Prediction of the position of external markers on the chest and abdomen for latency compensation in radiotherapy

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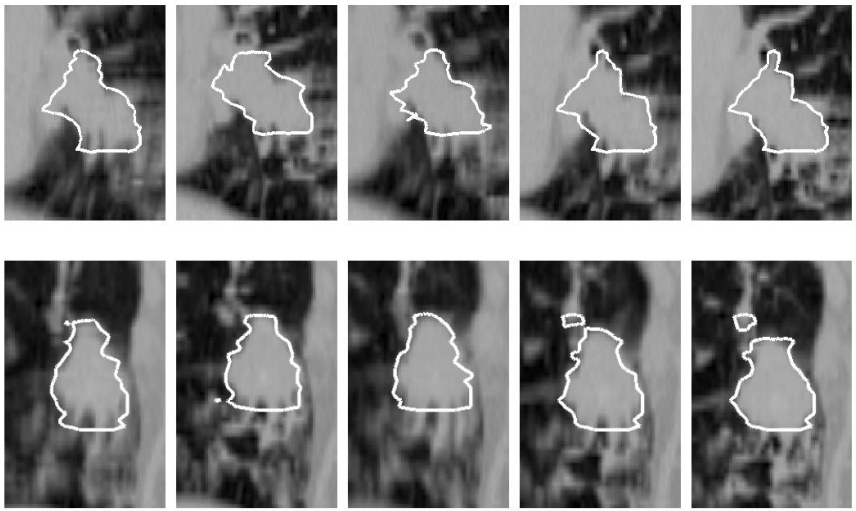
THE 121ST SCIENTIFIC MEETING OF THE JAPAN SOCIETY OF MEDICAL PHYSICS

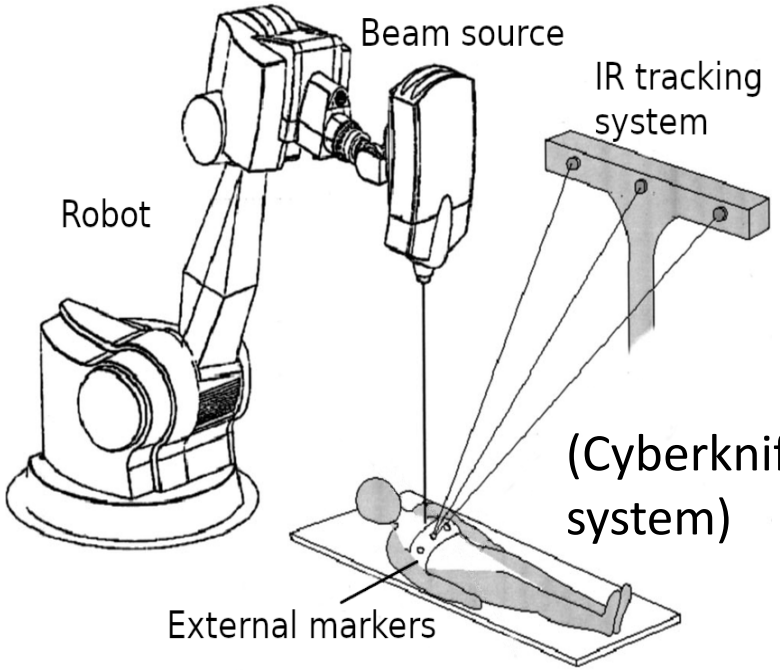
Disclosure of Conflict of Interests

We have nothing to declare for this study

Introduction
External markers in lung cancer radiotherapy



CBCT images of a lung tumor over time
Top : sagittal cross-sections
Bottom : coronal cross-sections



Position of the markers at t ⇨ Geometric correspondance model ⇨ Position and shape of the tumor at t

