Real-time 3D Microwave Tomography of Brain Stroke Status Using Low-computing Demand

Cristina Origlia

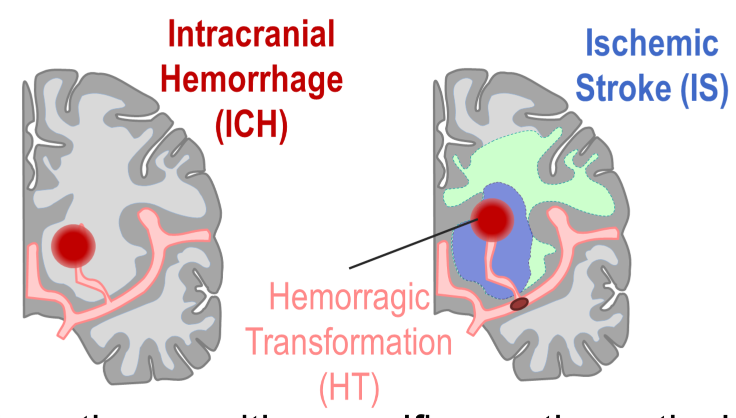
Supervisors: Prof. Francesca Vipiana, Dr. Jorge A. Tobon Vasquez

ScuDo – Scuola di Dottorato – Doctoral School – WHAT YOU ARE, TAKES YOU FAR

37th Cycle

Research context and motivation

- **Brain stroke** affects more than 10 millions people per year. With the limitations of conventional methods, prevailing medical issues are:
  - accelerating stroke **detection**;
  - **classifying** ischemic and hemorrhagic cases;
  - continuously **monitoring** stroke status.

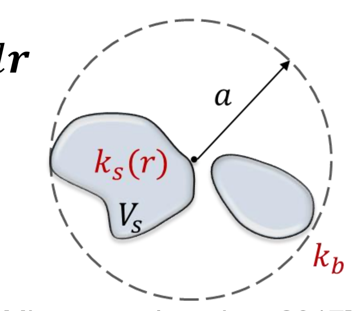


- **Real-time imaging** methods achieve short reconstruction times with specific mathematical techniques at the expense of quantitative accuracy. They solve **linearized models** of scattering such as those based on the Born or Rytov's approximations.

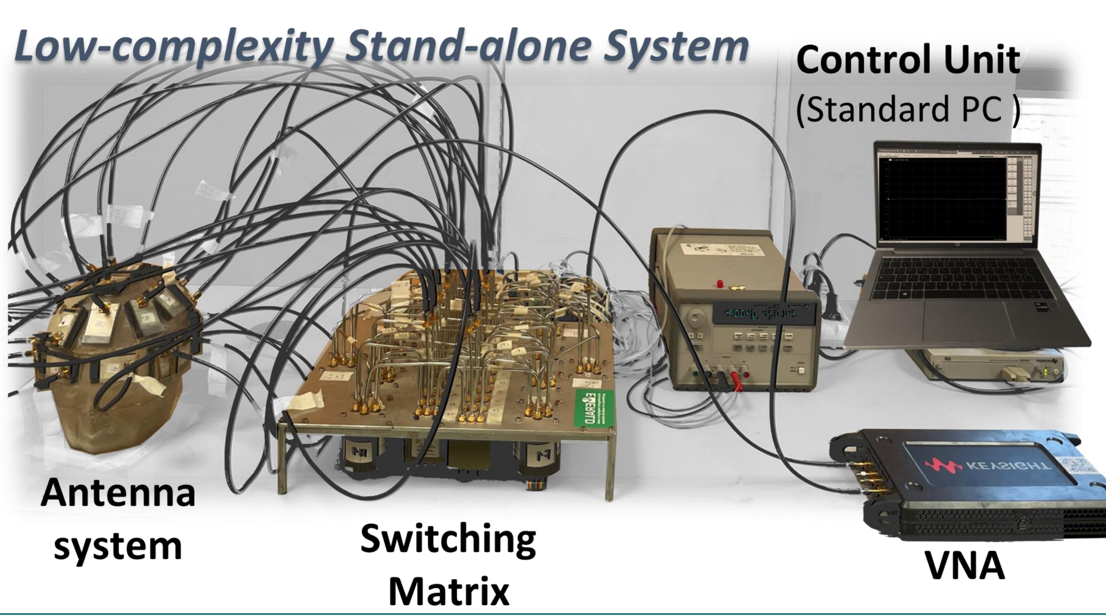
Forward model of scattering: $\Delta S_{p,q} = -\frac{j\omega\varepsilon_b}{2a_p a_q}\int_D \underbrace{\Delta\varepsilon(\boldsymbol{r})}_{\text{unknown}} \boldsymbol{E}_p^{inc}(\boldsymbol{r}) \cdot \boldsymbol{E}_q^{tot}(\boldsymbol{r}, \Delta\varepsilon(\boldsymbol{r}))\, d\boldsymbol{r}$

