Offline and online LSTM networks for respiratory motion prediction in MR-guided radiotherapy

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What was your motivation for initiating this work?

The adoption of magnetic-resonance-guided radiotherapy (MRgRT) has brought about the large-scale acquisition of images. This situation is ideal for the development of artificial intelligence (AI) methods. With the use of the 0.35T MRIdian MR-linac, 2D cine-MRI images are acquired at each fraction for beam gating at a frequency of either 4Hz or 8Hz. While gating is a very robust way to ensure target coverage, it comes at the cost of increased treatment times, with duty cycles as low as 20% [1]. An alternative that has seen recent interest for MRgRT is multi-leaf collimator (MLC) tumour tracking [2], which can be achieved by rigidly shifting the MLC to match the tumour centroid displacement, as observed on 2D cine-MRI. Recent proof-of-principle work with the 1.5T Unity MR-linac has shown that MLC tracking should be feasible [3, 4], and the Australian MR-linac project has even demonstrated the tracking of multiple targets [5]. Optimal MLC tracking requires accounting for system latency, which has been reported to be about 350ms for different MR-linacs [5-7]. The goal of this project was to exploit AI for respiratory motion prediction in the context of MRgRT, by leveraging a multi-institutional database of 0.35T cine-MRI data (88 patients/16 hours of motion from Ludwig Maximilian University (LMU) in Munich, three patients/three hours of motion from Gemelli in Rome). Long short-term memory (LSTM) networks are a class of models that are well-suited to sequential inputs and the prediction of time series, and we aimed to evaluate their performance for MRgRT, as well as to compare them with state-of-the-art methods such as linear regression.

What is the most important finding of your study?

The main finding was that for both 250ms and 500ms predictions, the LSTM was superior to the linear regression model. This was an encouraging finding, since linear regression has often been reported as the best method for this task (see, for example, Joehl et al. [8]). Another key result was that the LSTM was fast enough to be used to predict future positions in real time, and that it was also possible to retrain it online to account for the latest 20s of data. This was in fact the model that performed best; it achieved a mean root-mean-square error of 1.20mm and 1.00mm at 500ms prediction time for the LMU and Gemelli testing sets, respectively. The Gemelli data had not been seen by the baseline LSTM (prior to online retraining), which indicated that LSTMs generalised well, at least for 0.35T data.

What are the implications of this research?

We are currently investigating more advanced LSTM models that make use of convolutions [9] to act directly on cine-MRI frames to predict full 2D segmentations in the future. This could open application of the method to deformable MLC tracking, in which not only a rigid shift of the aperture but additional conformation to the current target shape is executed [10]. In parallel, we are seeking experimental validation of our findings on a prototype MR-linac with the use of an unseen set of motion traces. Through the performance of this study, we aim to demonstrate the robustness of LSTM models that are continuously trained online, which we believe have a role to play in the future of MLC tracking in MRgRT.

References

1. Eze C, Lombardo E, Nierer L, Xiong Y, Niyazi M, Belka C, Manapov F, Corradini S: MR-guided radiotherapy in node-positive non-small cell lung cancer and severely limited pulmonary reserve: a report proposing a new clinical pathway for the management of high-risk patients. Radiat Oncol 2022, 17(1):43,10.1186/s13014-022-02011-8.
2. Keall PJ, Sawant A, Berbeco RI, Booth JT, Cho B, Cervino LI, Cirino E, Dieterich S, Fast MF, Greer PB, Munck Af Rosenschold P, Parikh PJ, Poulsen PR, Santanam L, Sherouse GW, Shi J, Stathakis S: AAPM Task Group 264: The safe clinical implementation of MLC tracking in radiotherapy. Med Phys 2021, 48(5):e44-e64,10.1002/mp.14625.
3. Uijtewaal P, Borman PTS, Woodhead PL, Hackett SL, Raaymakers BW, Fast MF: Dosimetric evaluation of MRI-guided multi-leaf collimator tracking and trailing for lung stereotactic body radiation therapy. Med Phys 2021, 48(4):1520-1532,10.1002/mp.14772.
4. Uijtewaal P, Borman PTS, Woodhead PL, Kontaxis C, Hackett SL, Verhoeff J, Raaymakers BW, Fast MF: First experimental demonstration of VMAT combined with MLC tracking for single and multi fraction lung SBRT on an MR-linac. Radiother Oncol 2022, 174:149-157,10.1016/j.radonc.2022.07.004.
5. Liu PZY, Dong B, Nguyen DT, Ge Y, Hewson EA, Waddington DEJ, O'Brien R, Liney GP, Keall PJ: First experimental investigation of simultaneously tracking two independently moving targets on an MRI-linac using real-time MRI and MLC tracking. Med Phys 2020, 47(12):6440-6449,10.1002/mp.14536.
6. Glitzner M, Woodhead PL, Borman PTS, Lagendijk JJW, Raaymakers BW: Technical note: MLC-tracking performance on the Elekta unity MRI-linac. Phys Med Biol 2019, 64(15):15NT02,10.1088/1361-6560/ab2667.
7. Yun J, Wachowicz K, Mackenzie M, Rathee S, Robinson D, Fallone BG: First demonstration of intrafractional tumor-tracked irradiation using 2D phantom MR images on a prototype linac-MR. Med Phys 2013, 40(5):051718,10.1118/1.4802735.
8. Johl A, Ehrbar S, Guckenberger M, Klock S, Meboldt M, Zeilinger M, Tanadini-Lang S, Schmid Daners M: Performance comparison of prediction filters for respiratory motion tracking in radiotherapy. Med Phys 2020, 47(2):643-650,10.1002/mp.13929.
9. Romaguera LV, Plantefeve R, Romero FP, Hebert F, Carrier JF, Kadoury S: Prediction of in-plane organ deformation during free-breathing radiotherapy via discriminative spatial transformer networks. Med Image Anal 2020, 64:101754,10.1016/j.media.2020.101754.
10. Ge Y, O'Brien RT, Shieh CC, Booth JT, Keall PJ: Toward the development of intrafraction tumor deformation tracking using a dynamic multi-leaf collimator. Med Phys 2014, 41(6):061703,10.1118/1.4873682.

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