Introduction
Motion prediction in lung cancer therapy

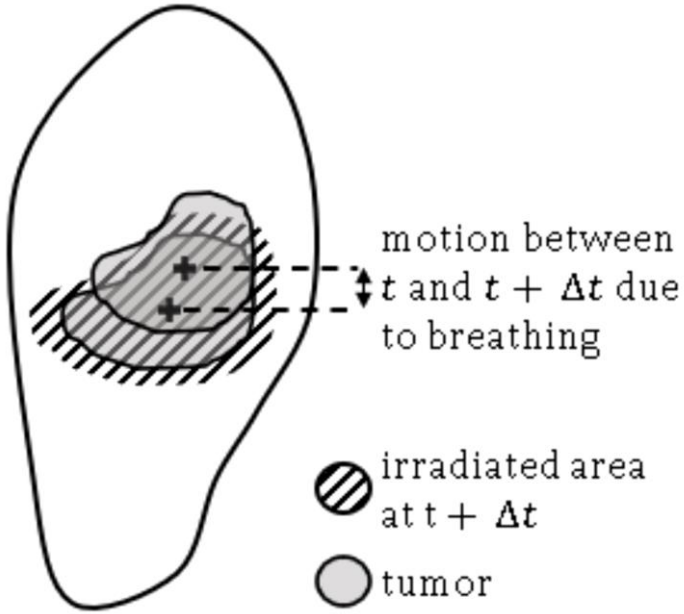
Most systems have a latency Δt between 0.1s and 2.0s

Delay causes :
- Image acquisition and processing
- Treatment robot control
- Radiation beam preparation & delivery

Latency is compensated via prediction

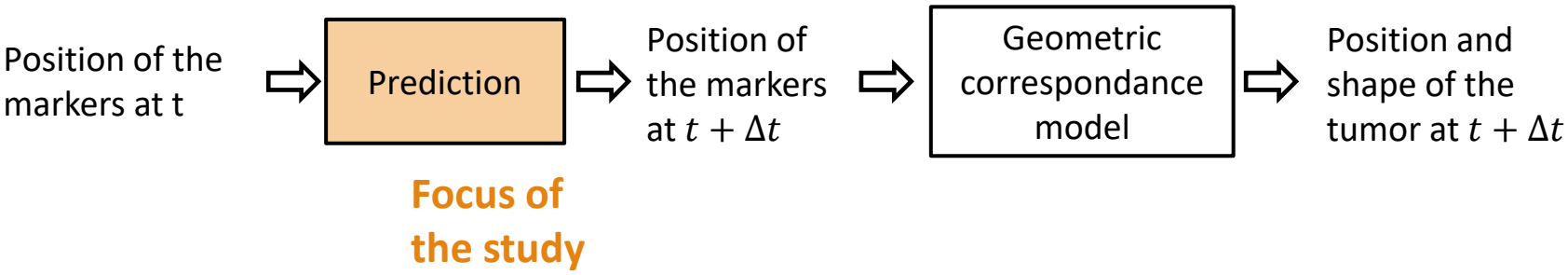
Characteristics of a good prediction algorithm
- ❑ Low tracking error
- ❑ Low oscillation of the predicted signals
- ❑ Real-time processing (fast)
- ❑ Robustness to irregular breathing patterns

Uncompensated latency
→ much damage to healthy tissues
& unaccurate tumor targeting

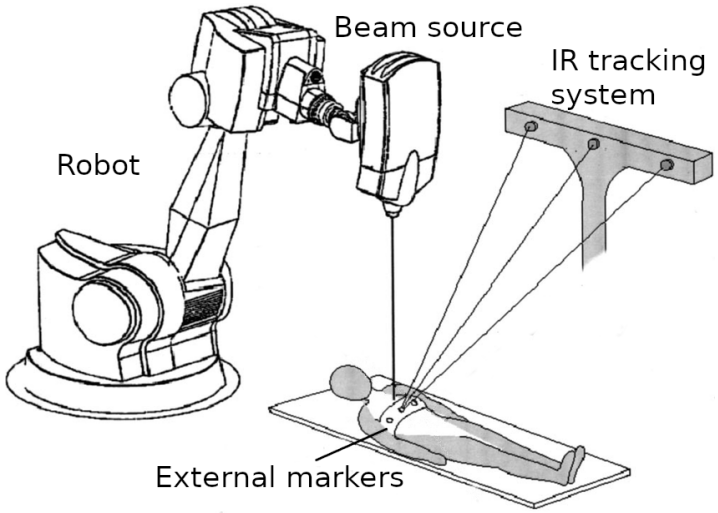


Objective

Evaluate Recurrent Neural Networks (RNNs) trained online with Real-Time Recurrent Learning (RTRL) for predicting the position of external markers for latency compensation in tumor indirect tracking



Method
Dataset used and training/evaluation partition



Input data :

- 9 time series sequence of the 3D position of infra-red emitting markers on the chest (3 recordings from 3 people)
- 10 Hz
- Duration : 73s to 222s
- Amplitude: 6mm to 40mm in the spine axis
- Data available online -> all my results are reproducible (as opposed to many previous studies)