Born's approximation: $\boldsymbol{E}_q^{tot}(\boldsymbol{r}, \Delta\varepsilon(\boldsymbol{r})) \approx \boldsymbol{E}_q^{inc}(\boldsymbol{r}), \quad a^2|k_s^2(\boldsymbol{r}) - k_b^2| \ll 1, \boldsymbol{r} \in V_s$

Rytov's approximation: $\boldsymbol{E}_q^{tot}(\boldsymbol{r}, \Delta\varepsilon(\boldsymbol{r})) \approx \boldsymbol{E}_q^{inc}(\boldsymbol{r})e^{\psi}, \ (k_s^2(\boldsymbol{r}) - k_b^2)/k_b^2 < 1, \boldsymbol{r} \in V_s$



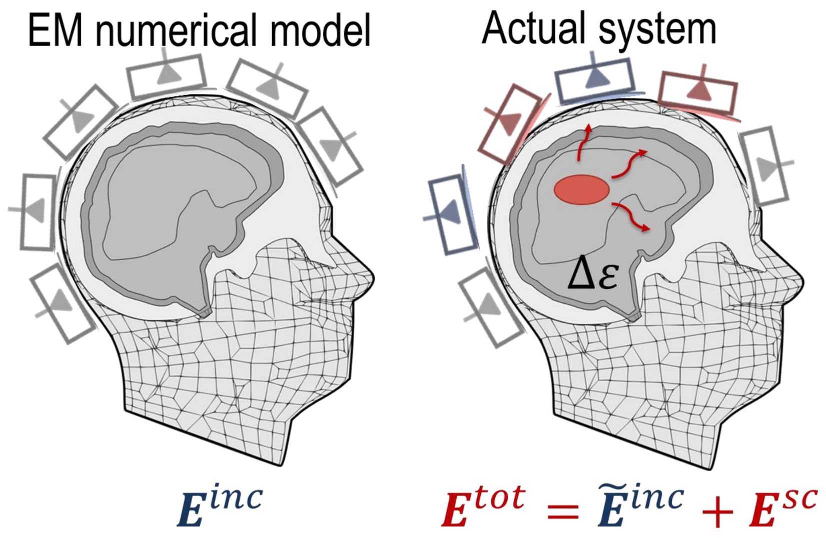
[Nikolova, Introduction to Microwave Imaging, 2017]



- 22 printed-monopole antenna system
- working frequency: 1GHz
- TSVD+Born inversion algorithm (~2sec. solving time)
- Realistic phantom for experiments in pre-clinical validation

Addressed research questions/problems

- Most inversion strategies assume a priori knowledge of a reference electromagnetic scenario, where $\boldsymbol{E}^{inc}$ is computed. Thus, **modeling errors** due to inaccuracies in the physical system (or uncertainties due to patient's anatomy) lead to unwanted artifacts in the output image.
- System calibration is necessary to add actual information on the real behaviour of the system.



