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# Improved Tracking Performance in High Frame Rate Imaging Using Iterative Phase Tracking

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***Abstract* - High frame rate ultrasound imaging is necessary to enable tracking of rapid dynamic events such as the carotid pulse wave velocity. Several studies have shown that it is feasible to use motion tracking methods that are applied on standard ultrasound frame rates also on very high frame rates. However, few studies have addressed the issue of accumulated tracking errors over vast numbers of frames during Lagrangian tracking. These could stem from e.g. limited signal-to-noise ratio often resulting from the use of plane wave imaging. One recently proposed solution was to combine motion tracking with an iterative tracking scheme. The purpose of this study has been to evaluate if the iterative tracking scheme could be exploited to increase the robustness of a phase-based tracking method in high frame rate plane wave imaging to track the carotid artery wall diameter. The results showed the iterative tracking scheme to give increased robustness with significantly (p<0.0003) less differences in measured lumen diameters between adjacent lines. Thus, this study enforces the suggestion to use the iterative tracking scheme during Lagrangian tracking in high frame rate imaging.**

***Keywords - High frame rate imaging, Motion estimation, Iterative tracking scheme, Accumulated errors***

## I. Introduction

The ability to measure amplitudes and velocities of short-time dynamic events in the cardiovascular system can provide important diagnostic information. For instance, several pathological processes leading to cardiovascular diseases starts with a gradual increase in arterial stiffness and thus an increase in arterial pulse wave velocity (PWV). To enable accurate non-invasive measurements of local PWV using ultrasound, high frame rate imaging is needed. Different types of motion tracking methods have been applied. Lou et al. described a method based on 1D cross-correlation used to measure PWV in vivo at a frame rate of 1127 Hz [1]. Hasegawa et al. used a phase tracking approach to measure PWV in vivo at a frame rate of 3472 Hz [2]. Nagaoka et al. made numerical comparisons between four different motion tracking methods along with an in vivo evaluation on PWV using one of them [3]. It was determined that phase tracking was an accurate method as long as aliasing was avoided.

These and other studies have demonstrated that it is feasible to measure local PWV with motion tracking using high frame rate ultrasound imaging. However, motion between consecutive frames during high frame rate imaging is small compared to measurement uncertanties caused by limited signal-to-noise ratios. This increases the accumulated error in Lagrangian tracking [4]. Since, in many applications motion tracking is performed during relatively long time periods, the tracking error, accumulated over the large number of frames obtained at high frame rate imaging thus increases even more.

To address this issue, during Lagrangian tracking, Albinsson et al. described an iterative tracking scheme that decreases the number of frames used to estimate the tracked location in each frame; thereby decreasing the accumulated error [4].

However, the proposed iterative tracking scheme was only evaluated in the longitudinal direction of the carotid artery and by using a block match approach. In other cases, such as estimations of the PWV, tracking is usually performed in the axial/radial direction and since other motion tracking approaches might differ in terms of accumulated errors, it would be of interest to evaluate also these circumstances. Therefore, the purpose of this study has been to combine phase tracking and the recently proposed iterative tracking scheme to evaluate if motion tracking in the axial/radial direction becomes more stable during high frame rate imaging of the diameter change in human carotid arteries.

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## II. Materials and Methods

### A. Data Collection

The common carotid artery of eight healthy, normotensive, human volunteers (age 26-66 years) was scanned 2 cm proximal to the bifurcation. The volunteers were in a supine position and had rested for at least 15 minutes prior to the ultrasound examination. The scanner used was a ULA-OP 256 [5] equipped with a 9-MHz center frequency probe (model LA533, Esaote S.p.A., Florence, Italy). Plane waves were transmitted with a pulse repetition frequency of 7000 Hz and the related raw echo signals were acquired during 1.7 s. The images were then exported to MATLAB (The Mathworks Inc., Natick, MA) for post-processing.

### B. Motion tracking

The arterial wall was manually outlined in the first frame and then automatically tracked in the radial direction using: A) a phase-based motion tracking method (PT) and B) the same phase-based method coupled with an iterative tracking scheme (IPT).

The PT method, previously described in [6], was somewhat simplified for use on RF data. In short, the local time-domain phase was extracted from the RF data using the Hilbert transform. Then, local average phase gradients were estimated through an averaging convolution. The local average phase differences between consecutive frames were estimated using the same averaging convolution. The local motions between frames were then derived using the phase differences divided by the phase gradients.