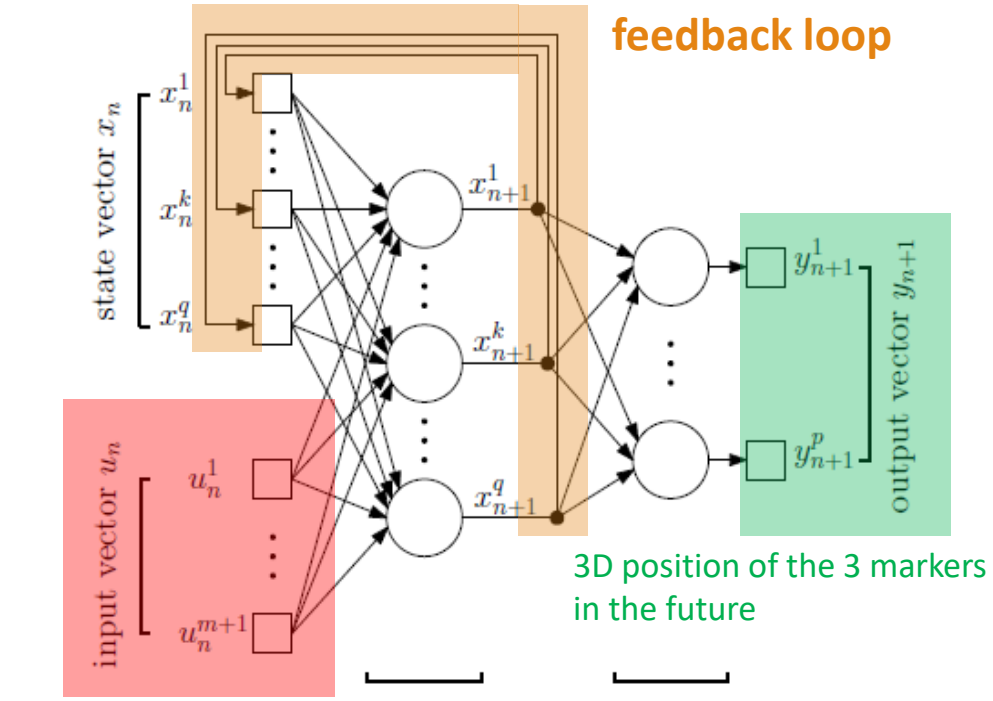
0s to 30s : algorithm training

30s to 60s : automatic parameter tuning with grid search

Parallel computing for search speedup

60s to tmax : algorithm prediction performance evaluation

Method
RNNs trained with RTRL



RNN architecture

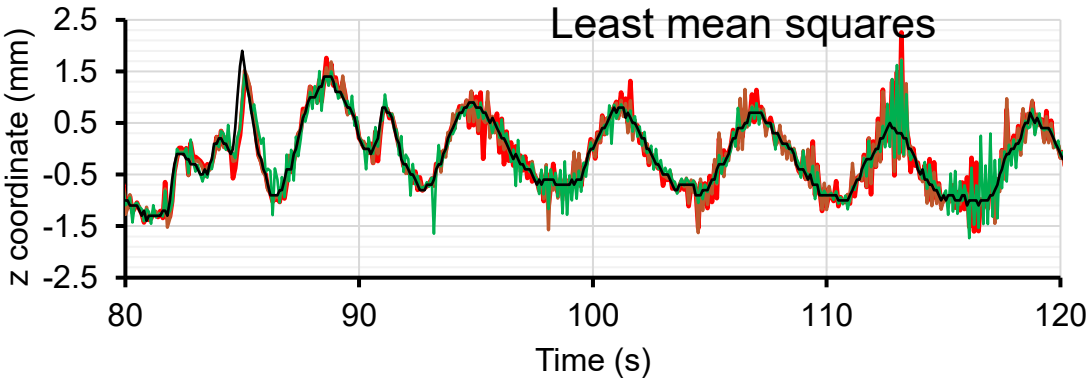
RTRL (real-time recurrent learning) : Online method

