RECENTRE

REal-time motion CorrEctioN in magneTic Resonance

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Annovi Alberto[2]; **ARGIENTO Benedetta**[1,2]; Capuani Silvia[3,5]; Cacioppo Matteo[3]; Ciardiello Andrea[2,6]; Coccurello Roberto[5]; Giagu Stefano[2,3]; Giove Federico[4]; Lonardo Alessandro[2]; Lo Cicero Francesca[2]; Maiuro Alessandra[2,3]; Mancini Terracciano Carlo[2]; Merola Mario[1,2]; Montuori Marco[5]; Nistico Emilia[3]; Perticaroli Pierpaolo[2]; Rossi Biagio[2]; Rossi Cristian[2]; Rossi Elvira[1,2]; Simula Francesco[3]; Voena Cecilia[2].

1 - Intent

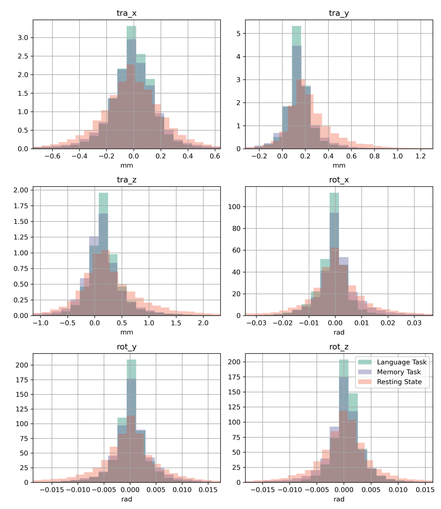
Magnetic Resonance (MR) is a non-invasive modality for investigation of tissue structure and function, but hindered by susceptibility to motion artifacts.

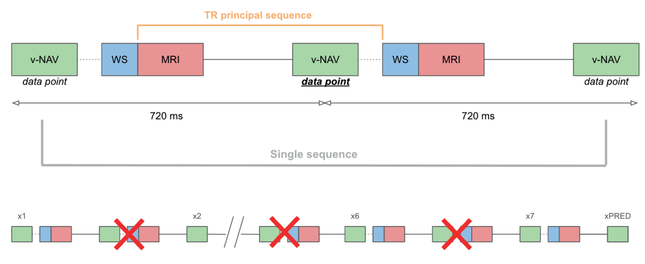
The RECENTRE project introduces an innovative **real-time motion correction technique for MRS**, leveraging advanced deep learning methods incorporating high-speed algorithms from experimental high-energy physics.

2 - Dataset

Human Connectome Project (HCP):

- 1113 Subjects with Simenes 3T MRI
- Repetition time (TR) of $720\ \mathrm{ms}$
- echo time of $33.1\ \mathrm{ms}$
- 3 different acquisition type:
  - **Resting State** (1200 frames),
  - **Working memory task** (316 frames),
  - **Language task** (405 frames)





The motion parameters (3 translations and 3 rotations) used were obtained from **rigid realignment** during post-processing of the acquired MRI data.

Given the low repetition time (TR), a single sequence was defined as consisting of **two acquisition points**.

3 - Framewise Displacement Approach

Framewise displacement (FD), a subject-specific time-series indexing an **overall estimate of movement over time**

$$FD_{total}(\mathrm{mm}) = \sum |T_{i,t} - T_{i,t+1}| + 50 \cdot \frac{\pi}{180} \sum |R_{i,t} - R_{i,t+1}|$$

$$FD_{predicted}(\mathrm{mm}) = \sum |\widehat{\boldsymbol{T}}_{\boldsymbol{i,t+1}} - T_{i,t+1}| + 50 \cdot \frac{\pi}{180} \sum |\widehat{\boldsymbol{R}}_{\boldsymbol{i,t+1}} - R_{i,t+1}|$$

$$FD_{gain} = \frac{FD_{total} - FD_{predicted}}{FD_{total}}$$

where $T_{i,t}/T_{i,t+1}$ and $R_{i,t}/\mathrm{R}_{i,t+1}$ are 3 translation parameters (mm) and 3 rotation (rad) parameters and $\widehat{\boldsymbol{T}}_{\boldsymbol{i,t+1}}$ and $\widehat{\boldsymbol{R}}_{\boldsymbol{i,t+1}}$ are the predicted quantities.

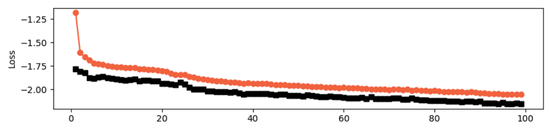
4 - Gated Recurrent Unit (GRU)

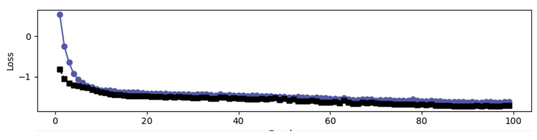
- **Recurrent Neural Network** (RNN)
- Designed for sequential data (simpler variant of LSTM)
- Fewer parameters → faster training, less overfitting;
- Reduces vanishing gradient problem;
- Similar performance to **LSTM**, with lower computational cost.

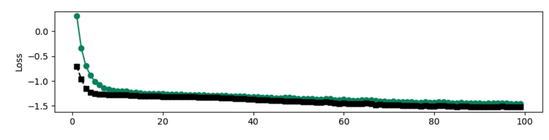
Layer (type:depth-idx)	Output Shape	Param #
GRUModel	[64, 9]	--
├─ GRU: 1-1	[64, 20, 128]	251,520
├─ LayerNorm: 1-2	[64, 128]	256
├─ ReLU: 1-3	[64, 128]	--
├─ Linear: 1-4	[64, 128]	16,512
├─ LayerNorm: 1-5	[64, 128]	256
├─ ReLU: 1-6	[64, 128]	--
├─ Dropout: 1-7	[64, 128]	--
├─ Linear: 1-8	[64, 9]	1,161
└─ Linear: 1-9	[64, 6]	774

Total params: 270479

$loss = NLL - \beta FD_{Gain}$ with $\beta = 0.1$







5 - Results

- **Clear linear trends** and consistently high R^2 values (all above 0.87)
- Very good motion prediction in all the dimension
- Capturing both large and small movements with reasonable accuracy

- Most values of FD gain are positive → NN predictions tends to undestimate the motion on average across patients
- Negative gains → NN may occasionally overstimate slight increases in estimated motion

Next steps

The GRU will be integrated in the workflow of the Siemens syngo MR MAGNETOM system, where the **Siemens Image Calculation Environment** (ICE) operates image reconstruction exploiting roto-translation correction parameters predicted by the the GRU NN model implemented on the **Siemens Framework for Image Reconstruction Environment** (FIRE).

The FIRE server will be deployed onto the Siemens MARS computer leveraging the on-board GPU cards to enhance the performance of the NN inference task.

The net will be **validated with in-vivo** data taken with the Siemens 3T Prisma MR scanner installed at the **IRCSS Santa Lucia of Rome**.

Biblography?
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2 *Istituto di Fisica Nucleare*
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Get in touch with me:
argiento@na.infn.it
bargient@cern.ch