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Ultrasound-based Lung Motion Modelling

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Introduction
Respiratory motion poses great challenges in pencil beam scanned (PBS) proton therapy of mobile targets. In a recent study, we presented the potential of tumour tracking using a patient-specific motion model on simulated 4DCT(MRI) data sets [1]. A statistical motion model was used to estimate dense lung motion information from 2D abdominal ultrasound (US). While this study was based on Gaussian process (GP) regression [2], an alternative approach using cubic polynomial regression could be used likewise [3]. Compared to GP models, polynomial regression models have the advantage of reduced computational complexity since they can be addressed with ordinary least squares analysis. In this work, we aim to compare the two US-based motion models using the 4DCT(MRI) data sets presented in [1].

Materials and Methods
Simultaneous acquisitions of abdominal US imaging and time-resolved 4DMRI [4] were performed on two healthy volunteers on a 1:5T clinical scanner (MAGNETOM Aera, Siemens Healthineers, Erlangen, Germany). Continuous acquisition during 10 min of free breathing resulted in approximately 700 distinct respiratory states. Deformable image registration was applied to compute the deformation vector field (DVF) with respect to a reference exhalation volume for each respiratory state. These DVFs were then used to animate full-exhale CTs of two lung cancer patients, resulting in four synthetic 4DCT(MRI) data sets [1].
Low-dimensional respiratory surrogate signals were extracted from the 2D US image series using principal component analysis (PCA). For the GP regression model, PCA was also performed on the lung deformation field. The data sets were split into a training and test set, comprising 500–650 and 50–73 US/MR image pairs, respectively. Both, the GP regression model and the cubic polynomial regression model were evaluated on the same data sets and compared below.

Results
We defined the prediction error as the magnitude of the difference between the reference and the predicted DVFs. Figure 1 shows the distribution of the mean and the 95th percentile prediction error. It can be seen that the GP model outperforms the cubic polynomial model in all data sets.

Conclusions
This analysis suggests that the GP model is more accurate than the cubic polynomial model which comes however at the cost of increased computational complexity. In the context of radiotherapy, uncertainty quantification using GP models could be used to monitor motion prediction confidence and if necessary to interrupt the treatment. In a future work we will investigate the performance of the GP model for beam adaption in PBS proton therapy of lung tumours.

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References
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