Towards Real-Time proton range verification using dynamic MRI

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Highlight

With the arrival of hybrid Photon-MRI solutions in standard radiotherapy [1], real-time adaptive treatment or treatment verification are on the way. In proton therapy, the hardware solution doesn't exist yet but is under serious consideration [2-3]. Proton treatments, with their particular dose distribution profile, should benefit even more than photons of such an hybrid device. In this context, we developed a tool to study the possible new treatment strategies that could emerge from such an hybrid machine and their possible gain. This particular work aims at visualizing a proton PBS treatment plan on continuous 2D MR images and compare a real-time recomputed range based on those images with the planification range computed on the average CT.

Materials and Methods

1. First, the breathing motion is tracked on the MRI dynamic sequence using an in-house tool to track anatomical interfaces. For each new frame, the motion amplitude is compared to the 4DCT motion to select the phase and slice which match best the current MRI frame [Figure 1]. This gives a matched CT sequence which is a rough approximation but already a lot closer to the real motion than the original looped 4DCT.

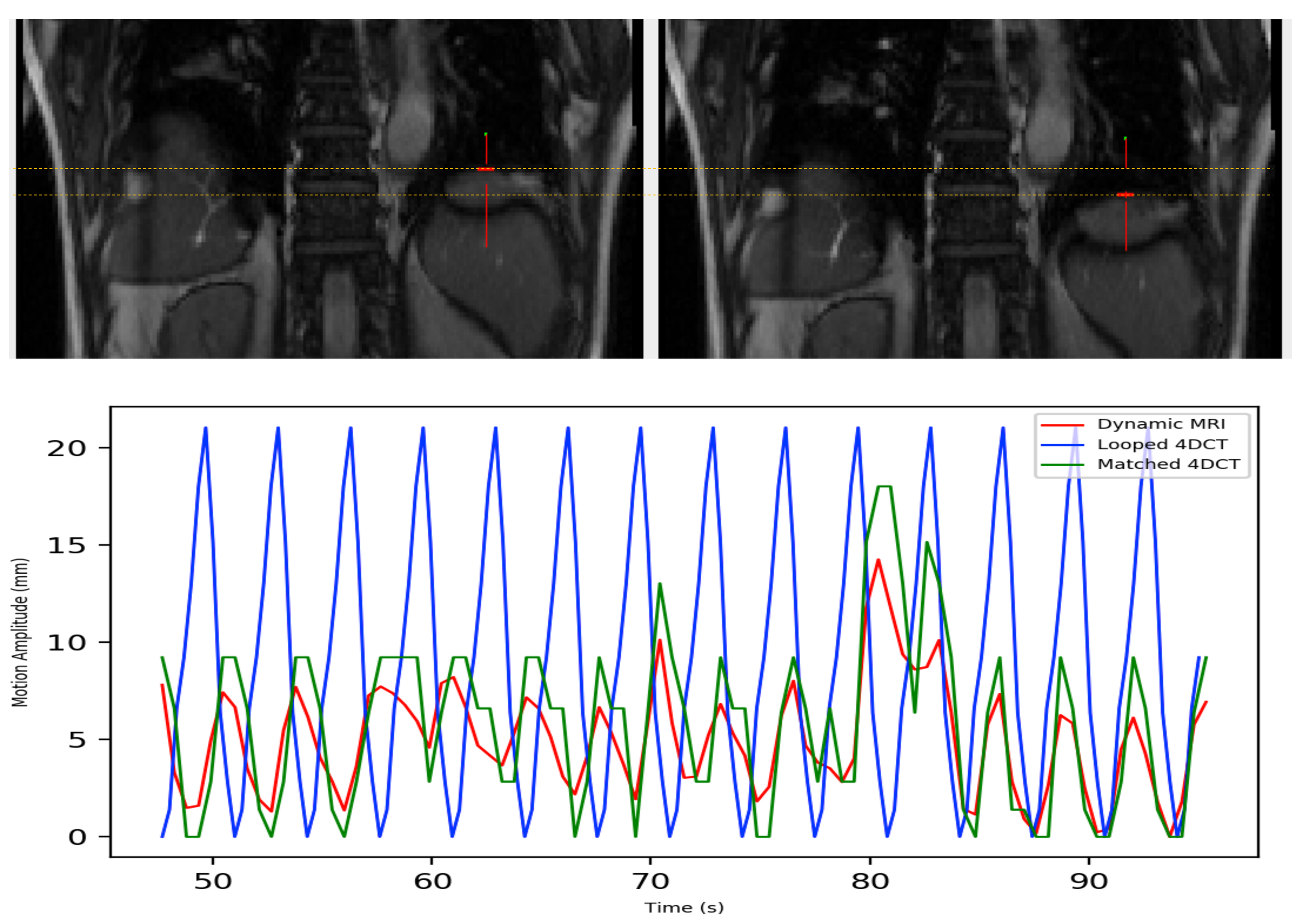

Figure 1: 2 examples of diaphragm amplitude tracked through time on MRI and resulting motion signals for MRI, Matched CT and original CT

2. Then, a fast 2D non-rigid registration is computed to deform the selected matching CT slice on the current MRI frame, to imitate the irregular breathing motion seen on the MRI as best as possible [Figure 2]. The registration was done using the Elastix registration tool [4] with a mask for the bone structures over the CT images.