- If the scatterer **violates Born's accuracy limits** images contain artifacts which reflect differences between $\boldsymbol{E}^{tot}$ and $\boldsymbol{E}^{inc}$, rather than contrast $\Delta\varepsilon$.
- Evaluate Born's approximation assumption: does the **quantitative information** still have clinical relevance? What is the expected error and how can we mitigate the effects?
- Goal implementation: **real-time** stroke monitoring.
- Acquisition of **experimental data** on life-like **multitissue model**. Variety of tissues electromagnetic properties alterates the penetration of the radiation and notoriously affects the imaging process.

Publications

- Published works: 4 conferences, 2 chapters in volume

[1] Origlia, C., Rodriguez-Duarte, D.O., Gugliermino, M., Tobon Vasquez, J.A., Scapaticci, R., Crocco, L., and Vipiana, F., "Experimental validation of a microwave scanner for bain stroke monitoring in realistic head models ", 2023 IEEE APS/URSI, Portland, Oregon, USA, 2023.
Paper awarded with the *IEEE Antennas and Propagation Society 2023 C.J. Reddy Travel Grant for Graduate Students*

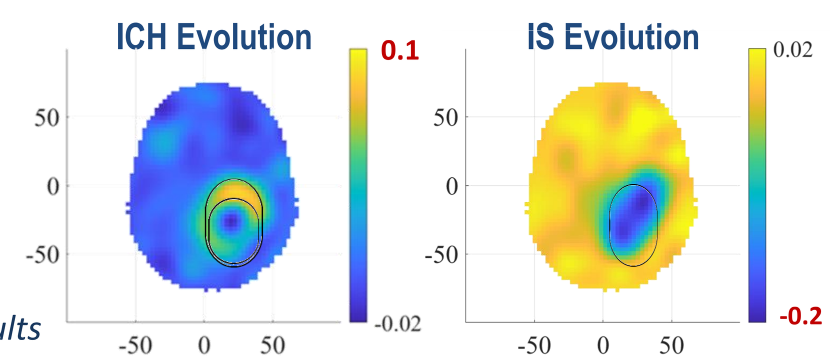
[2] Origlia, C., Rodriguez-Duarte, D.O., Vipiana F., Real-time 3D microwave tomography of brain stroke status using low-computing demand, URSI International Symposium on Electromagnetic Theory 2023, Vancouver, BC, Canada, 2023.
Paper awarded with the *URSI EMTS 2023 Young Scientist Award* and the *Honorable mention URSI EMTS 2023 Young Scientist Best Paper Award*

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement No 764479

Novel contributions

- **Hybrid simulation-measurement calibration**: $\boldsymbol{E}^{inc}$ is retrieved as linear combination of synthetic basis functions representing the system, through measurement-derived coefficients.
- An **ad-hoc dynamic phantom** can mimic stroke evolution: it has a stable multilayer external structure and an internal liquid cavity where the stroke-like target can expand (Materials: mixture of graphite powder/urethane rubber, 3-D printing filament filled with carbon fibers. alchol-water-salt.
- **TSVD + Born's** algorithm has proved its potential for **quantitative evaluation**, useful in stroke type differentiation. The information on real and imaginary part of the dielectric contrast function can be used to distinguish ICH and IS.

