Optical flow analysis on undersampled radial acquisitions for real-time tracking of the pancreas in MR guided radiotherapy

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PURPOSE Motion is a well-known problem for radiotherapy in upper abdomen organs. Conventionally, margins are used to ensure full dose coverage of the target volume at the cost of extra radiation exposure of surrounding healthy tissue. For pancreatic tumors however, this approach is severely limited by the close vicinity of radiation sensitive organs such as the duodenum. The recent introduction of MR-guided radiotherapy opens up the way to track organs to reduce or remove the margins[1,2]. In order to achieve this, gated irradiation procedures or dose accumulation calculations for fractionated radiation plans are required, preferably based on accurate real-time tracking on cine-MR. One way to evaluate motion in cine-images is using the optical flow algorithm[3], which has been successfully applied and validated on fast single slice EPI images with a sub second temporal resolution, for HIFU treatments[4,5]. Although highly efficient, EPI is also prone to geometrical distortions, which makes this technique less suitable for radiotherapy purposes. In this study we therefore investigate the feasibility of optical flow motion analysis on undersampled radial acquisitions. The goal is to achieve real-time motion characterization with comparable temporal resolution to EPI, but without distortions. Simultaneously, the pancreatic motion is assessed in order to find the optimal tradeoff between undersampling artifacts, temporal resolution, and field-of-view (FOV).

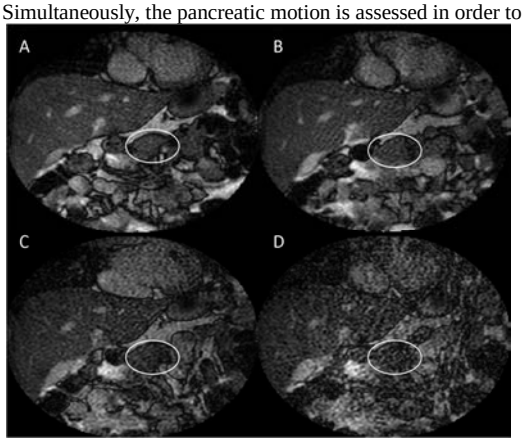

Figure 1. Coronal bSSFP images recorded at (a) 3Hz, (b) 4Hz, (c) 6Hz and (d) 12Hz with the pancreas encircled

METHODS

MR-imaging: Six healthy subjects were scanned on a Philips Achieva 1.5 T scanner. 2D balanced steady-state free-precession (bSSFP) coronal scans (TE/TR = 1.29/2.6 ms, $\alpha=30^0$, FOV=294x294 mm^2, voxelsize=1.53x1.53x7 mm^3) were acquired during free-breathing for 2:50 minutes. Scan planes were angulated parallel to the spine to obtain the principal axis of motion. Moreover, the breathing signal was recorded using a respiratory pressure belt. For each subject four radial scans were acquired, with varying amounts of undersampling (using 100%, 75%, 50% or 25% of the spokes) resulting in temporal frequencies of 3, 4, 6 and 12Hz in order to also capture high frequency motion including the higher harmonics of the cardiac cycle.

Simulations based on in vivo data: In order to assess the effects of signal-to-noise ratio (SNR) and undersampling (i.e. streaking) artifacts on the optical flow analysis, fully sampled radial raw data were reconstructed offline using 100%, 50%, or 25% of the data. Optical flow analysis was performed on all reconstructed data. The reconstructed time-series mimic the undersampled *in vivo* data, but allow a quantitative assessment of the optical flow analysis, as the motion described by each time-series is identical to the fully sampled data.

2D in vivo data: Optical flow analysis was performed on the *in vivo* data sets, to assess the effect of increased temporal resolution and to characterize the pancreatic motion up to 6Hz. 2D motion vector fields were calculated using optical flow analysis and used to register the image time-series. Temporal variance maps of the registered images served as a measure for the residual error in the registered images. Principal component analysis (PCA) and power spectrum analysis on all data were used to assess the minimal sampling frequency needed for accurate tracking.

Multi-slice in vivo data: Based on the results from the first two experiments a pilot scan was performed in which two orthogonal 2D slices were scanned in an interleaved fashion to gain insight in the 4D motion of the pancreas. The coronal slice was planned as for the 2D data whereas the sagittal slice was positioned to intersect the tail of the pancreas. The interleaved turbo-field echo (TFE) images were scanned using 45% of the spokes, which resulted in a temporal frequency of 3Hz. Optical flow analysis was performed and assessed quantitatively.

