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# Estimation of respiratory breathing signal from 2D US sequences and 4DCT of the liver

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*Abstract*— **One challenge of High Intensity Focused Ultrasound (HIFU) for treating primary liver tumors is the management of the breathing motion during treatment. An extracorporeal HIFU transducer with an integrated ultrasound (US) imaging probe has been specifically designed for treating the liver. The imaging probe produces 2D images and the tumor itself may not always be visible in US images. A pre-operative 4D-Computed Tomography (CT) image is acquired to infer the tumor location. To retrieve spatio-temporal correspondence between the 4DCT and 2D+t US sequences to guide extracorporeal HIFU treatments temporal Principal Component Analysis and Hilbert transform was applied. The correspondence was visually verified by radiologist.**

***Keywords— Multimodal image fusion; Image-guided therapy; High Intensity Focused Ultrasound***

## I. Introduction

***Keywords—Multimodal image fusion; Image-guided therapy; High Intensity Focused Ultrasound***

High-Intensity Focused-Ultrasound (HIFU) is a promising technique for treating liver tumors, thanks to its non-ionizing nature and its potential to coagulate the targeted tissue quickly and in a non-invasive way. One challenge of HIFU for treating primary liver tumors is the management of the breathing motion during treatment. An extracorporeal HIFU transducer with an integrated ultrasound (US) imaging probe has been specifically designed for treating the liver, which place an ultrasound (US) imaging probe in the center of an extracorporeal HIFU transducer, such that the imaging plane is aligned with the HIFU acoustic axis [1, 2, 3]. Because the tumor itself may not always be visible on US images, a pre-operative 4D-Computed Tomography (CT) image is acquired to infer the tumor location. Here, we propose to retrieve spatio-temporal correspondence between the 4DCT and 2D+t US sequences to guide extracorporeal HIFU treatments.

## II. Materials and Methods

### A. Image acquisition

To study the feasibility of US guidance according to the pre-operative planning CT image, US sequences were acquired in 10 patients after informed consent.

Trials were conducted on patients undergoing radiotherapy treatment with a planned 4DCT injected image (Philips Brillance). 4DCT reconstruct an averaged respiratory cycle from a continuous acquisition covering between 10 to 15 cycles, using a helical acquisition and phase-tagging of respiratory signal acquired with a respiratory belt. Ten 3D volumes were reconstructed representing the anatomy of the patient at evenly distributed phases of the respiration. Several 2D+t US sequences of about 30 s, targeting structures in the liver, have been acquired by a radiologist after CT acquisition. A hand-held US probe (Clarity, Elekta) was available, providing 2D images sequences in the coordinate system of the CT scanner thanks to a calibrated optical tracking system. In our case spatial correspondence is obtained by a calibrated optical tracking system. The whole patient examination is preceded as follows. First the patient is laying on the CT table and his position is aligned according to tracker coordinate system. As references points during both examinations radiological markers attached to the thorax and side part of abdominal surface are used. Then the CT table is moving into the scanner gantry, CT examination was performed and after the table is moving back to the previous position. The 4DCT and US acquisitions were performed in the same session, asking the patient to remain as still as possible during and between the examinations, so as to minimize any motion or deformation. The patient is laying at the same horizontal position in the scanner room. We observe that spatial correspondence must be validated by the radiologist to obtain reasonable final results.

### B. Ultrasound series data analysis

Since no respiratory signal could be recorded simultaneously to the ultrasound image sequence, such a signal was estimated retrospectively from the images themselves. In the previous work [3], we relied on the assumption that the probe was fixed with respect to the patient. Now before the Principal Component Analysis (PCA) probe motion compensation approach was introduced. Original US sequence (2D + time) was processed to adjust the position of every US slice to the first one, and corresponding pixels values for new position were found based on the minimal Euclidean distance

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criteria. The concept of applying approach is demonstrated on Fig. 1.

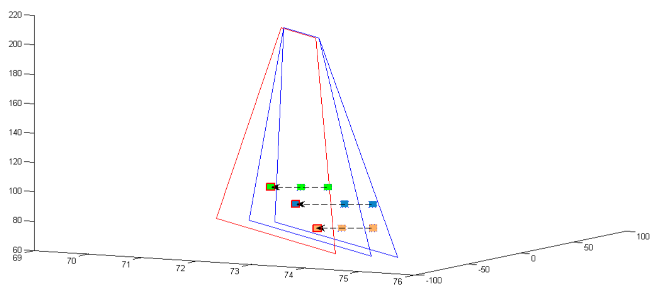

Fig. 1. Generation of probe motion compensation US sequence (first fame – red color; next frames – blue color – projected to the first frame)

After motion probe compensation we assumed, that, the only cause for variability within the images of the ultrasound sequence is the motion of organs, which is mostly due to breathing. Following the ideas proposed in [4], a PCA model was estimated from the pixels of the sequences, and assimilated the breathing signal to the coefficient corresponding to the main component of the PCA. In order to avoid deformation of the patient body caused by US probe pressure only pixels within a mask defined by lower, brighter and time-varying intensities region were retained. The discrimination of inhalation versus exhalation was performed visually by an expert, and the respiratory phase was estimated from the breathing signal using the phase of the Hilbert transform.