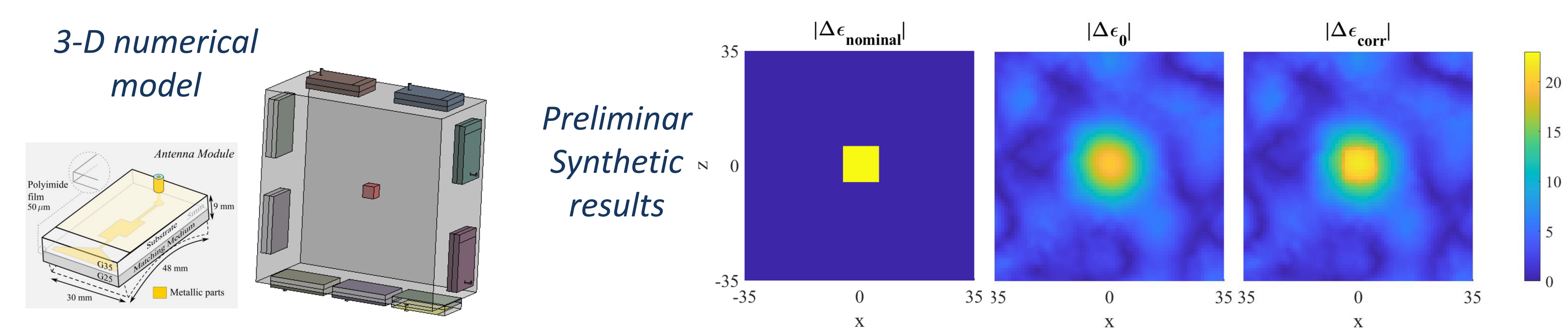


- A **Rytov-based correction factor** is used to update the initial contrast guess (from linear inversion):

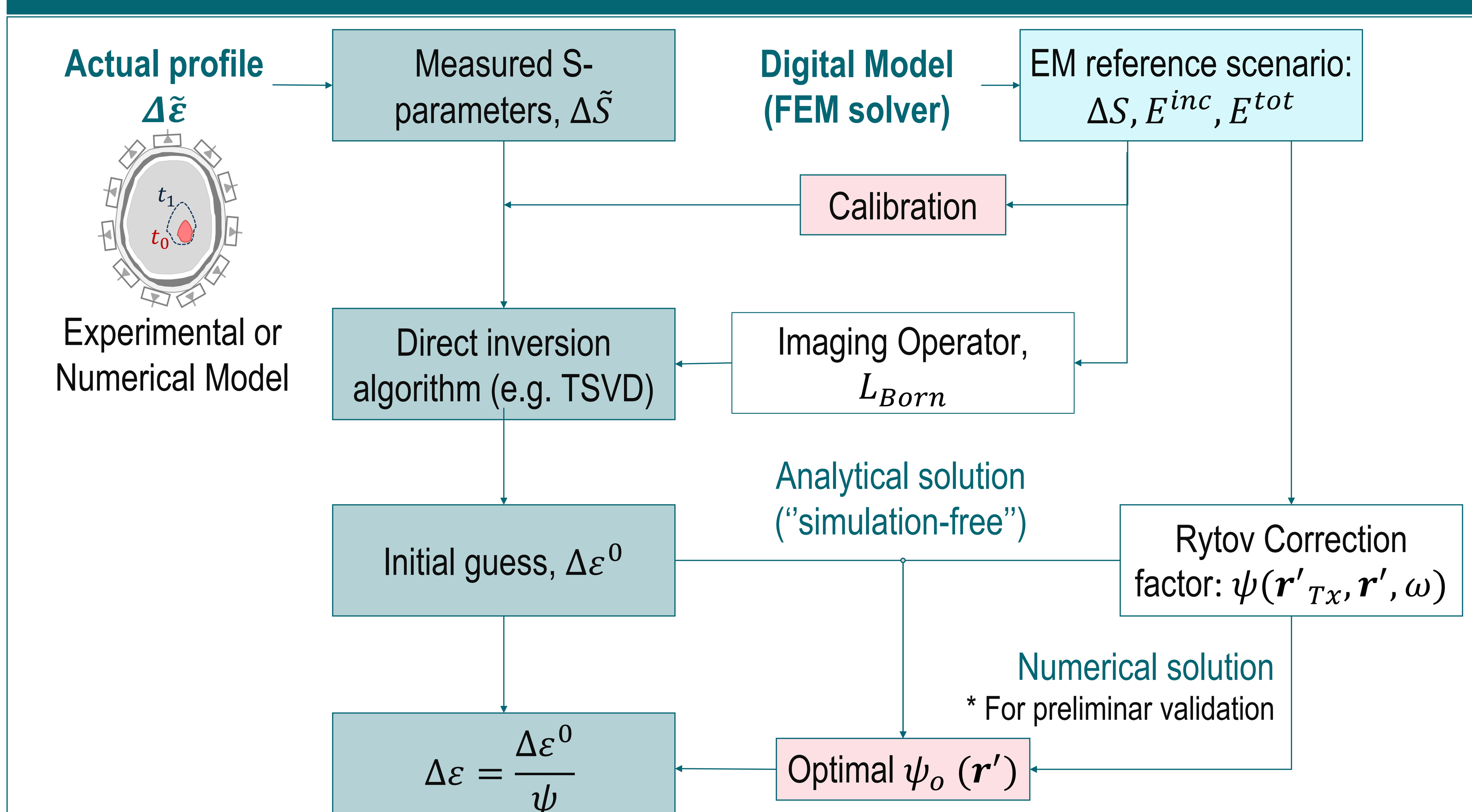
$$\boldsymbol{E}_q^{tot}(\boldsymbol{r}, \Delta\varepsilon(\boldsymbol{r}), \omega) \approx \boldsymbol{E}_q^{inc}(\boldsymbol{r}, \Delta\varepsilon(\boldsymbol{r}), \omega) \cdot \psi(\boldsymbol{r}, \Delta\varepsilon(\boldsymbol{r}), \omega) \quad (1)$$