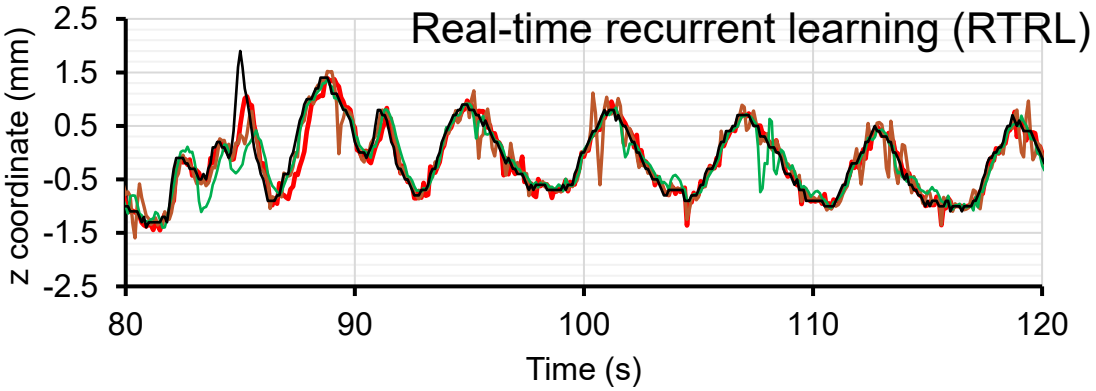
Synaptic weights continuously changing

→ continuous adaptation to the changing individual breathing patterns of each patient

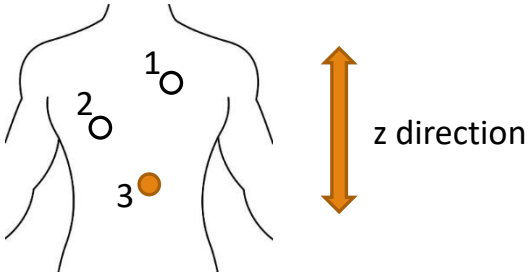
Results
Predicted position of the markers (normal breathing)

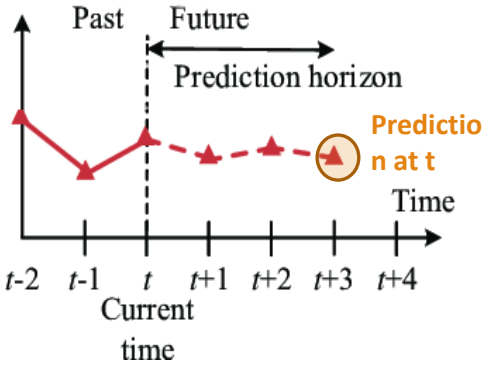
Prediction of the z coordinate (spine axis) of marker 3 in sequence 5