Iterative phase tracking (IPT), based on the work of Albinsson et al. [4], utilizes an iterative jumping process in its motion tracking algorithm. Instead of estimating the motion between consecutive frames, the PT is performed in levels with ever decreasing distance between the frames. The process starts by estimating the motion between frames separated with a factor of $2^k$, where in this study k = 5. Then, these frames are used to estimate the motion between themselves and the frames centered between them. In other words, if selecting only the frames separated by $2^{k-1}$ frames, every second frame is used to estimate the motion between itself and its neighbors. The motions are translated to change in positions with respect to the first frame (Lagrangian tracking). The process then continues with frames separated by $2^{k-2}$ and so on until all frames have been included. In each iteration the number of used frames double and for each frame there will be two estimations of the change in tissue position. These are averaged before moving on to the next iteration.

This means that the maximum number of motion estimations (where one motion estimation is defined as all calculations between two frames) using the iterative tracking scheme is

$$max\ nbr\ of\ estimations = 2k + \frac{N}{2^k} \tag{1}$$

$$where,\ \frac{N}{2^k} \in \mathbb{N} \tag{2}$$

$$if\quad N > 2^k + 1,\quad then\ 2k + \frac{N}{2^k} < N \tag{3}$$

where N+1 is the total number of frames used. Hence, using the iterative tracking scheme, if $k$ is chosen so that $N > 2^k + 1$, the maximum number of motion estimations, required to denote the position of the tissue in any separate frame, will always be lower compared to tracking consecutive frames. Also, the estimated position in each frame is the direct average of two calculations and an indirect average of several. The IPT method thus has less accumulated calculation errors than the PT method and gives, theoretically, a better representation of the actual movement in the ultrasound recordings.

### C. Pulse wave velocity estimation

The estimation of the PWV was based on the time delay in estimated changes in lumen diameter between adjacent lines. First, the acceleration of the lumen diameter for each line was derived. Then the Hilbert transform was applied to the acceleration curves. The time lag between adjacent lines were derived in a manner similar to the PT described in section II-B. However, instead of using two different frames, two adjacent lines were used. Specifically, the tracked positions in the acceleration curves corresponded to the foot of the lumen diameter curve (end diastole). The kernel size was ± 30 ms around this position. The average time lag between adjacent lines in combination with the distance between lines were then used to derive the PWV.

### D. Performance evaluation

The performance of the IPT method compared to the PT method was evaluated in terms of tracking stability. Since the ground truth was unknown it was assumed that the actual changes in lumen diameter between adjacent lines were negligibly small. Hence, lower standard deviation of the estimated motion between lines across the arterial wall was defined as better tracking stability. Further, a method resulting in lower variation between estimated PWV in different cardiac cycles within the same subject was considered more robust.

## III. Results

Figure 1 illustrates the tracking error after 11 000 frames (about 2 cardiac cycles). The colored line, denoting the onset of the intima layer, was originally very smooth (manually outlined in the first frame – Fig. 1A). The tracking was then performed line by line and local accumulated errors resulted in irregularities (Fig. 1B). It can be seen that the IPT gives a significantly smoother tracking when compared to PT. Figure 2 shows the standard deviation of the differences in tracked lumen diameter between adjacent lines. IPT was significantly ($p<0.0003$) more stable than PT (median = 0.035 mm (PT) and 0.022 mm (IPT)). Figure 3 shows the change in diameter over time (in the vertical direction) versus adjacent lines (in the horizontal direction) for PT and IPT, respectively. Again, the smoother coloring in Fig. 3B illustrates that IPT is more robust compared to PT.

The PWV was estimated to be 5.12±1.68 m/s using IPT and 5.52±1.93 m/s using PT. However, neither the difference in estimated PWV nor the variation in estimated PWV between different cardiac cycles was significant ($p=0.66$ and $p=0.86$ respectively) depending on the tracking method used.

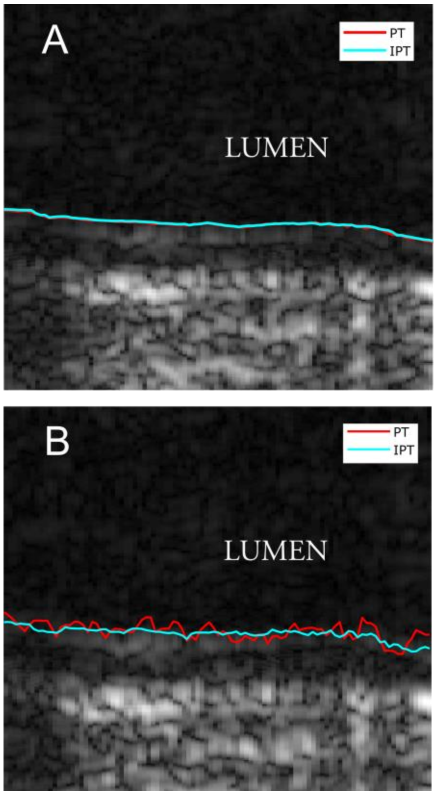


*Figure 1. A) Manually outline of the onset of the intima layer in a carotid artery wall. In this first frame, the starting lines for PT and IPT are on top of each other. B) Illustration of the accumulated tracking error (irregular pattern) after 11 000 frames.*

