The Sequential Detection of Artery Sectional Area Using Optical Flow Technique

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Abstract: - The main goal of presented work is reliable detection of sectional area of an artery during a time in the in the B-mode ultrasound video sequence frames. Presented algorithm is a part of a long-term project [1]. The innovative concept of the work rests in the automatic monitoring of artery border tissue movement using the Lucas-Canade optical flow technique [2]. Invariant features uniformly selected in the artery border area are tracked in whole video sequence. Volume cut is estimated by using fitted ellipse from set of these points, so that the most suitable artery shape will be denoted in every frame. Output cardiac cycle curve can be used for analysis of volumetric changes of artery in arbitrary body part which can be displayed using a B-mode sonograph.

Key-Words: - Optical Flow, Feature Detection, Artery Section Area, B-mode Ultrasound Image, Cardiac Curve

1 Introduction

A long-term effort for blood circulatory system analysis led to developing of many techniques, mostly using blood pressure measurement using an inflatable cuff. The sonographic displaying is being used in practise of medicine more likely for a pathology finding in combination of a B-mode sonographic image with a Doppler analysis of blood flow. Unfortunately, the Doppler techniques are not very dependable on exact geometric dimensions of an artery and are very sensitive to a sonographic probe position, orientation, movement etc. There is a possibility of direct B-mode image processing in order to track artery boundaries and to analyse its changes in time (in sonographic video sequence). This dependence (geometric parameters on time or on the number of frame in the video sequence) may be used for different analyses, namely being related to a blood pressure and artery elasticity. Hence, the purpose of our work was the artery section area determination in the sonographic video sequence, computation of its area and plotting to a graph.

There exist some methods proposed by other authors in recent years which extract artery boundary by different ways. A segmentation process is usually used for this purpose as namely Canny edge detection, wavelet filtering, watershed or fuzzy C methods described in [3] and in consequential articles. The state-of-the-art methods are in their principles very sensitive to random artery abnormalities. On the other hand, the proposed method takes as a challenge the minimization of these problems and estimation of cardiac curve from noisy and low quality data.

Main advantages of the method being presented consist in fact that it doesn’t need setting of various parameters. It is almost automatic, high accurate and reliable due to various image qualities. Borders of artery are not usually high perceptible which makes it difficult to be detected. Our method does not depend on clearly visible border, which increases its reliability. It can follow the measured artery even when the sensor moves (which causes global motion in the image).

In the beginning, there were established some properties of a method being founded. The method should be preferably non-parametric, automatic, high accurate and reliable. In the view of high-accuracy and reliability of artery shape detection in general first frame, the artery circle can be situated in any part of the image. Moreover, the image contains different descriptive information and the region of interest may be different for different source data (see Fig. 1).

For that reason, the method comprises first and only one manual step, where the operator has to do a simple
initialisation which means denotation the artery in an image. Some tests of the carotid shape reliable detection in a common source image using Hough transformation have been done (as for example in [4]) but the result was not 100% which is unacceptable in the practice of carotid shape analysis. Hence, some manual algorithm input is supposed. The process of cardiac cycle determination is then fully automated with the exception of a small part of the initialisation step.

Fig. 1 Raw ultrasound image after acquisition.

2 The method description

The complete method consists of several consequential image processing steps. The main idea is to track a movement of tissue near the artery border. This is realized by features localised on the artery edge. These features are selected as distinctive points which are tracked during the whole video sequence. Resulted artery cut is computed as an area bounded by them.

2.1 Initialisation

In first step, some suitable features have to be selected, so that the artery edge can be tracked. It is done by finding most distinct corners in the image. Founded feature positions are distanced enough one from another by considering the most distinct corners and checking that the distance between the newly considered feature and the features considered earlier is larger than minimal distance. It ensures uniform distribution of selected features in defined area.

This initialization should be done in the first frame of the video sequence regarding to next processing steps. The proposed procedure is semi-automatic (as mentioned in chapter 1) which means that some area have to be denoted for detecting of features. The area has to safely include an artery border, so the suitable shape has been founded in the ring with variable diameter and fixed border width. Example of the initialisation step can be seen in Fig. 2.

The ring (defined by user) can be used as a mask for the method of features to track finding. It is a method implemented in the OpenCV library [5]. Principle of the function is following.

Fig. 2 Initialisation step: the ring-shaped mask for a good features to track finding procedure (the cut from source image).