Horizon 2s — Horizon 1.2s — Horizon 0.4s — Original

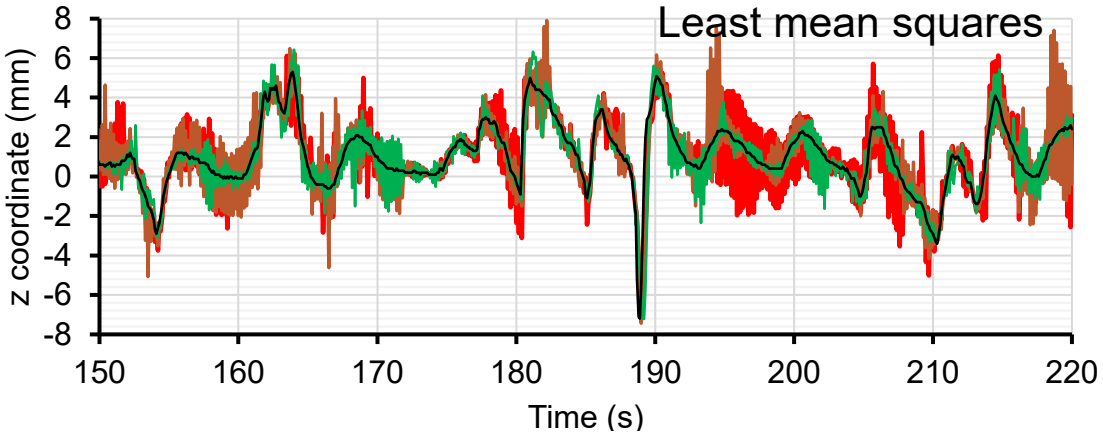


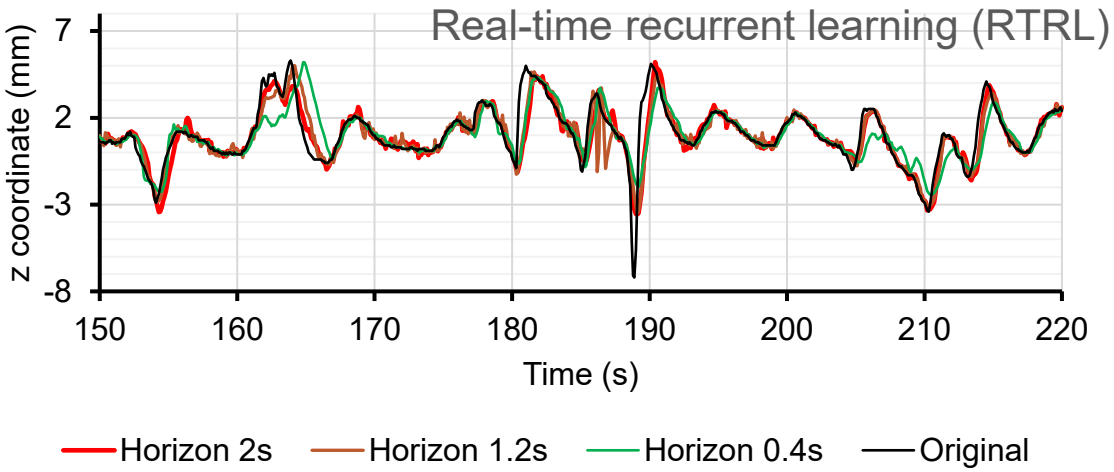


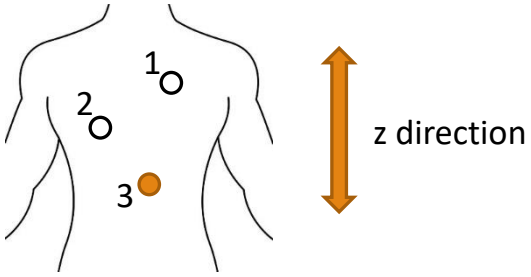
Horizon: time in advance for which the prediction is made

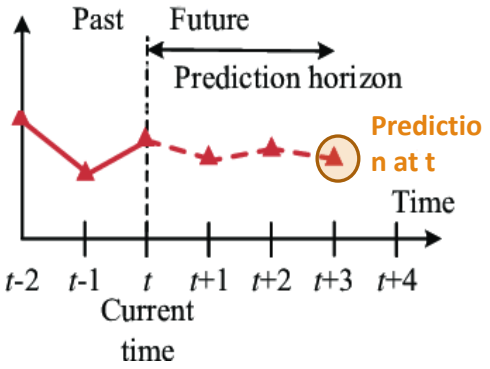
Results
Predicted position of the markers (irregular breathing)