### *C. CT data analysis*

To evaluate the estimated US breathing signal, the corresponding planes for US frame position have been generated for every CT phases. The spatial correspondence between US and CT data was validated by radiologist and if necessary manually alignment. Then, temporal PCA analysis was applied on the corresponding 10 CT slices and we assimilated the breathing signal to the coefficient corresponding to the main component of the PCA. To compare the biomedical signals Hilbert phase were used [5]. In our case to compare the estimated breathing signal from US sequence to motion observed 4DCT the both CT and US phase signals are normalized and corresponding 4DCT phase for every US frame were found.

## III. Results And Discussion

The retrospective estimation of a breathing signal from the US image sequence was found based on main component of temporal PCA analysis. The example of the data analysis is presented below. Fig. 2 generally presents the manner to find the temporal correspondence. First breathing signal is estimated by score of main component of PCA analysis (Fig. 2a) and angle of Hilbert transform is calculated (Fig. 2b). After validation by radiologist the spatial US-CT correspondence and PCA temporal analysis, PCA score signal and phase of CT is presented (Fig. 2e and 2d). We observed that manual registration if necessary is mainly applied in craniocaudal direction. It is connected with the patient alignment procedure, which will be discussed in the next paragraph. The phase signals are presented as normalized values in percentage range. For each US frame value of the phase, signal is selected and corresponding 4DCT phase is found, which produce the correspondence plot (Fig. 2c). Fig. 3 presents image fusion in opposite breathing phase for the US, which signals analysis is presented in Fig. 2. The upper row presents inhale phase (US frame number: 250) and lower row presents exhale (US frame number: 175). The spatio-temporal correspondence was visually verified by radiologist. The correspondence between structures presented in US and CT images could be found, but the matching is not perfect. The possible reasons are:

- Linear interpolation is used to find the nearest 4DCT phase. In the future 4DCT deformation field could be used to estimate the deformation between decimal phases.
- The pattern of motion is not the same for 4DCT sequence and US sessions. 4DCT reconstruct an averaged respiratory cycle from a continuous acquisition covering between 10 to 15 cycles, using a helical acquisition and phase-tagging of respiratory signal acquired with a respiratory belt. During 30s US acquisition we observed usually a few whole breathing cycles.
- Patient position fixation system is not used. We asking the patient to remain as still as possible during and between the examinations, so as to minimize any motion or deformation. In the future, some fixation system will be used to manage global motion of the patient, which has impact to final accuracy of tracking [6].

The retrospective estimation of a breathing signal from the US image sequence was found based on main component of temporal PCA analysis. The similar analysis was performed for corresponding section plane of 4DCT sequence. By calculating Hilbert transform phase of main PCA score signal for both CT and US signals temporal correspondence could be find. The quality of final spatio-temporal correspondence, which can be observed in the CT-US image fusion, depends on accuracy of spatial correspondence. Our future work will be to introduce external markers both in breathing and no breathing part of the patient body to manage patient movement between CT and US session. Now we don't use any surrogate breathing signal. The markers attached to no breathing part of patient body helps to manage global patient motion between and during sessions. The tracking of markers attached to the breathing part of the patient can produce surrogate breathing signal [7]. The previous worked [8, 9] showed that could be useful for real-time comparison online patient breathing phase and phase estimation from CT images.

