High-Speed Automatic Segmentation of Intravascular Stent Struts in Optical Coherence Tomography Images

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Abstract
Recently, Optical Coherence Tomography (OCT) has become one of the preferred clinical techniques for intracoronary diagnostic imaging. Thanks to its high resolution imaging capability, the OCT technique allows to identify microscopic features associated with various types of coronary plaque and to track of stent position, malaposition and neo-intimal tissue growth after stent implantation. Accurate high resolution visualization of stent struts can help to examine the status of implanted stents potentially leading to proper treatment of the coronary artery disease. However, unfortunately, current stent identification involves time-consuming segmentation algorithms sometimes requiring labor-intensive manual analysis process. To resolve the problem, we propose a high-speed automatic segmentation algorithm of intravascular stent struts in OCT images.

Unlike the other "automatic" stent segmentation algorithms, which are mainly based on time-consuming machine learning algorithms with manual addition and removal of stent struts for correction during the analysis process, our algorithm does not require any manual adjustments of stent struts. Our algorithm first analyzes 10 consecutive cross-sectional OCT images to take boundary information into account to enhance the accuracy of guide-wire segmentation and lumen segmentation. Then, it performs stent segmentation by automatically eliminating guide-wire signals using the previous segmentation results. The implementation of our algorithm uses the Intel(R) IPP library on CPU and the CUDA technology on GPU, which achieves the average analysis time of 0.28s/frame and the detection rate ranging from 84% to 88.6% for about 120 continuous images per patient. As such, the proposed algorithm is robust and fast enough to be integrated in clinical routine.

Keywords: OCT images, stent segmentation, CUDA

Introduction
The high resolution imaging capability of Optical Coherence Tomography (OCT) allows accurate visualization of stent struts potentially leading to proper treatment of the coronary artery disease. However, current stent segmentation algorithms based on time-consuming methods, such as machine learning, take much time [1-3], and some of them requires manual adjustments of stent struts [3]. Such time-intensive algorithms may be useful for processing huge OCT images after achieving them, but they are too slow to be usable in hospital operating rooms for clinicians to decide whether additional ballon inflation is needed. In this paper, we propose a high-speed automatic stent segmentation algorithm fast enough tob e usable in operating rooms.

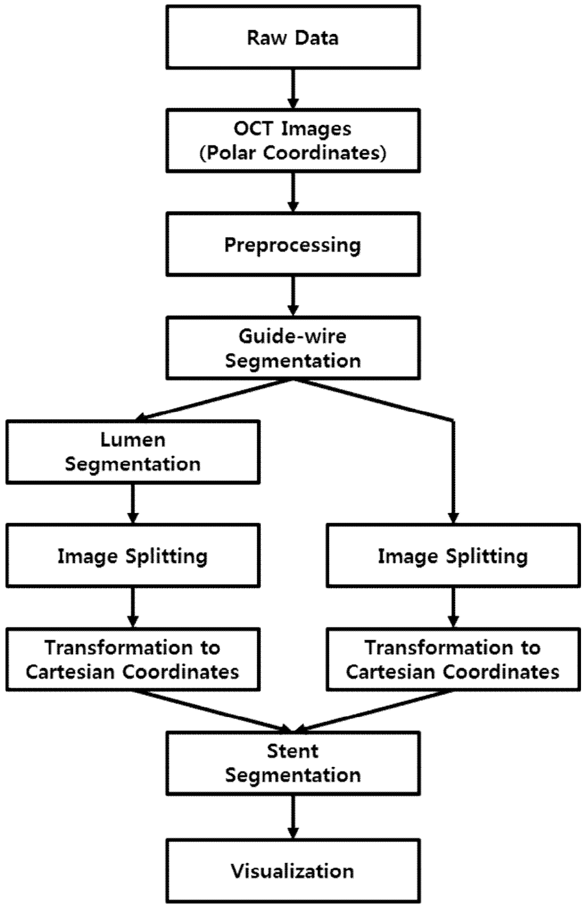

Fig. 1 Flowchart of the algorithm

Method
Our segmentation algorithm is fully automatic as Fig. 1 presents except that we set up some system-dependent parameters manually before running the algorithm. Once we set up the parameters, we do not need to change them as long as the Optical Frequency Domain Imaging (OFDI) system remains the same.

The algorithm takes raw data stored in hard disks as its input. The raw data is then converted to OCT images by using the Intel® IPP library on CPU and CUDA technology on GPU.

Table 1 The results of our automatic stent segmentation algorithm

Sequence Number	Number of Images	Number of Stents	Number of Segmented Stents	Accuracy (%)	Running Time (sec)	Running Time per Image (sec)
1	126	1,519	1,313	86.4	35.140	0.279
2	126	1,087	913	84	35.266	0.280
3	117	1,106	980	88.6	32.680	0.279
Total	369	3,712	3,206	86.4	103.086	0.279

Preprocessing

Before performing any segmentations, we first remove noises caused by a catheter and an optical fiber in each OCT image by applying the Average filter to blur the images. In order to enhance the accuracy of both guide-wire and lumen segmentation algorithms, we build "long images" by attaching 10 OCT images side by side.

Guide-wire Segmentation

Unlike most stent segmentation algorithms which do not consider OCT images with guide wire or remove guide wire during preprocessing, we use guide-wire information for stent segmentation. We use three observations to reduce false positives in guide-wire segmentation. First, the position of a guide wire in each OCT image is always in the upper third of the image. Secondly, the position of a guide wire seldom changes between adjacent images. Finally, the size of a guide wire almost never changes between adjacent images. Using these observations, we apply Otsu's threshold [4] to the long images we built in the preprocessing step to segment guide wire.

Lumen Segmentation

Our lumen segmentation is based on Z. Wang *et al.*'s algorithm [5]. They apply Otsu's threshold to OCT images and find the brightest pixel for each A-line. When a detected lumen candidate is disconnected, they connect the disconnected pixels using interpolation. However, their algorithm does not work when it cannot find lumen information for either edge of an OCT image because it cannot apply interpolation. To resolve the problem, our algorithm uses the long images to compensate edge information, which results in more precise lumen segmentation.

Stent Segmentation

Like most automatic stent segmentation algorithms [6-9], our algorithm uses the properties of stents presented at each A-line such as the peak intensity and the existence of stent shadow. In addition, we use the results from both guide-wire segmentation and lumen segmentation. By eliminating the detected guide wire from consideration and by calculating the average distance between the segmented lumen and stents and removing outliers, we could reduce false positives and improve the accuracy of stent segmentation.

Results

The results of the entire stent segmentation algorithm are shown in Table 1. The total number of images used is 369 from 3 patients and the average accuracy of the algorithm is 86.4%. The accuracy of the algorithm is comparable to others, but its high speed 0.279 second/image is unprecedented.

Conclusion

We present a high-speed automatic stent segmentation algorithm, which takes advantage of both guide-wire and lumen segmentation. The high speed and accuracy of the algorithm make it acceptable for clinicians to use in hospital operating rooms.

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