Prediction of the z coordinate (spine axis) of marker 3 in sequence 1



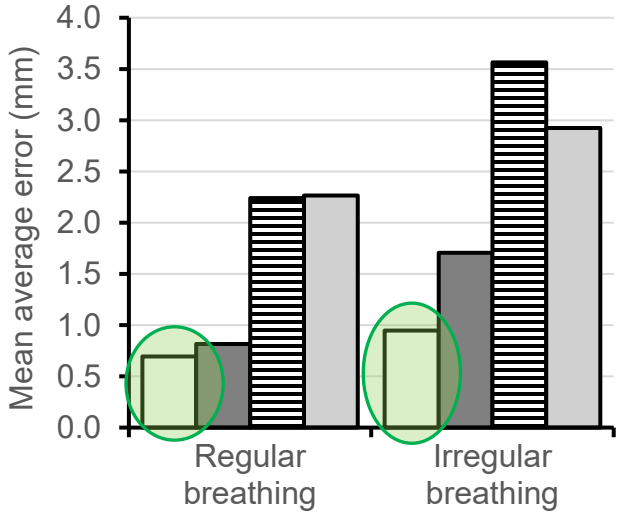


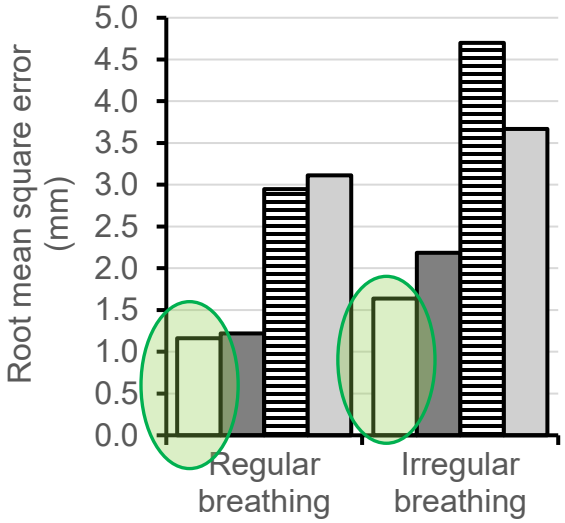


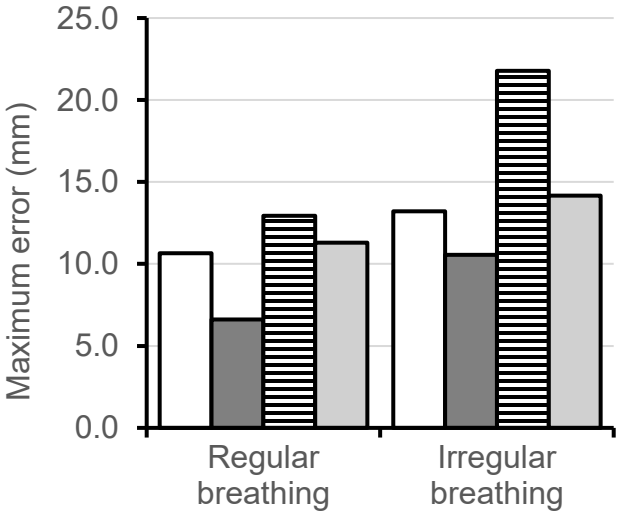


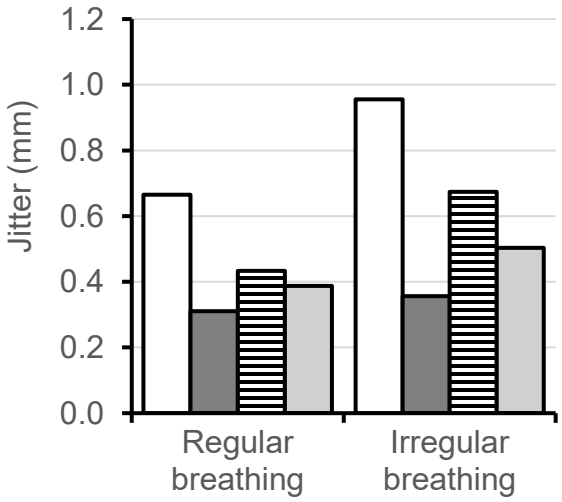
Horizon: time in advance for which the prediction is made

