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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



Tracking systems

Optical

- (+) high resolution
large volume
- (-) direct line-of-sight
No intra-corporeal interventions

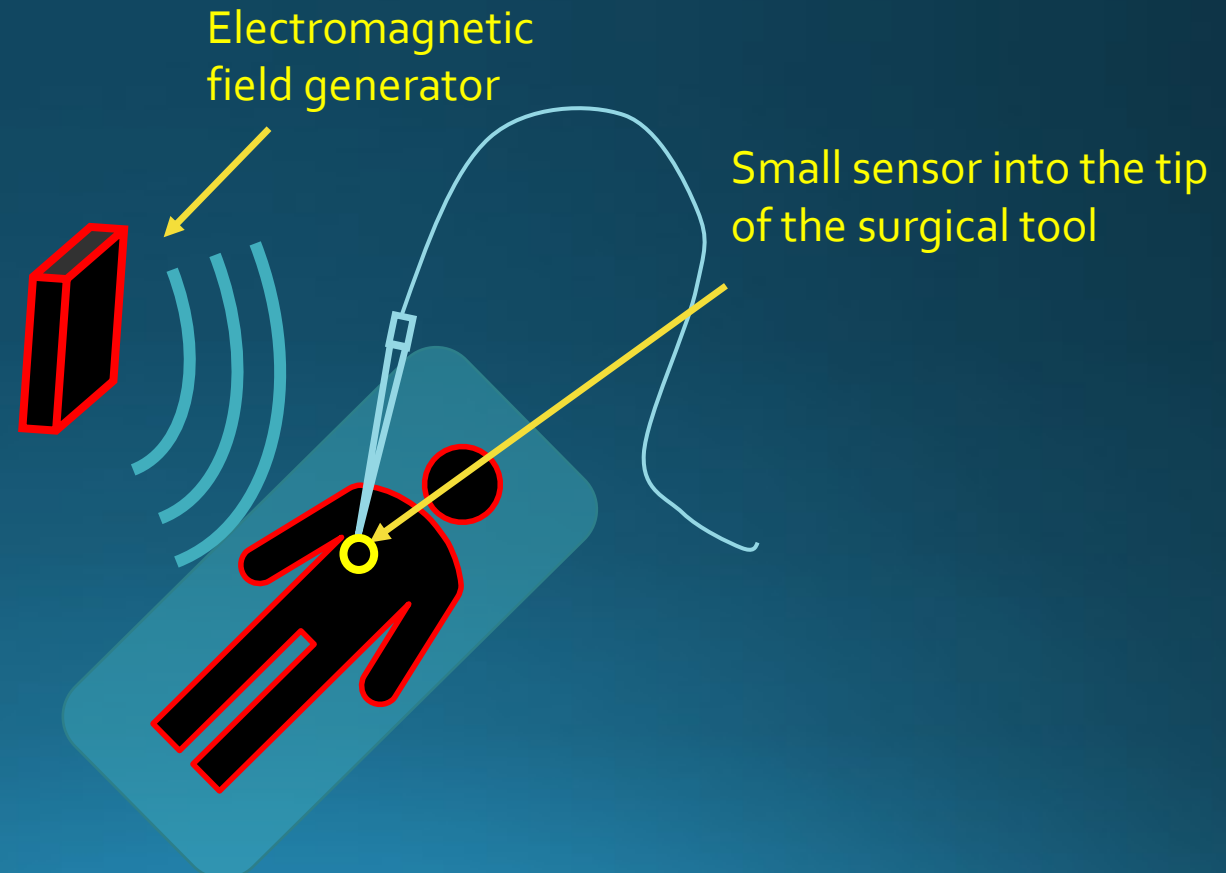
Electromagnetic

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

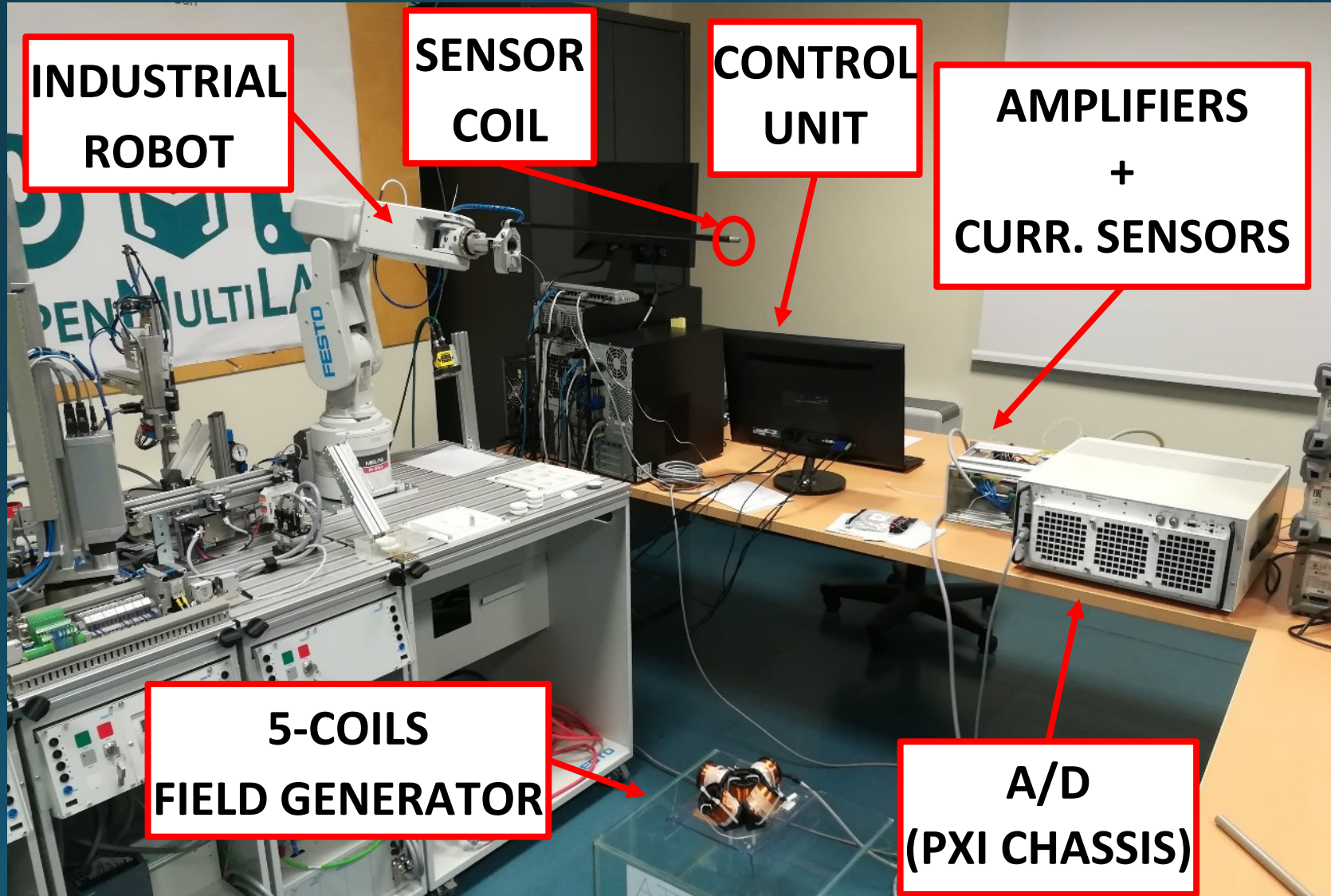
Tracking systems

Electromagnetic

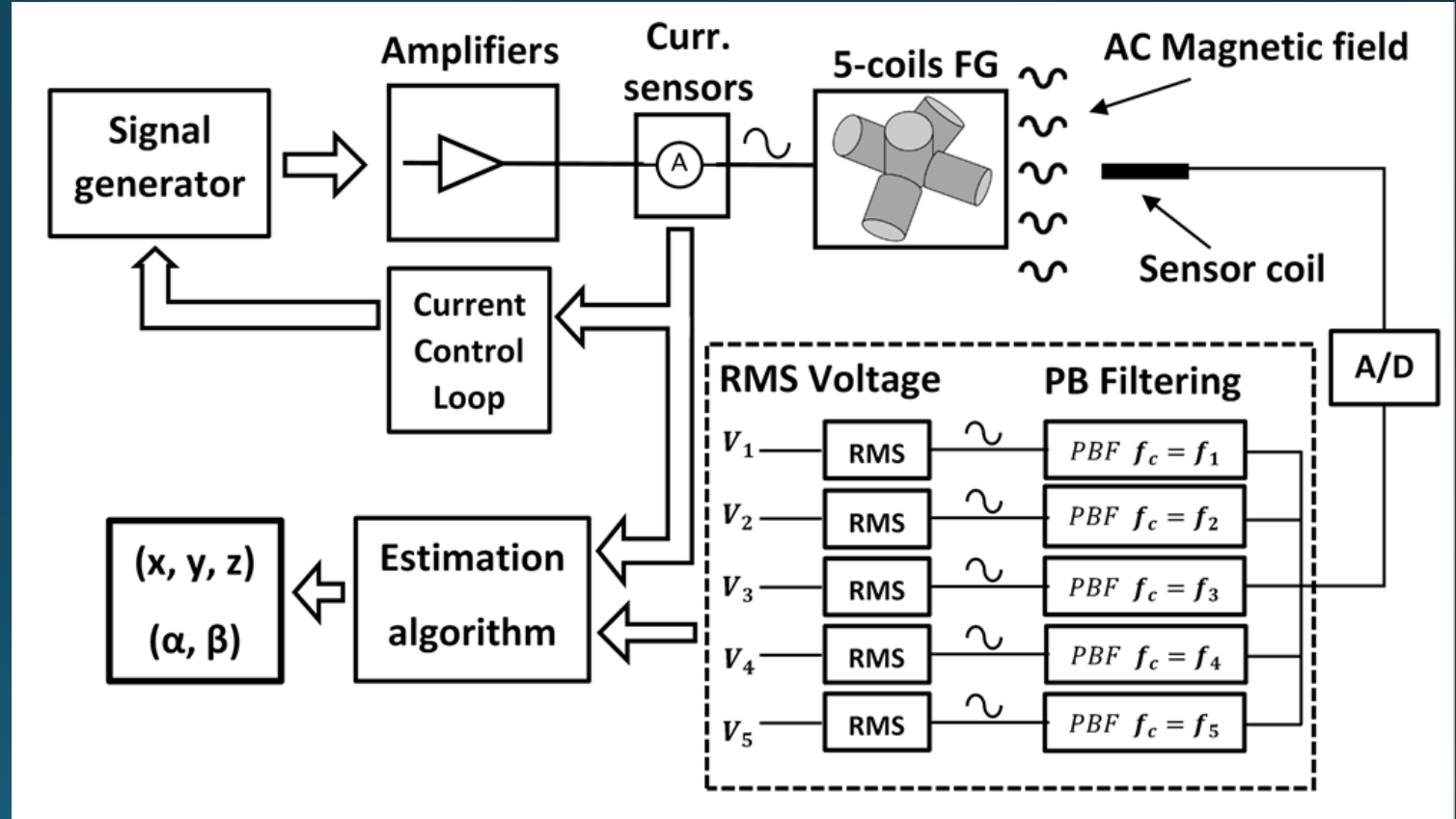
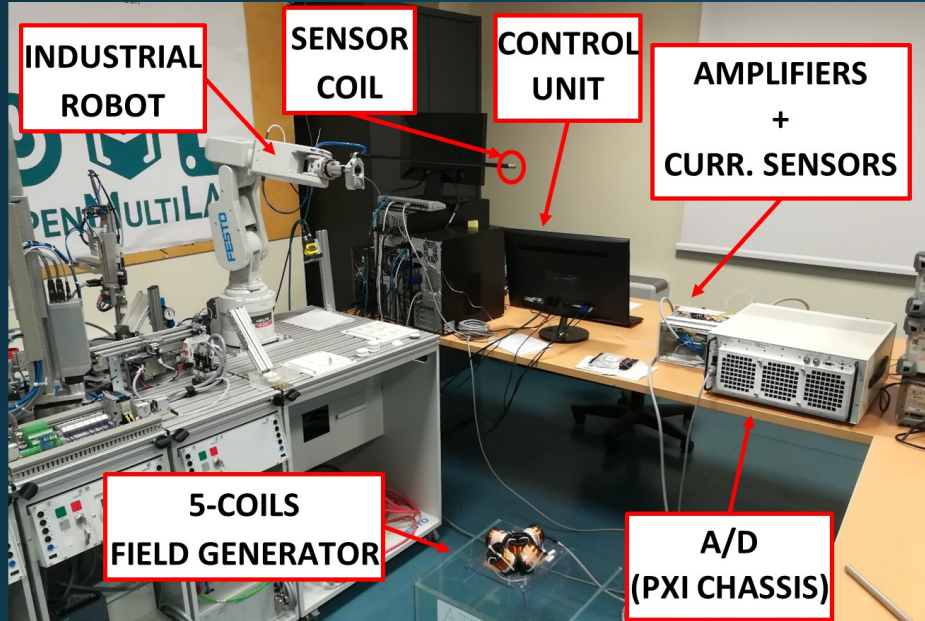
- (+) No direct line-of-sight
Small sensor inside the instrument
- (-) Sensitivity to EM interferences
Short range: **< 0.5 m**
Generator near to the patient
⇒ impediment for the surgeon!



Experimental Setup



Experimental Setup



LABVIEW: control program

Reading Sampling Parameters

Sample Rate = fc [Hz]
60000,00

Samples per channel
3000

PID gains

proportional gain (Kc)
0,024

integral time (Ti, min)
0,005

derivative time (Td, min)
0

output range

output high
0,4

output low
0

RMS_DATA PATH

C:\Users\utente\Desktop\Tesi Masmec RAGOLIA\Labview\Labview Ragolia_15_10_2018 labview 2016\Data Acquisition File

WAVE_DATA PATH

C:\Users\utente\Desktop\Tesi Masmec RAGOLIA\Labview\Labview Ragolia_15_10_2018 labview 2016\Data Acquisition File

RMS_concatenated string

C:\Users\utente\Desktop\Tesi Masmec RAGOLIA\Labview\Labview

WAVE_concatenated string

C:\Users\utente\Desktop\Tesi Masmec RAGOLIA\Labview\Labview Ragolia_15_10_2018 labview 2016\Data Acquisitions\2018-12-07 11-14data.xlsx