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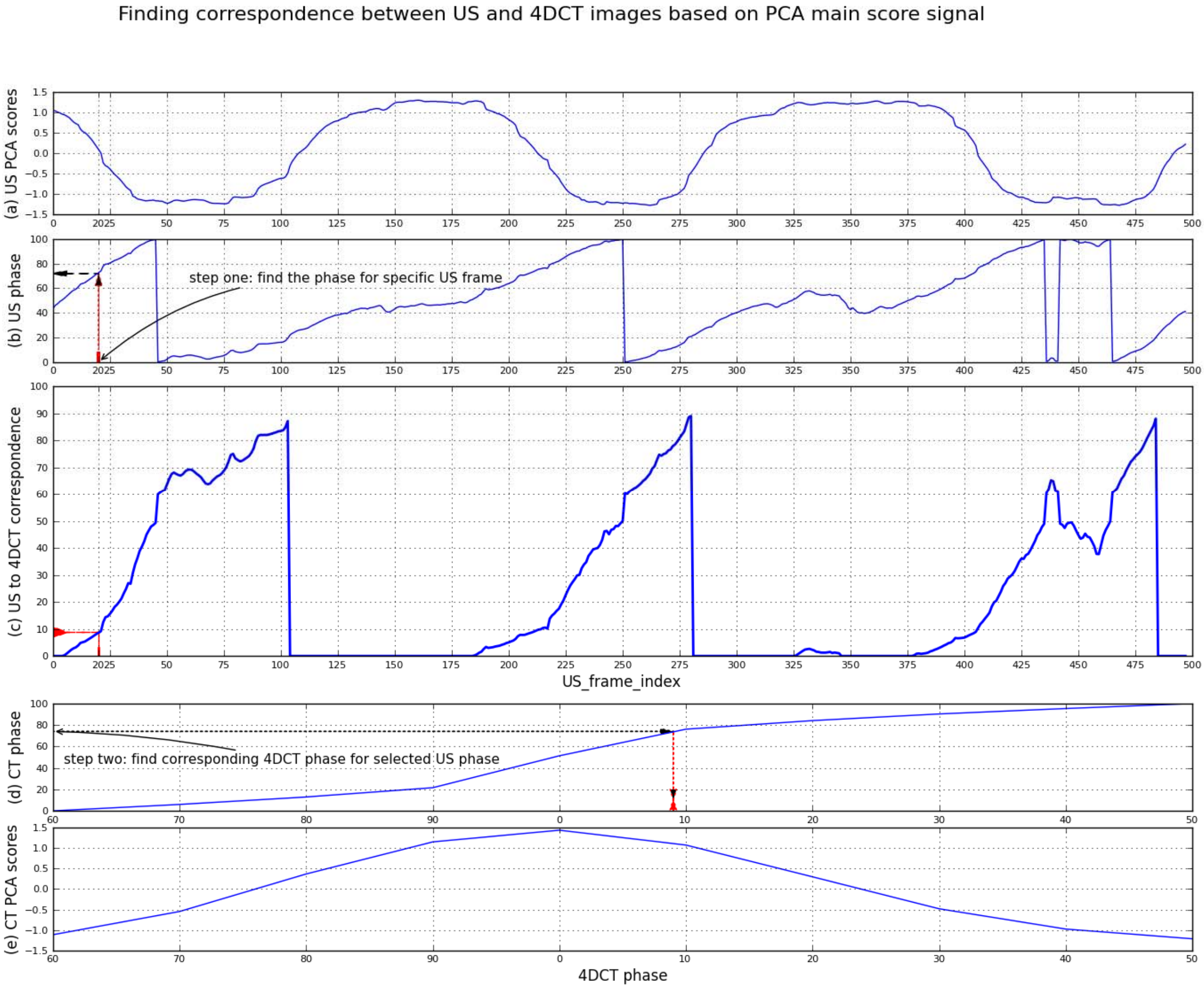


Fig. 2. Finding correspondence between US sequence and 4DCT images: main scores of PCA analysis for US sequence (a) and for 4DCT sequence (e), Hilbert transform phase signal for US sequence (b) and for 4DCT sequence (d), 4DCT phase corresponding for each US frame (c)

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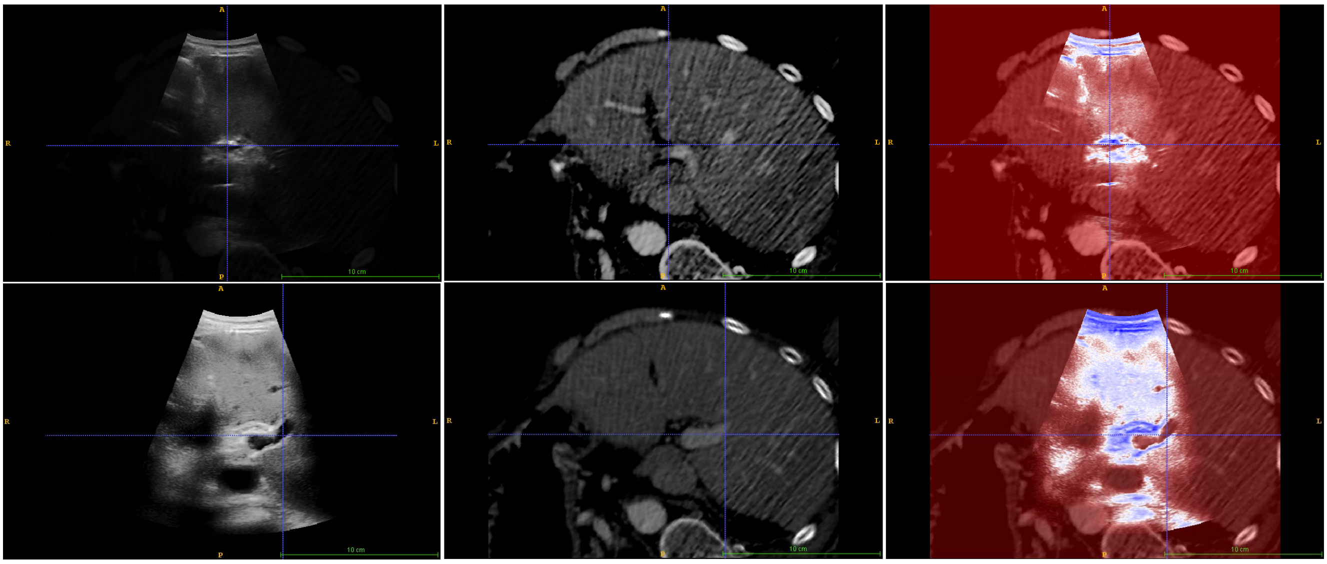


Fig. 3. . US image (left), slice of the 4DCT data at the corresponding respiratory phase and section plane (middle), fusion with US in color overlay (right). Top and bottom rows represent two different time steps: inhale (up) and exhale (down)