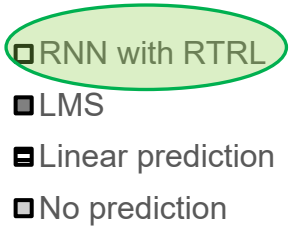
Results
Prediction performance









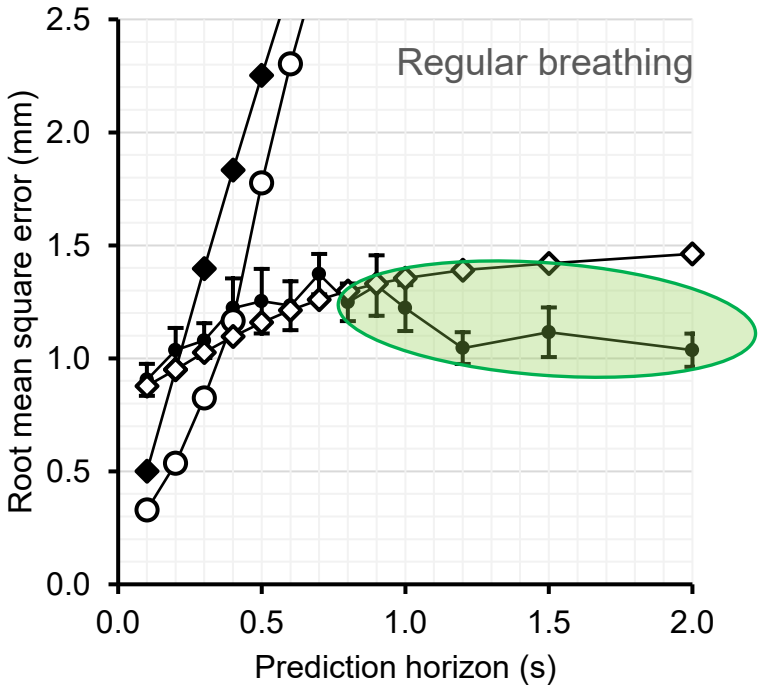


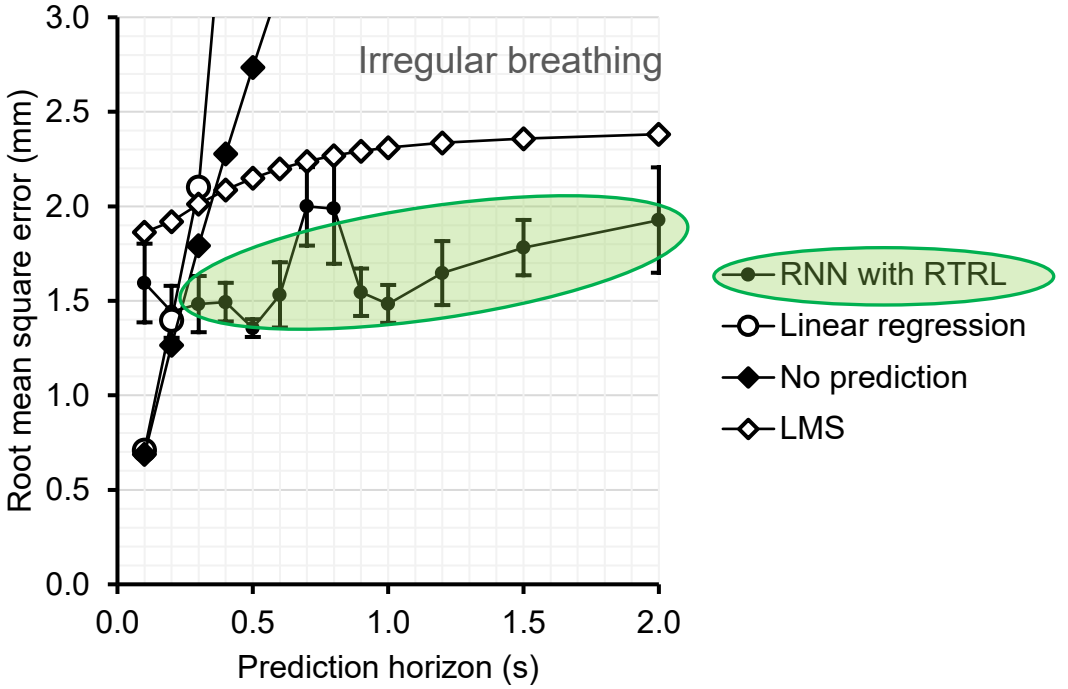
*LMS = least mean squares (adaptive filter)

Prediction with RTRL achieved the lowest MAE and RMSE

- Here the performances are averaged over the horizon values considered
- Linear prediction performs very well for low horizon values.

