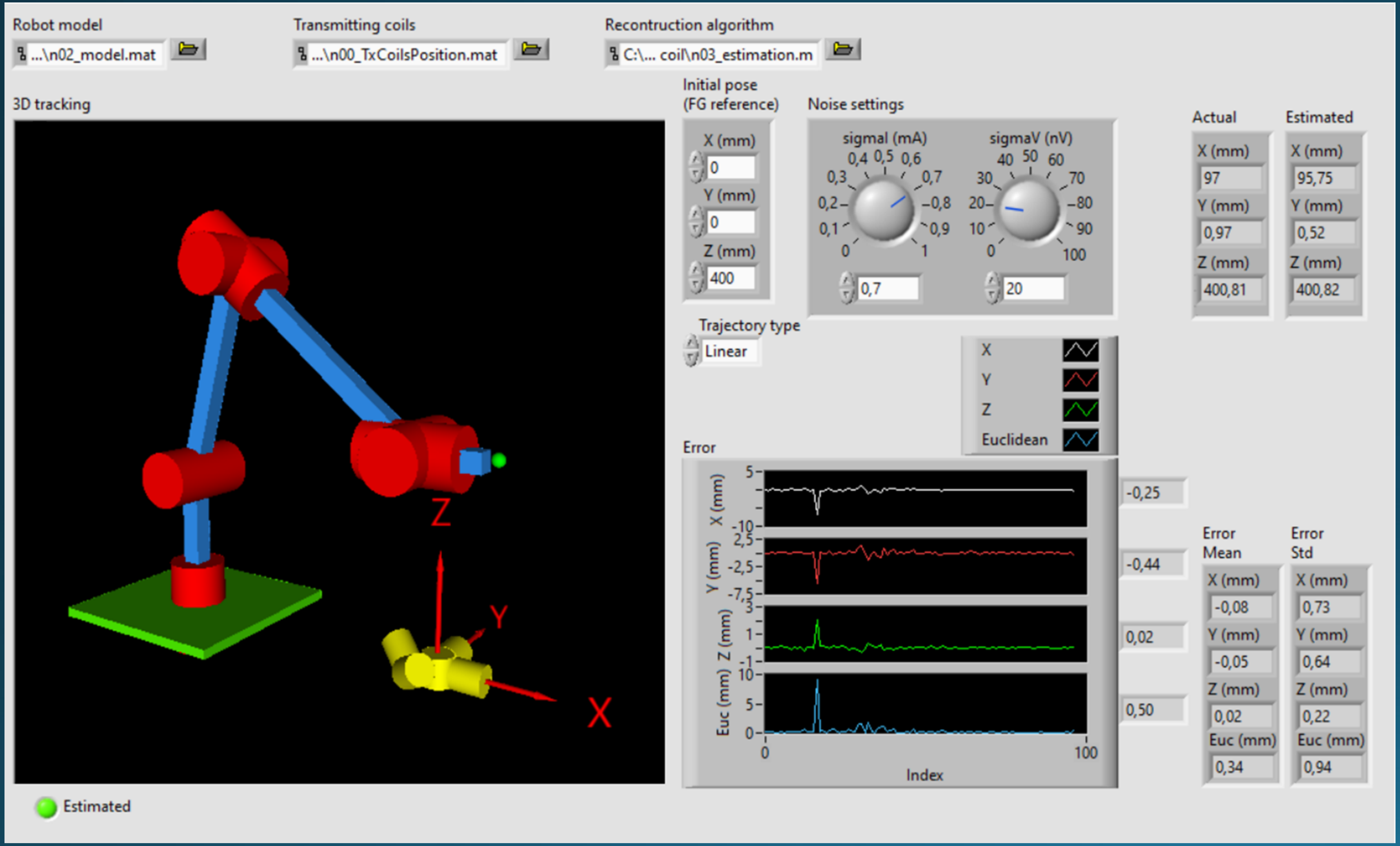
Arrangement of TX coils

Effect of DAQ systems

What affects tracking accuracy?

