Cardiac Phase Detection in Intravascular Ultrasound Images

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Abstract

Image gating is a problem related to image modalities which involve quasi-periodic moving organs, such as the heart. Therefore, during intravascular ultrasound (IVUS) examination, with automatic pullback, there is cardiac movement interference. This work aims to obtain gated images based on the images themselves, so it would be possible to reconstruct 3D coronaries with temporal accuracy. From the images, we extracted signals based on average intensity (AI), and, from consecutive frames, average intensity difference (AID), cross-correlation coefficient (CC) and a new approach using mutual information (MI). Firstly, our method was tested in simulated images, with different speckle noise level, contrast and patient's characteristics. The results have shown our method was able to achieve more than 95.0% of true positives and 2.3% of false positives, for all signals. Afterwards, we tested in a real IVUS examination, with ECG as gold-standard, where there were achieved 97.4% of true positives (CC and MI), and 2.5% of false positives.

1. Introduction

Currently, intravascular ultrasound (IVUS) is considered the method of choice to examinate the coronary vessel wall. The IVUS procedure is performed using an ultrasound transducer located at the tip of a dedicated catheter, which is firstly positioned distally in the target vessel and then is slid backwards with a motorized continuous pullback. The vessel is imaged as a sequence of cross-sectional slices, from distal to proximal portions of the artery. Due to heart movement during the cardiac cycle, the tip of the IVUS catheter (image acquisition reference) may move freely inside the vessel and assume different positions in a quasi-periodic way. Reference displacements might occur radially, laterally, rotationally and/or longitudinally. Therefore, during continuous IVUS imaging there is an interference of the cardiac movement and images might be acquired out of spatial order [1]. This fact is readily evident when observing the typical saw-tooth-like aspect of a longitudinal sequence of IVUS images. A method able to separate groups of images acquired at the same point in the cardiac cycle would obviate the artifacts related to heart movement and allow future dynamic studies.

The aim of this work is to detect images in the same cardiac phase, based only on the image sequence information. It is important to notice that most of the existing exams have no additional reference signal, as the electrocardiogram (ECG). Furthermore, this method would make possible the 3D reconstruction of coronary vessels with temporal and spatial accuracy in different cardiac phases, instead of a single one in the ECG-gated IVUS acquisition. This would allow dynamic studies of the vessel walls.

2. Materials and Methods

2.1. Materials

First of all, the methodology was tested in simulated images and, afterwards, it was also tested in a real IVUS examination, with ECG as gold-standard. Images were synthesized using Matlab® R13. The simulated image took a normalized intracoronary pressure signal based on [2], as basis for artery compliance and catheter tip displacement movements. We have tested different contrast, speckle noise and patient´s characteristics, totalizing 90 tests, with 1025 frames each, at a 30 frames/s acquisition rate. The real IVUS examination tested had 897 frames, at 30 frames/s rate, and was compared to the ECG as gold-standard. The ECG was recorded in a independent computer [2] and the acquisition was manually started on both the IVUS machine and ECG recorder. Acquisition delay between the two recording machines is compensated in the alignment step for validation purposes.

2.2. Methods

The proposed method involves synchronization of four different signals originated from the image sequence and then comparison with cardiac phase reference. The synchronization consists of three steps: signal extraction from images, wavelet-based filter and phase detection. The validation step compares the phase detection from the signal with the ECG reference. It was divided into two steps: alignment and metrics calculation. Figure 1 shows block diagrams of the synchronization and validation processes.

The signals were calculated from de image sequence based on Average Intensity (AI) and Average Intensity Difference (AID), according to [3], Cross-Correlation Coefficient (CC) [1] and a new approach using Mutual Information (MI) [4] of consecutive images. The wavelet-based filter [5] used was a four-level decomposition of the signal, using Daubechies4 wavelet. With the detail coefficients, the signal was recomposed. Then, the phase was detected on the crescent zero-crossing of the signal. Notice that it is not important determining a specific phase, but to have assured images in the same phase. From this information, it is possible to access other cardiac phases. In the validation step, alignment was necessary to adjust the phase detection to the reference, in order to be able to compare. The metrics analyzed were true positive and false positive rates and phase detection precision.

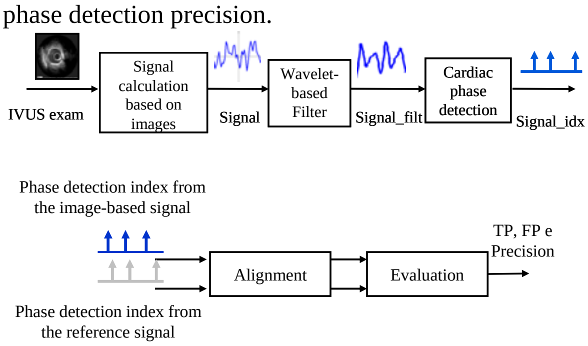

Figure 1. Block diagrams: above, from synchronization process and below, from validation process.

3. Results

The results from simulated images have shown that our method was able to achieve more than 95.0% of true positives and 2.3% of false positives, for all signals. For the real examination, we were able to achieve 97.4% of true positives (CC and MI), and 2.5% of false positives. The phase detection precision of the heartbeats had mean value close to zero ms and standard deviation of approximately 60 ms (2 frames).

4. Discussion and Conclusion

The proposed methodology reached the initial aim to detect images in the same cardiac phase. The results on synthesized IVUS images showed that the methodology is robust to contrast, speckle noise and “patient” variation implemented. Besides, its application to a real examination achieved similar results to the simulation. In addition to that, the wavelet-based filter had important contribution to the methodology. Furthermore, the process is independent of parameters settings or thresholds. Moreover, the validation process is a new approach to previous works, because it considers detailed comparison, beat to beat. However, the methodology should be tested in a wider range of IVUS examinations.

5. Acknowlegments

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6. References

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