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● *Original Contribution*

ANALYSIS OF CAROTID ARTERY TRANSVERSE SECTIONS IN LONG ULTRASOUND VIDEO SEQUENCES

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Abstract—Examination of the common carotid artery (CCA) based on an ultrasound video sequence is an effective method for detecting cardiovascular diseases. Here, we propose a video processing method for the automated geometric analysis of CCA transverse sections. By explicitly compensating the parasitic phenomena of global movement and feature drift, our method enables a reliable and accurate estimation of the movement of the arterial wall based on ultrasound sequences of arbitrary length and in situations where state-of-the-art methods fail or are very inaccurate. The method uses a modified Viola–Jones detector and the Hough transform to localize the artery in the image. Then it identifies dominant scatterers, also known as interest points (IPs), whose positions are tracked by means of the pyramidal Lucas–Kanade method. Robustness to global movement and feature drift is achieved by a detection of global movement and subsequent IP re-initialization, as well as an adaptive removal and addition of IPs. The performance of the proposed method is evaluated using simulated and real ultrasound video sequences. Using the Harris detector for IP detection, we obtained an overall root-mean-square error, averaged over all the simulated sequences, of 2.16 ± 1.18 px. The computational complexity of our method is compatible with real-time operation; the runtime is about 30–70 ms/frame for sequences with a spatial resolution of up to 490 × 490 px. We expect that in future clinical practice, our method will be instrumental for non-invasive early-stage diagnosis of atherosclerosis and other cardiovascular diseases. (E-mail: rihak@feec.vutbr.cz)

Key Words: **Artery, Ultrasound, Image processing, Video processing, Optical flow, Tracking, Interest point, Viola–Jones detector, Hough transform, Lucas–Kanade method.**

INTRODUCTION

Background and motivation

As the average age of the global population increases, it is desirable that people with high cardiovascular disease risk be diagnosed and receive appropriate treatment. According to World Health Organization statistics, cardiovascular diseases caused 31% of all deaths in the year 2015 (Department of Health Statistics and Information Systems 2016). Therefore, early detection is an important goal, and this poses challenges for the development of medical devices and diagnostic methods.

One of the most important methods for detecting cardiovascular diseases is clinical examination of the arteria carotis communis, or common carotid artery (CCA), using an ultrasound (US) video sequence in B-mode. From this video sequence, the movement of the arterial wall can be analyzed as a function of time. This movement depends on diagnostically relevant parameters of the artery such as tissue elasticity (Chen et al. 2009); arterial stiffness (Duprez and Cohn 2007); compressibility, compliance or distensibility (Gosling and Budge 2003); and pulse wave velocity (Milnor 1982). With a linear probe, the CCA can be scanned in a transverse (perpendicular) or longitudinal manner. The longitudinal scan represents the arterial wall as two almost parallel lines, whereas the transverse scan represents it approximately as a circle. Suitable parameters describing the dynamics of these geometric structures are important diagnostic markers.

In this study, we developed and tested a non-invasive, fully automated method for the analysis of arterial wall motion. More specifically, we aimed to estimate and track the time-varying CCA radius, based on a sequence of CCA transverse sections in a US video sequence. The video sequence is captured by a handheld US probe over several minutes. This examination scenario tends to produce two

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important artifacts: global movement and feature drift. The main goal of our work is to develop strategies and algorithms for compensating global movement and feature drift, to enable successful application of our method to examinations of arbitrary duration.

A global movement arises, for example, when the examiner searches for the artery position by moving the US probe, which can even cause the artery to move beyond the image border and back during the examination. The feature drift phenomenon is related mainly to micromovements (shaking) of the probe and/or tissue: the scatterers reflecting the US wave (echogenicity) are randomly appearing and disappearing in the US images, which may lead to errors in tracking the scatterers. Existing methods for a US-based analysis of arterial wall motion (see the next subsection for a survey of the state of the art) are not suited to the analysis of long video sequences because they do not properly take into account the phenomena of global movement and feature drift. The proposed method removes this limitation.