- EM interferences and field distortion
- DAQ system
- Arrangement of transmitting coils
- Motion-induced errors
- Limits of physical representation

Virtual platform

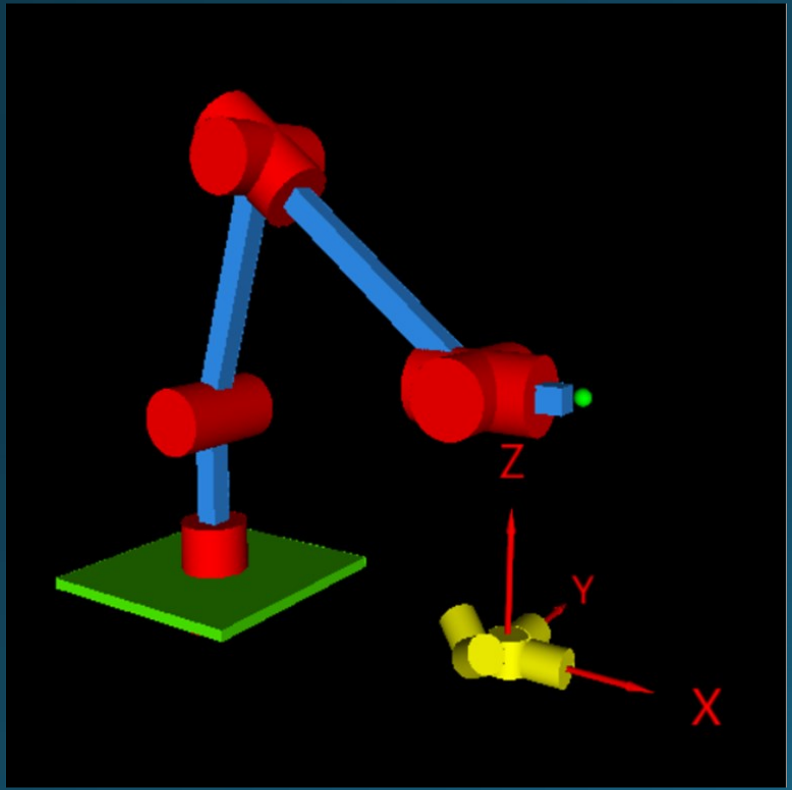


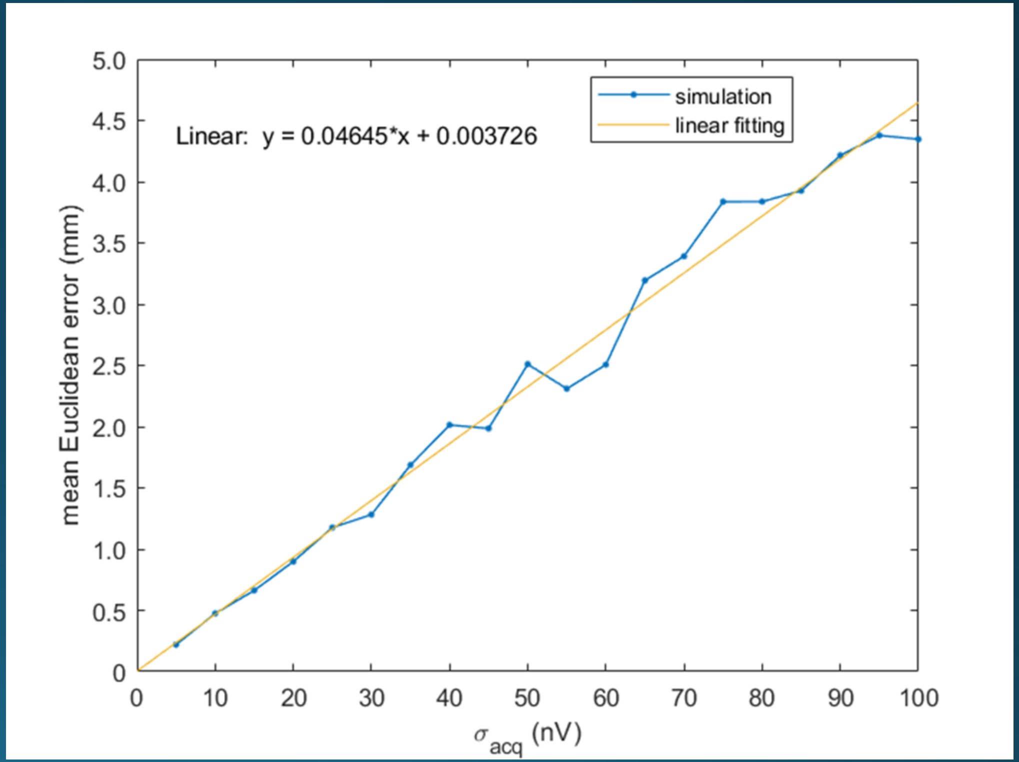
- model of the robot (e.g., CAD)
- geometrical arrangement and electrical properties of the transmitting coils of the FG
- reconstruction algorithm
- experimental or simulation mode (define custom trajectories)
- simulate measurement noise
- realtime plot and statistic of position tracking errors
- 3D view of tracking