Irms misurata

non-filtered sensor coil signal FFT

ENABLE MEASUREMENT

ACQUIRE WAVEFORM

ENABLE DELAUNAY

SENSOR			5 LEM (values for each frequency)		
MEAN	STD DEVIATION	RELATIVE STD [%]	MEAN	STD DEVIATION	RELATIVE STD [%]
43,407381u	1k	6,686090u	1k	15,4031	1k
113,115148u	2k	7,249225u	2k	6,40871	2k
1,771264m	3k	7,530615u	3k	0,43050	3k
747,742335u	4k	6,999495u	4k	1,002453	4k
1,205016m	5k	8,987488u	5k	1,002788	5k

ON_OFF GENERATION Control

Irms tolerance [%]

0,15

Corrente a Regime

M: 200

N mobile average

200

non-filtered sensor coil signal [Vrms]

27,1391m

Filtered sensor coil signal [Vrms]

31,6706m

5 sensor coil contributes RMS [V]

6,51626m 3,56068m 2,68206m 1,34833m 30,641m

Boolean gen senza controllo

Canale X:

Canale Y:

Canale Z:

Canale A:

Canale B:

V actuation

Volt_X: 0,11688

Volt_Y: 0,098694

Volt_Z: 0,12517

Volt_A: 0,17632

Volt_B: 0,20329

Volt_C: 0,26321

Volt_D: 0,29242

Signal Freq [Hz]

Freq_Start_X: 980

Freq_Start_Y: 2060

Freq_Start_Z: 3060

Freq_Start_A: 3680

Freq_Start_B: 4740

Irms setpoint

L_X [A]: 1

L_Y [A]: 1

L_Z [A]: 1

L_A [A]: 1

L_B [A]: 1

L_C [A]: 1

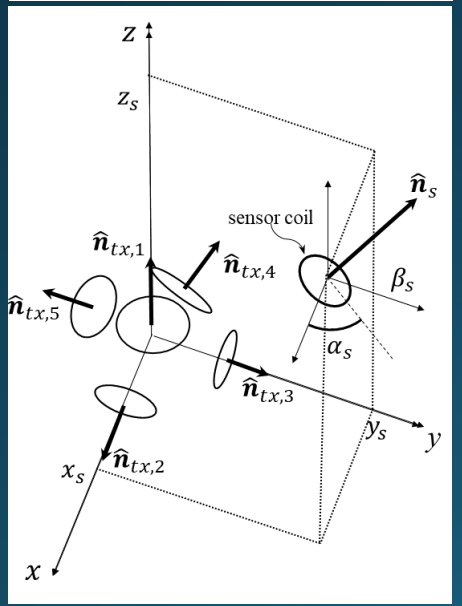
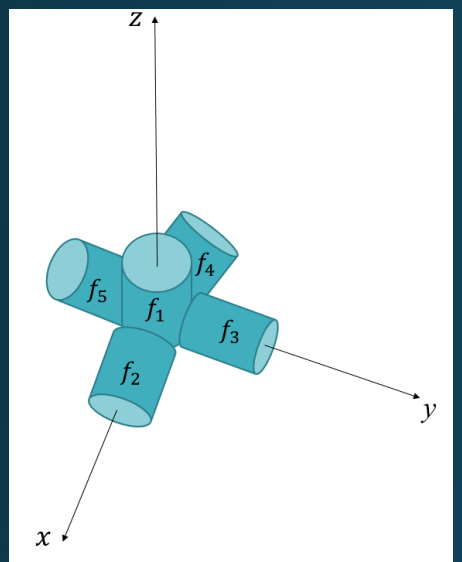
filtered LEM current rms matrix

LEM 1 rms	0,999588	0,0312552	0,0187075	0,0160444	0,0229177
LEM 2 rms	0,013274	1,00038	0,0468777	0,0213764	0,0151303
LEM 3 rms	0,00494727	0,0223408	0,999619	0,0506721	0,0212546
LEM 4 rms	0,00383106	0,0105663	0,0399864	0,999556	0,0652136
LEM 5 rms	0,00202498	0,00491746	0,0106602	0,0399119	0,99972

filtered LEM current rms

Irms (all signal power)	Irms measured for each LEM (row)	Irms filtered at proper frequency for each channel (column)	Irms filtered at proper frequency for each channel (diagonal)
RMS_X	0,999723	1,00064	0,99969
RMS_Y	1,00054	1,00191	1,00119
RMS_Z	0,999787	1,00139	1,00175
RMS_A	0,999909	1,00323	1,00199
RMS_B	1,00042	1,00059	1,00245

Magnetic dipole model



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

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

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

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

Double purpose:

Position reconstruction

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

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

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

Robot model: ...\\n02_model.mat

Transmitting coils: ...\\n00_TxCoilsPosition.mat

Reconstruction algorithm: C:\\... coil\\n03_estimation.m

Initial pose (FG reference): X (mm) 0, Y (mm) 0, Z (mm) 400

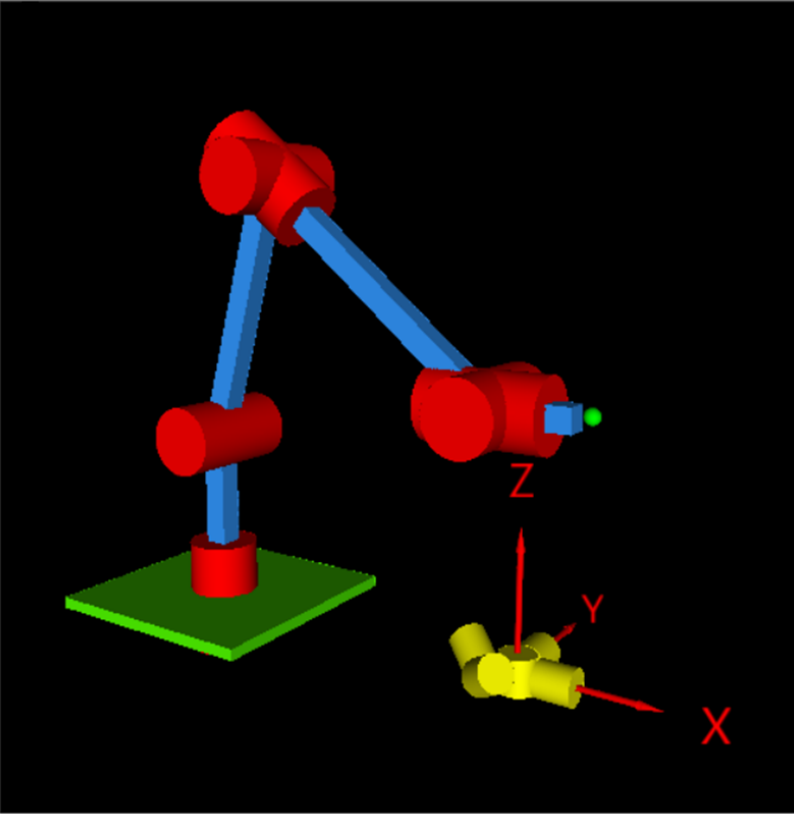
Noise settings: signal (mA) 0,7, sigmaV (nV) 20

Actual	Estimated
X (mm)	X (mm)
97	95,75
Y (mm)	Y (mm)
0,97	0,52
Z (mm)	Z (mm)
400,81	400,82

Trajectory type: Linear

Error:

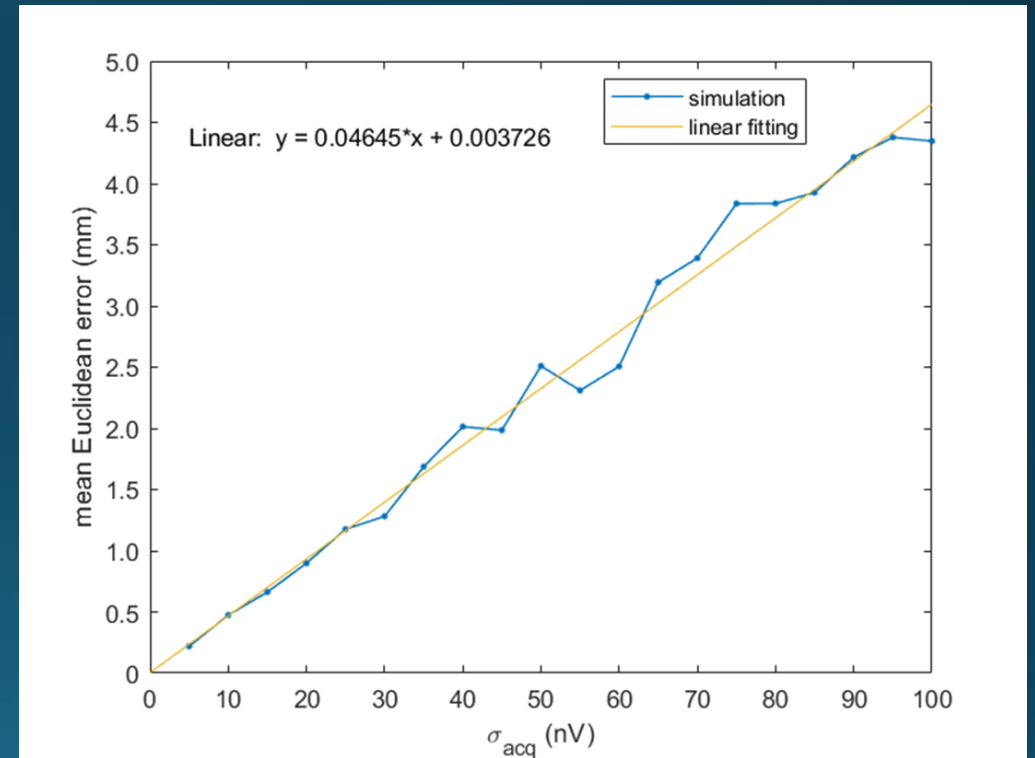
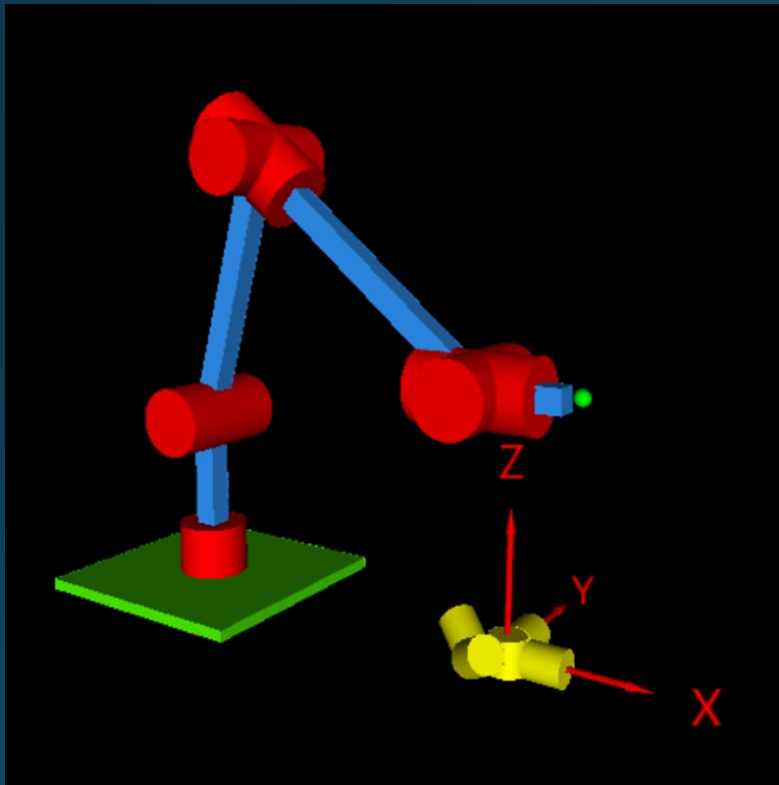
Error Mean	Error Std
X (mm)	X (mm)
-0,08	0,73
Y (mm)	Y (mm)
-0,05	0,64
Z (mm)	Z (mm)
0,02	0,22
Euc (mm)	Euc (mm)
0,34	0,94



