Automatic Coronary Artery Segmentation Using Spatiotemporal Analysis

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Introduction. The segmentation (background extraction) of coronary arteries (CA) for diagnostic purposes, such as measuring vessel diameters and analysing aneurism morphology, is typically performed on naturally noisy images with computer-aided techniques requiring time-consuming and operator-dependent visual judgement. This can lead to intra- and inter-observer variability. We propose a fully automatic and efficient CA segmentation framework using a spatiotemporal processing approach on selective angiographic image sequences capable of enhancing visual inspection, objectively computing vessel diameters, and detecting probable aneurism areas on the arterial tree.

Methods: The steps for automatic CA segmentation are: 1) angiographic sequences are retrospectively gated by synchronizing ECG tracings with frame acquisition periods, producing an array of end-diastolic phase images; 2) radiographic speckle and noise are removed using dual-tree discrete wavelet transform convolution; 3) intra-structure illumination non-uniformities are normalized with homomorphic filtering; 4) vessels and other curve-like shapes are extracted with an efficient multi-scale recursive anisotropic Gaussian filter bank. This is followed by 5) the removal of non-vessel structures using multi-pass, sequential optical flow motion analysis on the sequential curve-images, tracking the spatiotemporal diffusion of the radio-opaque tracer. Subsequently, 6) a motion-mask is computed with kernel graph-cuts image segmentation on the flow sequence, effectively isolating the arterial tree while a curve-connectivity pruning routine mitigates erroneous vessel sectioning and removes non-relevant, floating structures or artefacts. Aneurism are then automatically detected and highlighted in the final segmented CA image using a morphological analysis framework.

Results: The segmentation performance on 38 angiographic sequences, comprised of 13 patients (age range 2-17 years), was evaluated qualitatively in terms of vessel shape preservation and non-vessel structure presence inside the arterial tree region. Average segmentation time was 81.03±23.08 sec. for full end-diastole sequences (0.38±0.11 sec. per frame). From a qualitative perspective, the framework produced connected arterial trees preserving the original vesselness with few remnants of non-vessel structures (vertebrae, ribs, catheter) that were in-closed in the high-motion area. Some smaller vessels, characteristically located at the ends of the arterial tree and thus presented lower contrast in the raw images where suppressed. Quantitative performance was assessed by comparing the differences between 641 vessel diameters manually measured on the raw and automatically computed on the segmented images. Accordingly, there were no significant differences (one-way ANOVA, mean difference=0.0230±0.0825 mm, \( p=0.233 \)). Finally, aneurisms were successfully detected on data from Kawasaki disease patients.

Discussion. The fully automatic framework presented here effectively isolates the arterial tree from angiographic sequences using a novel spatiotemporal approach. Vessel diameters and morphology are not significantly affected by the process. In addition, the system’s aneurism detection and auto-diameter measurement capabilities, coupled with its rapid execution time suggests its potential usability for diagnostic purposes of vascular structures such as CA, where the mitigation of intra- and inter-clinician measurement variability is salutary.

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