Ragolia, M. A., Attivissimo, F., Di Nisio, A., Lanzolla, A. M. L., & Scarpetta, M. (2021). A virtual platform for real-time performance analysis of electromagnetic tracking systems for surgical navigation. Acta IMEKO, 10(4), 103-110. **doi:10.21014/acta_imeko.v10i4.1191**

Validation: DAQ device selection

Linear trajectory at 600 mm from FG

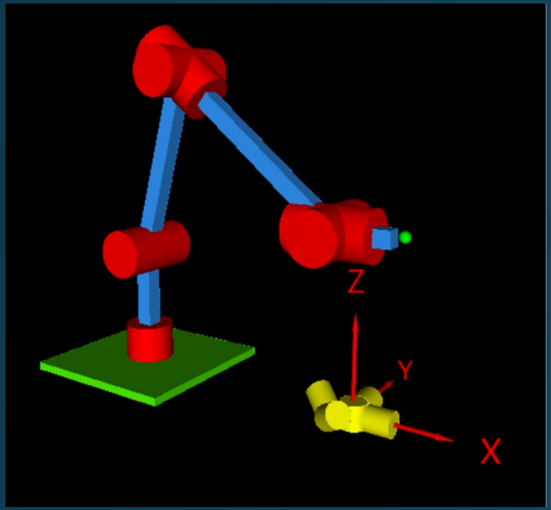


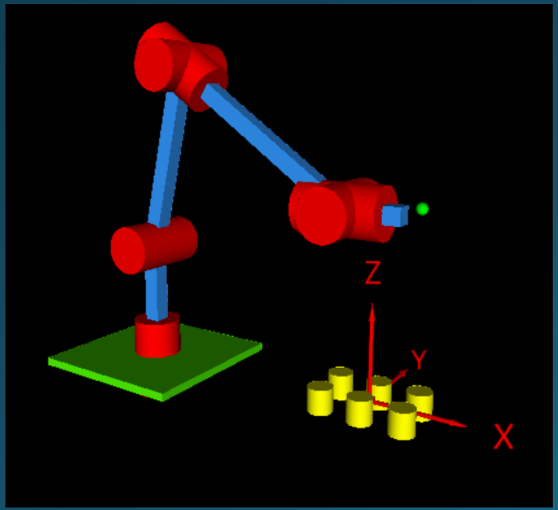


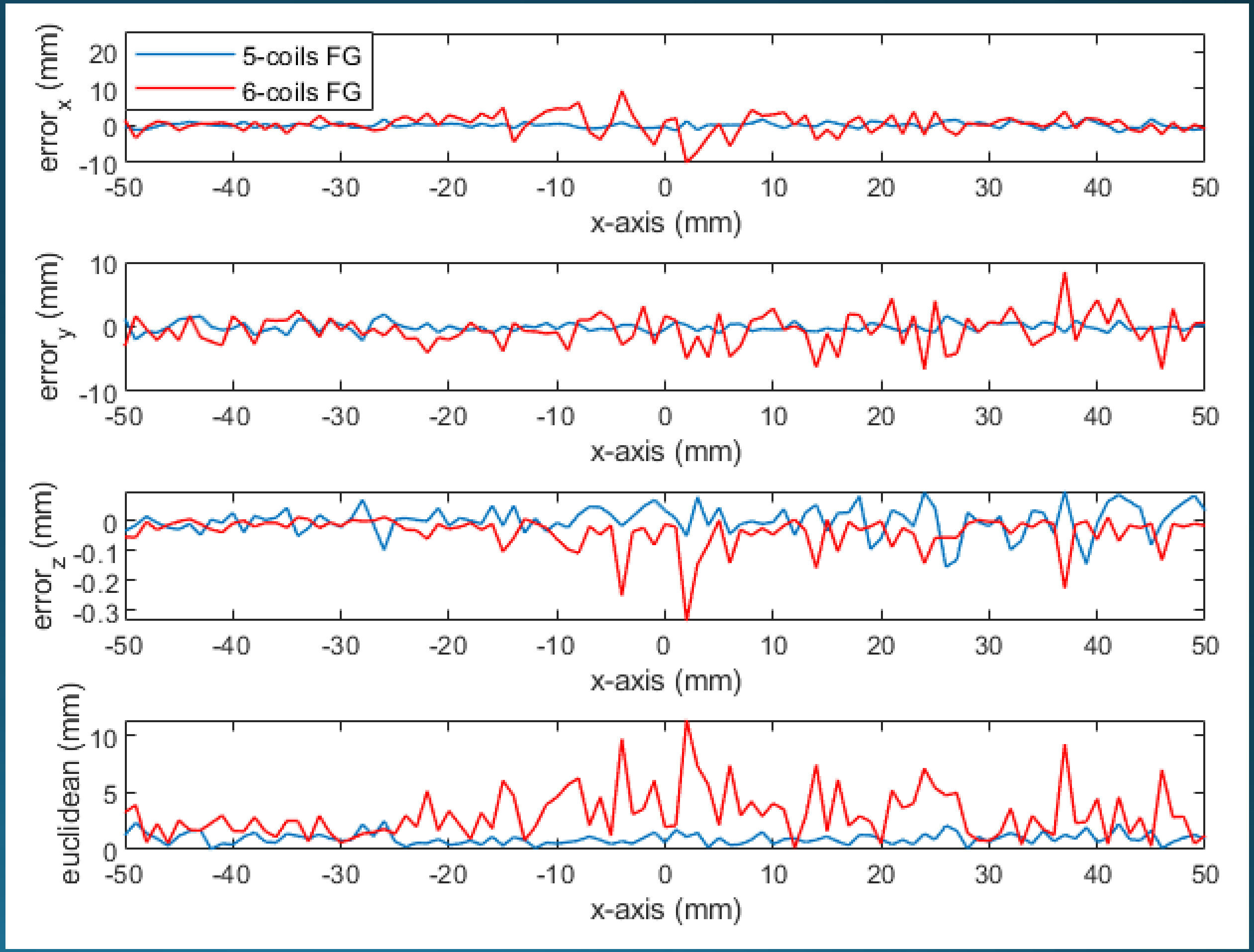
When we have to set up the measurement chain, it is important to select the DAQ device according to the accuracy requirements of the system. In particular, the noise floor indicated in the datasheet of the DAQ device is added to the induced voltage, thus it directly affects position repeatability and accuracy. In this way, the choice of a low-noise DAQ device can be evaluated for the purpose of improving performance. As expected, it can be observed an increasing position error with measurement noise, and the behavior is quite linear. This information could be particularly useful when choosing components, considering the trade-off between increased cost and required accuracy.