$$\Delta\varepsilon(\boldsymbol{r}) = \Delta\varepsilon^0(\boldsymbol{r})/\psi_o \quad (2)$$

- Analytical solution: $$[\psi_o - 1]G_b(\bar{r}, \omega) = k_0^2(\omega) \iiint \Delta\varepsilon^0(\boldsymbol{r}')G_b(\bar{r}', \omega)G_b(\boldsymbol{r}' - \boldsymbol{r}, \omega)d\boldsymbol{r}' \quad (3)$$

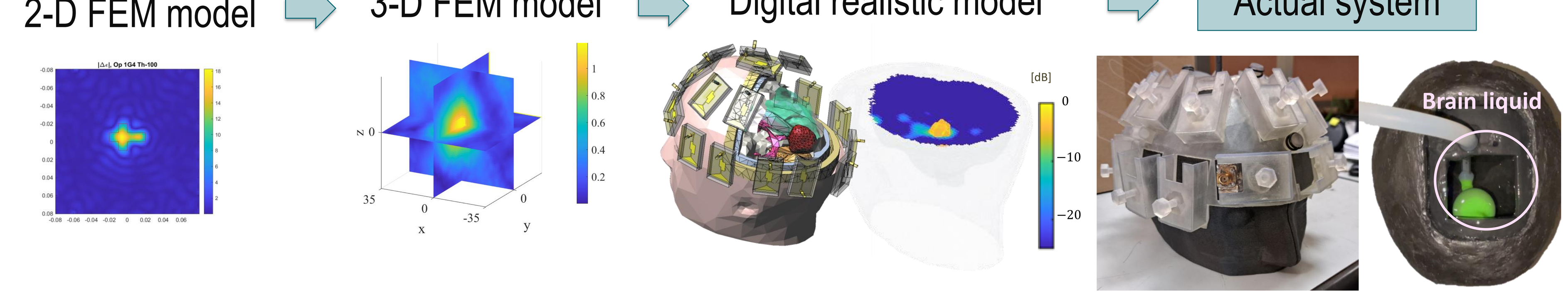


Adopted methodologies



- **Validation process:**

2-D FEM model → 3-D FEM model → Digital realistic model → Actual system



Future work

- Ongoing **external research activity** in collaboration with McMaster University, Hamilton, ON, Canada (Prof. Natalia Nikolova):
- Analytical solution of Green's function that allows simulation-free non-linear inversion
- Implementation of new simulation-free solution for scattering model inversion
- Study of the PSF as mean for system calibration
- Extended measurement campaign on ICH-IS phantom
- Investigate antenna array and imaging procedure for multifrequency implementation

McMaster University

Politecnico di Torino 1859

PhD program in **Electrical, Electronics and Communications Engineering**