Development and validation of a breathing motion prediction model for tumour motion management

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Einleitung

In precision radiation oncology (RO) tumour motion management (TMM) is required to reduce dose to healthy tissue for tumours subjected to respiratory motion. TMM typically consists of measuring, quantifying and mitigating the tumour motion. Each of these steps is affected by latencies (eg. image acquisition, data transfer, computation time and mechanical MLC movement) in the order of a few 100 ms. For tumour motion tracking these latencies are not negligible and consequently motion prediction is required.

The aim of this study was to develop and validate a long short-term memory (LSTM) neural network for breathing motion prediction of an optical surface scanner signal. The objective was to achieve a prediction horizon of 500 ms with a model trained only on a low number of healthy volunteers. Additionally to the breathing amplitude, the model was trained to predict the breathing phase. This should enable "smart imaging" in the future as during the breathing cycle longer time periods a linked with near maximum expiration compared to maximum inspiration. As a result, imaging performed with a constant time interval between images yields less information about the maximum inspiration breathing phase.

Material und Methode

Breathing motion data was acquired on an Elekta Versa HD Linac using a C-Rad surface camera. The training data for the LSTM network was based on breathing data of 25 healthy volunteers performing 5 min of regular breathing, followed by 1 min of chest breathing and 1 min of abdominal breathing. The validation dataset was based on four patients undergoing treatment with concurrent surface scanner imaging.

Linear interpolation to a constant time interval of 50 ms was performed on the breathing data. For noise reduction, a lowpass filter with a cut-off frequency of 1 Hz was used. For training of the LSTM model the breathing signal of the healthy volunteers was divided into training data and test data to perform hyper-parameter tuning. The best model was validated by performing a prediction on the patient dataset with a prediction horizon of 500 ms. The quality of the prediction was quantified by calculating the root mean square error (RSME) of the predicted data compared to the actual breathing signal for both the amplitude and the breathing phase. Using the breathing phase prediction the possible dose reduction required for kV-imaging of smart imaging compared to a fixed 1 s imaging interval was evaluated. Additionally, the mean time required for a prediction was measured using an Intel Core i9 CPU-10900K CPU @ 3.70 GHz.

Resultate

The mean breathing amplitude of the healthy volunteer dataset was 6.6 mm. For Patient 1, 2, 3 and 4 it was 1.2 mm, 4.5 mm, 1.0 mm and 20 mm, respectively.

The RSME for a prediction horizon of 500 ms for Patient 1, 2, 3 and 4 was for the breathing amplitude 0.15 mm (12 %), 0.08 mm (2 %), 0.05 mm (5 %) and 0.3 mm (2 %) and for the breathing phase 24°, 7°, 15° and 7°, respectively.

Using the breathing phase detection for triggering of the kV imaging could reduce the dose required for imaging by 20 %. The mean runtime required for performing a prediction was 11.2 (+/-1.2) ms.

Diskussion

Our LSTM neural network trained with breathing data of 25 healthy volunteers was able to predict the breathing amplitude and breathing phase with a prediction horizon of 500 ms. This prediction horizon is sufficient to compensate for imaging and image processing latencies as well as mechanical MLC movement required for tumour tracking. Furthermore, using the breathing phase prediction for triggering intrafractional kV-imaging has the potential of substantially reducing the imaging dose to the patient.

In this study the breathing data obtained by a surface scanner was used, which is only a surrogate of the actual tumour motion. Adding patient specific correlation between surface scanner data and the internal tumour motion using 4D-CT data as well as intrafractional kV-imaging will be investigated in future work to achieve highest geometric precision for TMM.