Validation: FG configuration comparison

Linear trajectory at 600 mm from FG

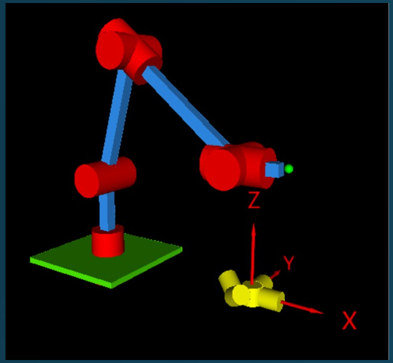


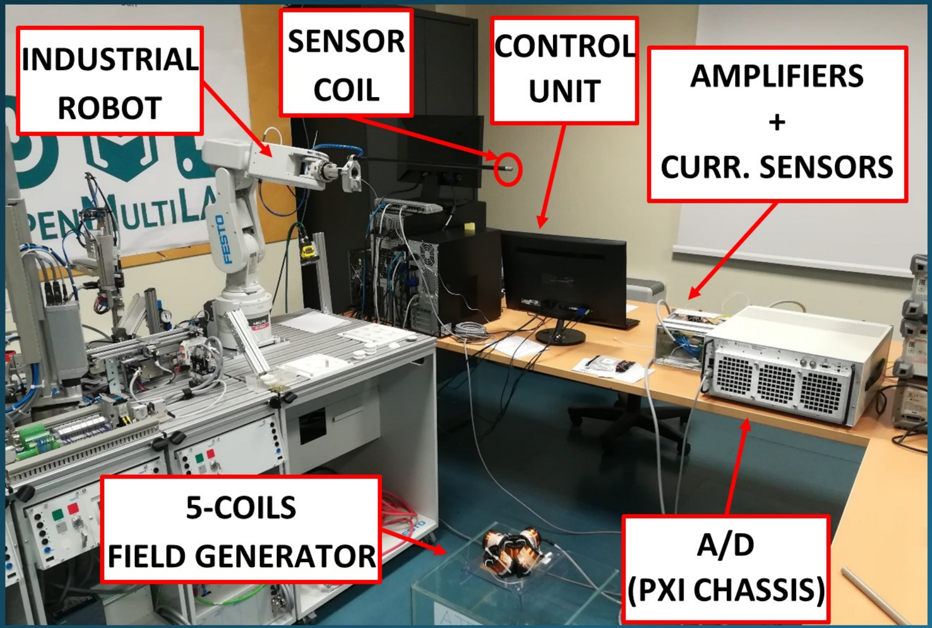


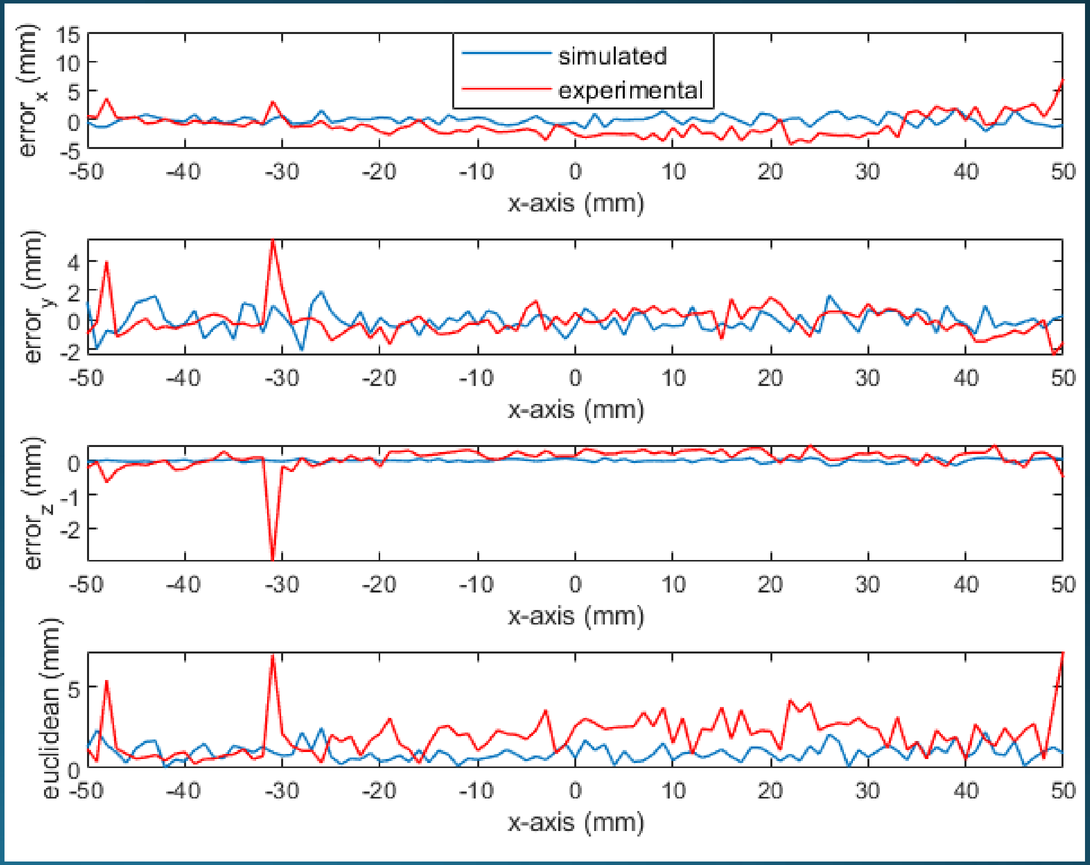


Validation: experimental

Linear trajectory at 600 mm from FG







Conclusions

- Virtual platform for real-time evaluation of EMTS performance

- Effect of system parameters

- Innovative EMTS prototype => place FG beyond 0.5 m
  - mean position error of $3\ mm$, at $60\ cm$ from FG

Future developments

- Other sources of error
- Dynamic system model
- Improved graphic and user interface

Related research papers

1) Ragolia, M. A., Attivissimo, F., Di Nisio, A., Lanzolla, A. M. L., & Scarpetta, M. (2021). A virtual platform for real-time performance analysis of electromagnetic tracking systems for surgical navigation. Acta IMEKO, 10(4), 103-110. doi:10.21014/acta_imeko.v10i4.1191
2) M. A. Ragolia, F. Attivissimo, A. Di Nisio, A. Maria Lucia Lanzolla and M. Scarpetta, "Reducing effect of magnetic field noise on sensor position estimation in surgical EM tracking," 2021 IEEE International Symposium on Medical Measurements and Applications (MeMeA), Neuchâtel, Switzerland, 2021, pp. 1-6, doi: 10.1109/MeMeA52024.2021.9478723.