State of the art

Existing methods for US-based analysis of arterial wall motion typically perform an explicit or implicit tracking of specific scatterers of particular relevance, which are referred to as *interest points* (IPs) or *features*. An IP is a "significant image point" with a high-intensity gradient (Harris and Stephens 1988), which corresponds to a high-echogenicity part of the tissue being scanned and is closely related to speckle (Tat et al. 2017). When estimating the motion of the arterial wall from noisy US video sequences, it is advantageous to track elements in successive US images that define the significant structure of the arterial wall. For the choice of such elements, IPs are natural candidates. Accordingly, tracking IPs is a well-established approach to motion analysis in US video sequences.

A number of methods for IP-based motion tracking have been proposed. These methods make use of the Lucas–Kanade algorithm (Říha and Potúček 2009), block matching (Golemati et al. 2003; Tat et al. 2017; Thangavel et al. 2014), block matching in combination with a Kalman filter (Gastounioti et al. 2010; Zahnd et al. 2013), the "echo tracking" (modified block matching) algorithm (Cinthio et al. 2005, 2006) or a combination of affine optical flow with multiscale image analysis (Gastounioti et al. 2011). Several methods perform a determination of the optical flow (Horn and Schunck 1981), with a preceding manual selection of the region of interest containing the arterial wall. We note that all these methods, with the exception of that of Říha and Potúček (2009), analyze a longitudinal cut of the artery. A comparison of different optical flow algorithms by Golemati et al. (2012) obtained the best results with the Lucas–Kanade algorithm, which, however, requires an explicit determination of the IPs prior to optical flow determination. Overall, optical flow algorithms provide good performance in estimating movement in US video sequences corrupted by noise. Therefore, we will use an optical flow algorithm—more specifically, the Lucas–Kanade algorithm—in our method.

Optical flow determination can be strongly affected by global movement and feature drift. Current methods for US-based analysis of arterial wall motion do not include a compensation of these detrimental effects. As a consequence, they are able to accurately track the arterial wall only for short US video sequences spanning a small number of cardiac cycles. The proposed method removes this restriction by including an explicit compensation of global movement and feature drift.

In addition to tracking IPs, the proposed method also performs an automated estimation of the region containing the arterial wall transverse section and an automated detection of IPs. State-of-the-art methods for estimating the region containing the arterial wall transverse section use pulsative movement analysis (Říha and Beneš 2010), the Viola–Jones algorithm (Říha et al. 2013), circular shape detection (Abolmaesumi et al. 2000), template matching (Liu et al. 2013), gradient analysis (Thangavel et al. 2014), an elliptic model of the arterial wall (Wang et al. 2009) or the Star algorithm combined with the elliptic model (Guerrero et al. 2007). Methods for explicit IP detection include the Harris detector (Harris and Stephens 1988), the Good Features To Track (GFTT) method (Shi and Tomasi 1994), the Features From Accelerated Segment Test (FAST) method (Rosten and Drummond 2006), scale-space or pyramidal (size-independent) variants of detectors (Lindeberg 1994) and combinations of detectors with feature descriptors, such as Scale Invariant Feature Transform (SIFT) (Lowe 1999) and Speeded Up Robust Features (SURF) (Bay et al. 2006). These methods were successfully used for US-based analysis of arterial wall motion, as described and referenced at the beginning of this section.

Contributions and organization of article

The proposed method is, to the best of our knowledge, the first method allowing an analysis of the movement of the arterial wall based on US video sequences of arbitrary length. It is able to automatically detect, track and measure the CCA in a transverse-section US video sequence of arbitrary duration. This ability results from a monitoring of global and local CCA parameters, which are used to compensate global movement and feature drift, respectively. The global (macro) parameters of the CCA are the center point and radius of a circle describing the arterial wall cross section. The local (micro) parameters of the CCA are related to IPs that experience feature drift. The proposed compensation of global movement and feature drift based on global and local CCA parameters is a novel approach that enables a highly robust and