Estimated

Validation: DAQ device selection

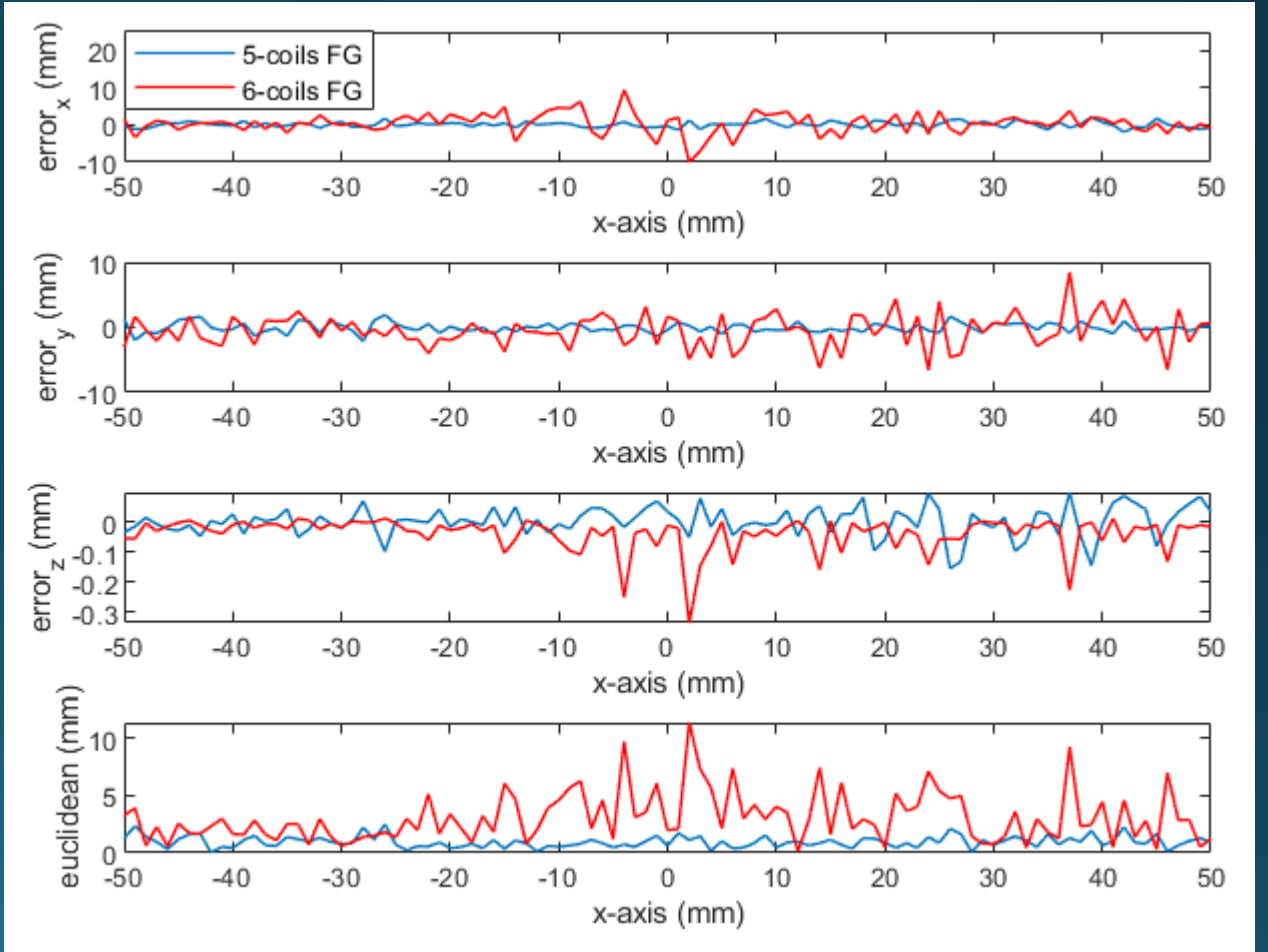
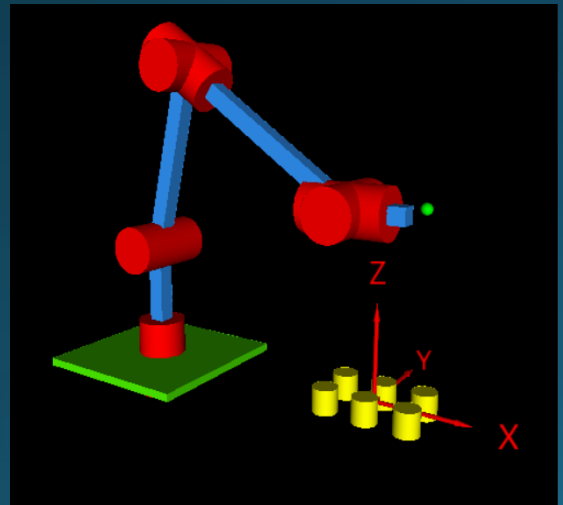
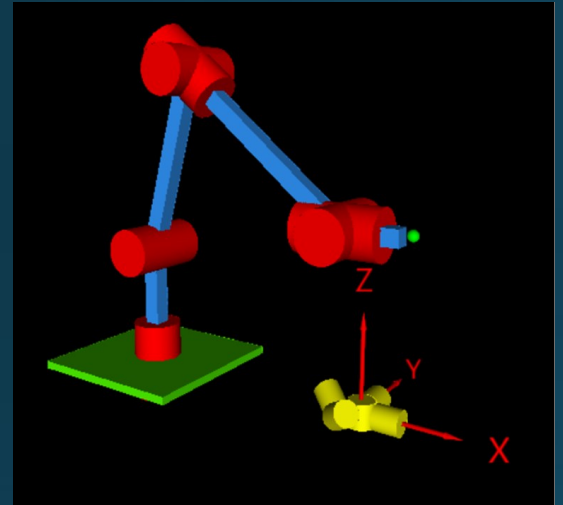
Linear trajectory at 600 mm from FG



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.