3) F. Attivissimo, A. D. Nisio, A. M. L. Lanzolla and M. A. Ragolia, "Analysis of Position Estimation Techniques in a Surgical EM Tracking System," in IEEE Sensors Journal, vol. 21, no. 13, pp. 14389-14396, 1 July1, 2021, doi: 10.1109/JSEN.2020.3042647.
4) Andria, G.; Attivissimo, F.; Di Nisio, A.; Lanzolla, A.M.L.; Ragolia, M.A. Assessment of Position Repeatability Error in an Electromagnetic Tracking System for Surgical Navigation. Sensors 2020, 20, 961. doi:10.3390/s20040961
5) M. A. Ragolia, F. Attivissimo, A. Di Nisio and A. Maria Lucia Lanzolla, "Assessment of position repeatability of surgical EM tracking systems employing magnetic field model," 2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA), Bari, Italy, 2020, pp. 1-6, doi: 10.1109/MeMeA49120.2020.9137161.
6) M. A. Ragolia, F. Attivissimo, A. D. Nisio and A. Maria Lucia Lanzolla, "Evaluation of Position RMS Error from Magnetic Field Gradient for Surgical EM Tracking Systems," 2020 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Dubrovnik, Croatia, 2020, pp. 1-6, doi: 10.1109/I2MTC43012.2020.9128837.
7) M. A. Ragolia et al., "Performance analysis of an electromagnetic tracking system for surgical navigation," 2019 IEEE International Symposium on Medical Measurements and Applications (MeMeA), 2019, pp. 1-6, doi: 10.1109/MeMeA.2019.8802220.

THANKS FOR YOUR ATTENTION!!

Questions, comments and suggestions are welcome!

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