RESULTS AND DISCUSSION **Fig. 1** shows example images of fully sampled and undersampled data. Streaking artifacts and reduced SNR become prominent when only 25% of the spokes are used (**Fig. 1d**), which is a concern as they may cause errors in the optical flow analysis. Simulations however showed relatively small deviations in the amplitude of the motion when 50% or 25% of the data was used for reconstruction. Inspection of the displacement time-courses showed that the discrepancies were most pronounced at maximum exhale and inhale. The mean difference over time between the 3Hz and 12Hz data set was 0.3 ± 0.4pixels (0.46 ± 0.62 mm). The residual error in the registered images for both the fully sampled and the undersampled data was approximately 1 pixel (1.53mm) in the region of interest, which is comparable to previous findings[4]. PCA showed that 97% of the motion was described by the first component. This component showed a high correlation with the respiratory belt signal. Power spectra showed a maximum frequency peak at 0.25Hz with smaller peaks up to 1Hz (**Fig. 2**). This implies that scanning at 3Hz should be sufficient to capture all quasi-periodic motion. Furthermore, a low frequency component was found in the power spectrum of the optical flow analysis. This can be explained by a global rigid body motion during acquisition which is detected by the optical flow algorithm. The preliminary results obtained from the multi-slice scans show the pancreatic motion in two orthogonal directions.A small displacement in the left-right is shown by the coronal plane, whereas the sagittal view characterizes the anterior-posterior displacement (**Fig. 3**).

CONCLUSIONS The results presented here show that the optical flow algorithm performs well on undersampled radial data. Simulations showed small errors when the algorithm was performed on 4-fold undersampled data. *In vivo* data showed that 97% of the pancreatic motion is respiratory induced. Additionally, smaller contributions up to 1Hz were observed which suggests that imaging at 3Hz would be sufficient to accurately track the pancreas during treatment. Analysis on two orthogonal slices show promising results for 4D pancreatic motion analysis.These findings can be used to obtain real-time position information during radiation and between fractions for more accurate dose deposition. Future work will include online motion analysis and real-time slice positioning adaptation.

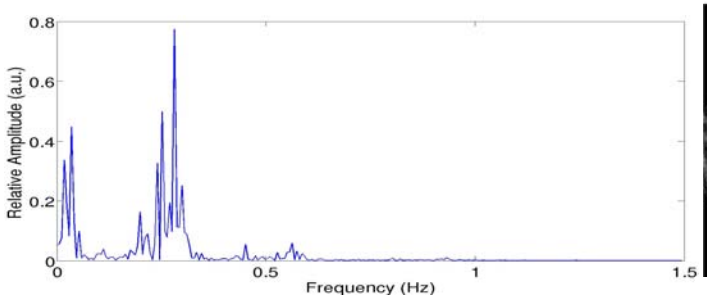

Figure 2. Power spectrum of pancreatic motion. For convenience the spectrum is shown up to 1.5Hz. Harmonics can be seen up to 1Hz

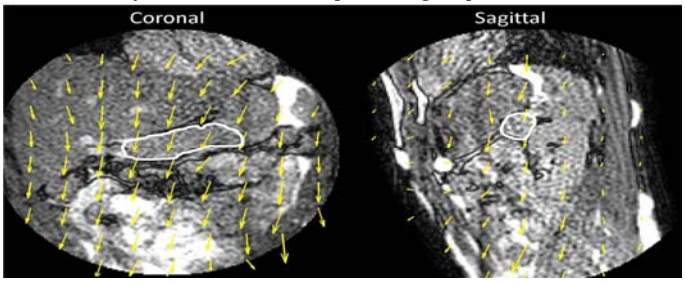

Figure 3. 4D motion analysis example. Coronal (left) and sagittal (right) images with the motion vector field displayed. For visual purposes only a subset of the vectors is shown. The pancreas is encircled in white

REFERENCES **1.** Lagendijk JJW, et al. *Radiotherapy Oncol* 2008;86:25-29 **2.** Raaymakers BW et al. *Phys Med Biol* 2009;54:N229-N237 **3.** Horn B, et al. *Artif Intel* 1981;17:185 – 203 **4.** Roujol S, et al. *IEEE Trans on Med Imag* 2011;30:1737 – 1745 **5.** Roujol S, et al. *IEEE Symp Biomed Imag*, 2011, pp. 508-511