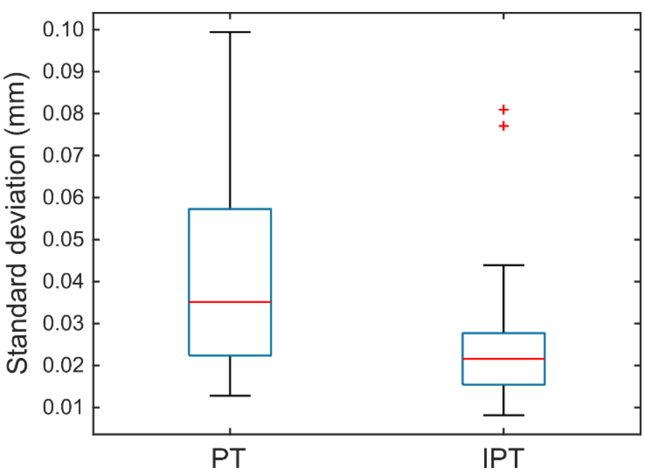


*Figure 2. The standard deviation of the differences in tracked diameter change between adjacent lines. The difference between PT and IPT is significant (p<0.0003).*

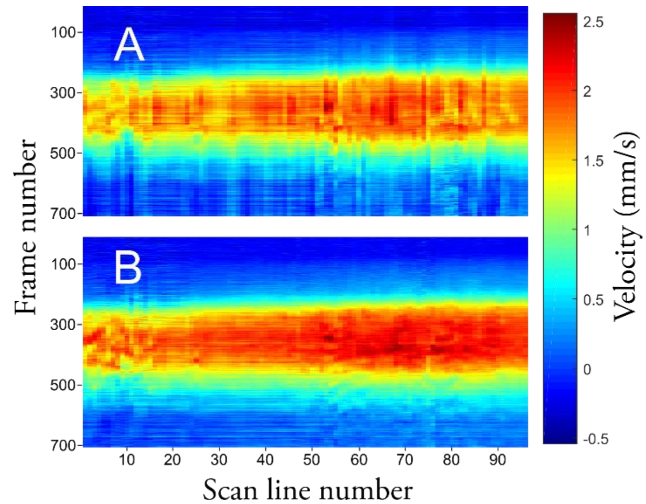


*Figure 3. A) Velocity in part of the measured diameter curve (vertically) for different adjacent lines (horizontally) using PT. B) same as in A but when using IPT. It can be seen that IPT produces more robust/smooth tracking*

## IV. Discussion and Conclusions

This study compared the tracking stability in high frame rate ultrasound imaging based on radial/axial motion tracking using a phase-based approach, with and without the use of a previously proposed iterative tracking scheme. The tracking was performed on the carotid artery wall, which also enabled subsequent analysis of the PWV.

The results show the motion tracking when utilizing the iterative tracking scheme to be significantly more stable. Hence, in applications were Lagrangian tracking is used to estimate motion in high frame rate imaging, this study enforces the suggestion to use an iterative tracking scheme. This will likely be even more useful if the tracking is performed during a longer period of time.

The reasons behind the improved performance are probably three-fold:

1) All tracking methods have estimation errors. The fewer estimations used to a given frame the less accumulated error;
2) The variation/standard deviation of tracking is decreased as every estimate is based on the average of two estimates;
3) Many tracking methods give a biased estimate. The biasing is decreased as the two estimates arise from anteroposterior frames.

However, in the case of estimating PWV the iterative tracking scheme seems not to provide additional robustness. This is probably due to the relatively large amount of averaging performed during the assumption that there is a linear time dependency between the motion along adjacent lines.

This study was based on a single phase-based motion tracking method (with or without the iterative tracking scheme). It is possible that the results may differ when using other motion tracking methods. However, the combination of these results and those by Albinsson et.al [4] using a block-matching approach, makes it likely that the iterative tracking scheme improves robustness also for other types of motion tracking methods.

It should be noted that the execution time is longer when using the iterative tracking scheme. Also, when using phase-based methods the iterative tracking scheme may potentially suffer from aliasing if the initial frame separation factor $2^k$ is set too high. If so, this number has to be decreased to the next level, $2^{k-1}$.

In conclusion, the proposed IPT scheme is superior to PT in motion tracking at high frame rates and could be exploited to limit cumulative errors. Particularly in cases demanding less spatial averaging.

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