Results
Prediction performance

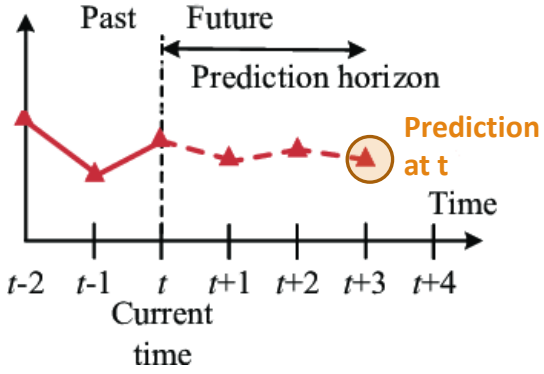




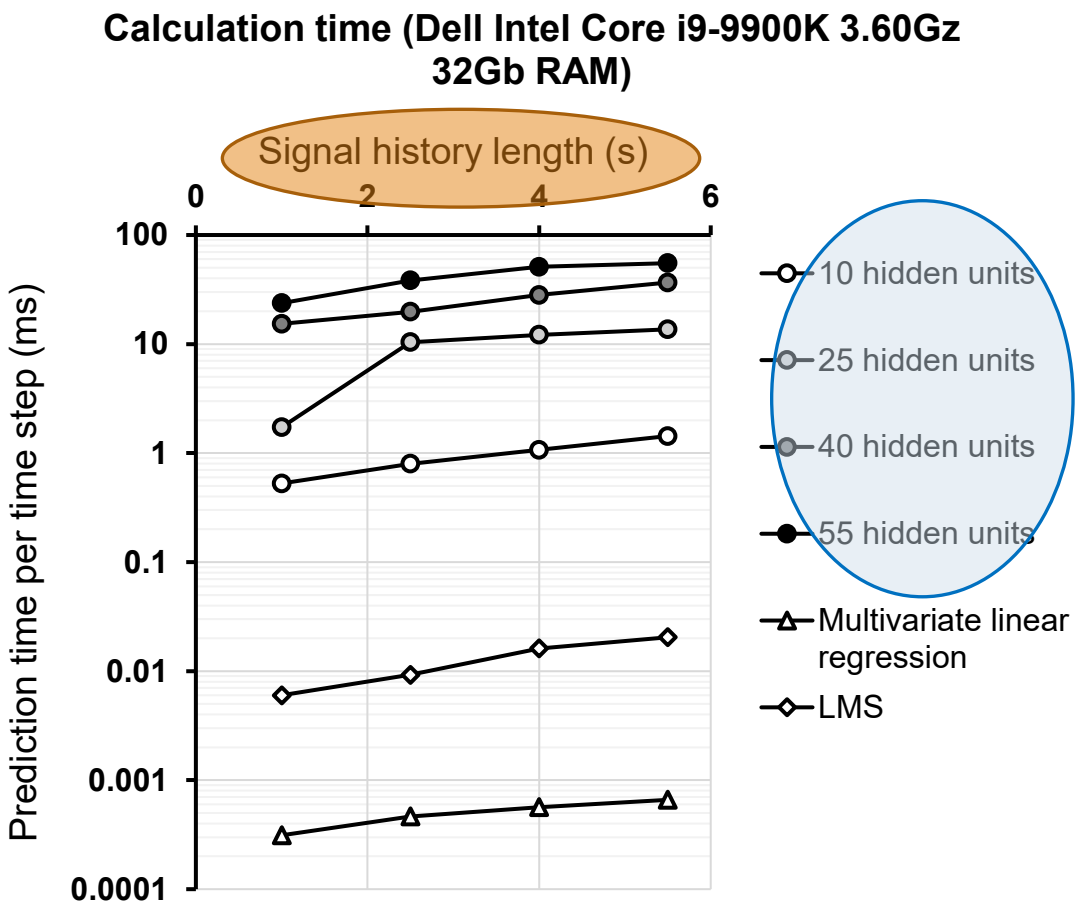
RNNs trained online achieved low RMSE for medium to high horizon values

Hypothesis : the horizon value beyond which RNNs work better depends on the sampling frequency

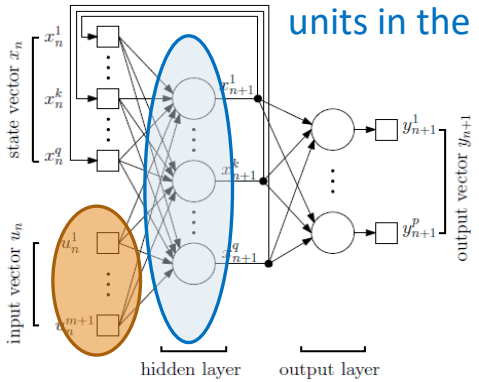
Horizon: time in advance for which the prediction is made :

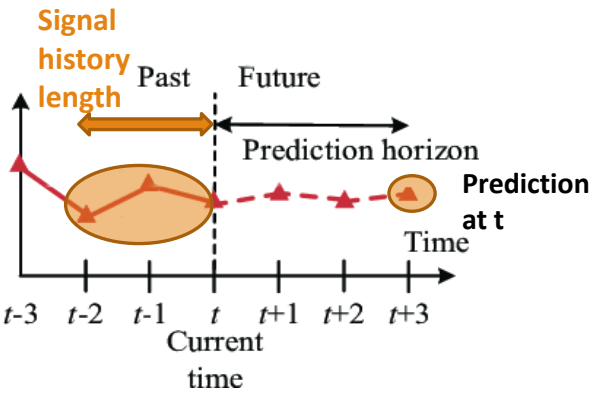


Results
Time performance



Number of hidden units in the RNN





Signal history length : amount of data in the past used for a single prediction

Summary

First study of online-trained RNNs for the prediction of the position of external markers in radiotherapy

- Accurate prediction (MAE 0.8mm & RMSE 1.4mm) using only 1min of training data
- Efficient for high look-ahead time even under irregular breathing conditions
- This will contribute to reduce irradiation to healthy tissues and increase irradiation to the moving tumor