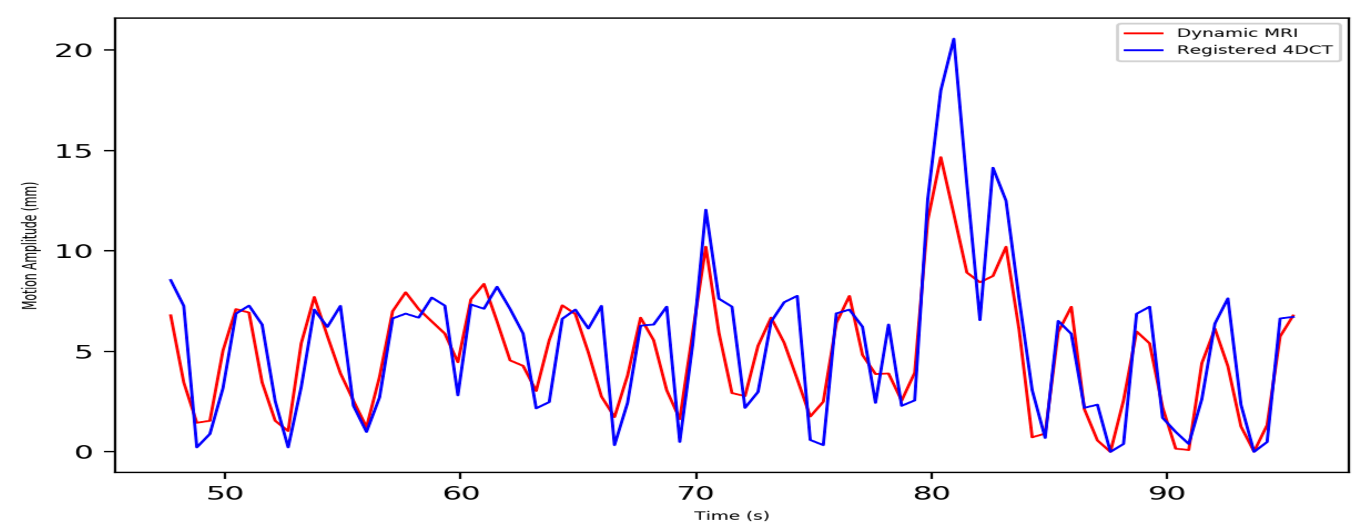

Figure 2: Comparison of motion amplitude observed on MRI and on the registered CT slices.

3. Finally, the spot range is recomputed on the deformed CT for the spots passing through the slice and delivered during the current frame acquisition time. (Around 400ms for our first tests)

The image data, (MRI True-FISP from Siemens 3T, and the 4DCT) come from patients treated for liver tumors in standard radiotherapy. A PBS proton plan was then computed on the Raystation6 to get the proton plan information.

Results

The breathing motion measured on the deformed CT seems to be well matched to the dynamic MRI, with a mean difference under 2 mm between both signals. The matching/registration methods can still be improved to imitate better the real motion, specifically in case of irregular breathing patterns (See previous figures, the high peak around 80 sec is not well matched). The method runs in 2 seconds/frame on a 4 core laptop. As the MRI acquisition rate is 2.5 Hz, this isn't performed in real-time yet. But we think it could already be fast enough with more computation power.

The recomputed range after registration should, for the majority of delivered spots, imitate better the reality than the range computed during the planification. Preliminary results shows that a large fraction of the recomputed spot range differ significatively from the planned range. For spots delivered through a sagittal plane, we measured differences from -9 to 54 mm (Mean = 20 mm, Std = 11 mm) and between -10 and 90 mm (Mean = 41 mm, Std = 26 mm) for the spots in a coronal plane. We only teste 1 plan and 1 patient so far, and with a target close to the diaphragm, a big difference is expected. The mean difference wasn't affected much by delivery starting time for the studied patient.

Conclusion

This method and the associated tool should allow a better estimation of the motion impact on proton spot range. The preliminary results have to be considered carefully. The quality measurement of the simulated motion is only based on the diaphragm and more motion comparisons still needs to be done (skin, ribs, …). The tool will allow us to compare and evaluate the quality of different treatment strategies and also study different approaches to improve treatment plans by simulating the existence of an hybrid MRI-Protontherapy machine allowing simultaneous imaging and treatment.

References

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