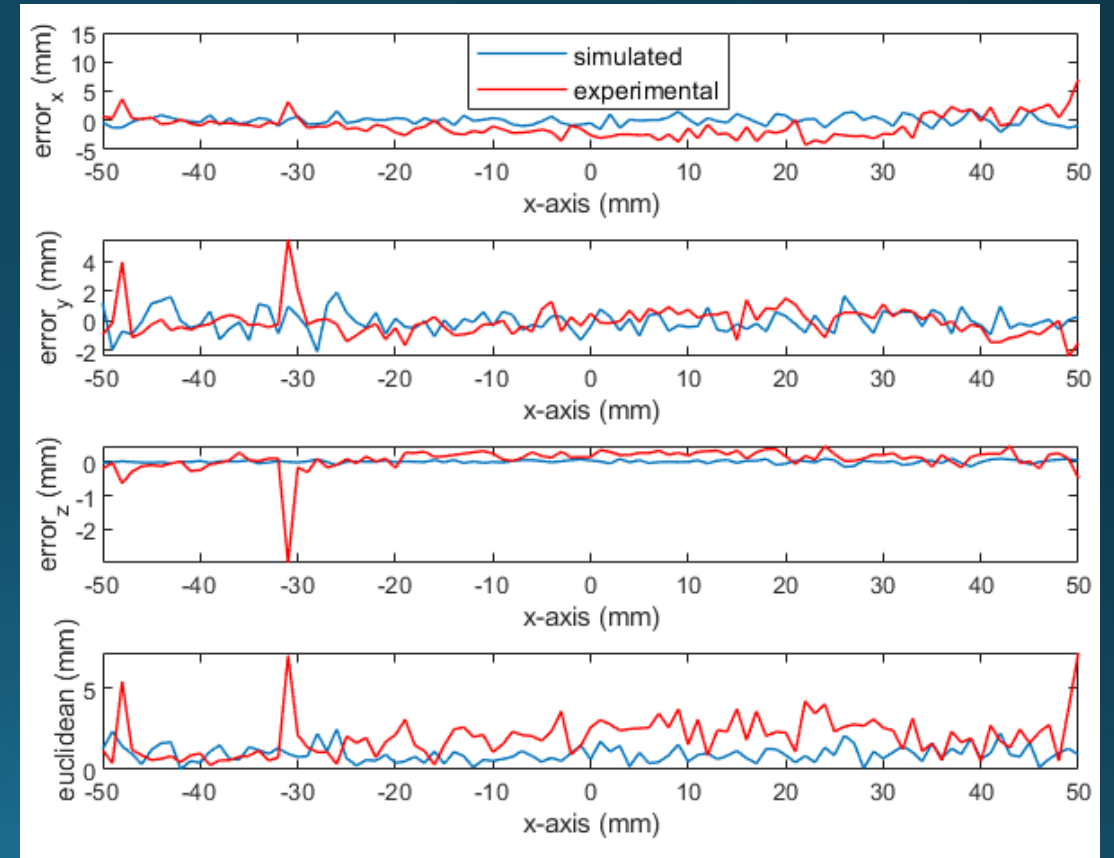
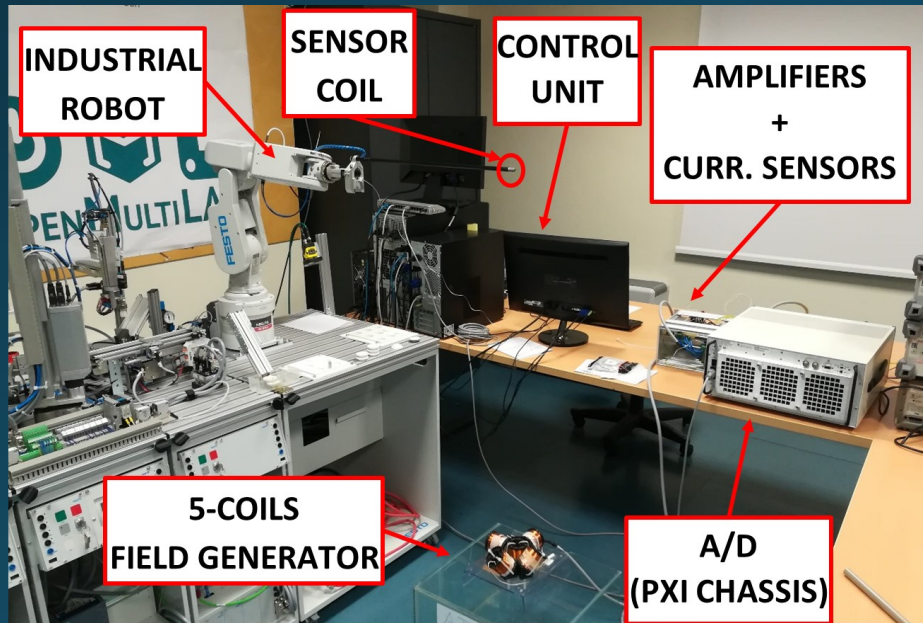
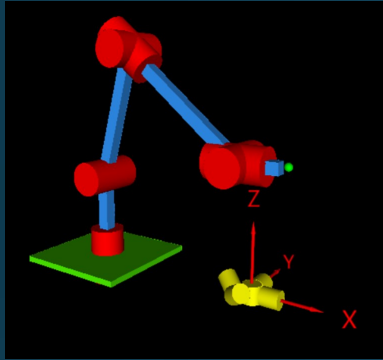
Validation: FG configuration comparison

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](https://doi.org/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](https://doi.org/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 July 1, 2021, doi: [10.1109/JSEN.2020.3042647](https://doi.org/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](https://doi.org/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](https://doi.org/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](https://doi.org/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](https://doi.org/10.1109/MeMeA.2019.8802220).



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THANKS FOR YOUR ATTENTION!!

Questions, comments and suggestions are welcome!

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