Firstly, the Hessian \( H(f(x,y)) \) of the image function \( f(x,y) \) has to be computed, which means the matrix of image second derivatives:

\[
H(f(x,y)) = \begin{bmatrix}
\frac{\partial^2 f}{\partial x^2} & \frac{\partial^2 f}{\partial x \partial y} \\
\frac{\partial^2 f}{\partial y \partial x} & \frac{\partial^2 f}{\partial y^2}
\end{bmatrix}.
\] (1)

Then some neighbourhood \( S(p) \) of every coordinate in resulting second derivative functions are counted in. This can be written as

\[
M(x,y) = \left( \begin{array}{c}
\sum_{S(p)} \frac{\partial^2 f}{\partial x^2} \\
\sum_{S(p)} \frac{\partial^2 f}{\partial x \partial y} \\
\sum_{S(p)} \frac{\partial^2 f}{\partial y \partial x} \\
\sum_{S(p)} \frac{\partial^2 f}{\partial y^2}
\end{array} \right).
\] (2)

Hence, there is a \( 2 \times 2 \) matrix for every pixel in an image. For this matrix eigenvalues are then computed for examination if there is a corner or not in terms of a method introduced in [6]. The method is denoting pixel as corner (good feature to track) if the smaller eigenvalue of the two eigenvalues is greater than some threshold. Thresholded potential corners are then reduced by further procedure which removes features being accumulated in some areas where the Euclidean distance between particular features is smaller than defined value.

Consequently, the initialization step produces a group of
features (their coordinates in an image) under the ring-shaped mask as can be seen in Fig. 3.

![Fig. 3 Detected features denoted in source image after the initialisation procedure.](image)

2.2 Artery sectional area computing

In the method, the artery is represented by a number of features after the initialisation step. The features are spread around the artery border which implies using of some fitting function. The shape being searched is given by artery cut anatomy and mostly comes up to a circle or ellipse (see Fig. 4).

![Fig. 4 Ellipse fitted to detected features.](image)

That’s why the features coordinates are processed in the least-squares sense and the best-fit ellipse parameters are computed. Based on this, the ellipse area can be computed as a pixels number in approximated artery sectional area for every frame in analysed video sequence.

Ellipse area can be computed simply by using the equation

\[ \text{ellipse area} = \pi \cdot \text{major axis} \cdot \text{minor axis}. \] (3)

The problem is how to track the features in whole video sequence, which is the problem whose solving is described in next chapter.

2.3 Features tracking in video sequence

For the sparse features tracking is suitable to use the above mentioned method for optical flow determination by Lucas-Kanade [2]. Its principle lies mainly in the applications of brightness constancy assumption

\[ E_x u + E_y v + E_t = 0, \] (4)

where \( E(x, y, t) \) is the video sequence, \( E_x = \frac{\partial E}{\partial x}, E_y = \frac{\partial E}{\partial y}, E_t = \frac{\partial E}{\partial t} \) and \( u = \frac{dx}{dt}, v = \frac{dy}{dt} \). The optical flow vector \((u, v)\) is searched for every feature which defines the shift of a given feature pixel \( E(x, y, t) \) in next image in video sequence \((t+1)\) step. In the equation (4) are two unknowns in one equation and so there has to be defined another equations based on spatial coherence assumption which leads to take into account \( n \) neighbouring pixels (mostly in squared window). This gives an over constrained system of linear equations written in matrix form as

\[
\begin{bmatrix}
E_{x1} & E_{y1} \\
E_{x2} & E_{y2} \\
\vdots & \vdots \\
E_{xn} & E_{yn}
\end{bmatrix}
\begin{bmatrix}
u \\
v
\end{bmatrix}
=
\begin{bmatrix}
E_{t1} \\
E_{t2} \\
\vdots \\
E_{tn}
\end{bmatrix}
\] (5)

which can be solved in the least square sense.

Moreover, the algorithm for optical flow estimation has two improvements in its implementation used from OpenCv library [5]: iterative scheme for better computational accuracy and pyramidal scheme for better determination of movements being larger than the size of analyzed window. These improvements ensure mainly stability of tracked points in the sense of following the same part of an image for whole tracking period. By tracking all selected points is solved another main problem with global motion in the image.

2.4 Complete method scheme

Finally, we can use the processing steps described in above mentioned chapters and we can process the whole video sequence as shows flow chart in Fig. 6.

The method in the chart tracks features movement (optical flow) in the video sequence, fits them an ellipse in every frame, computes the ellipse area and stores the output value for every frame (area of an ellipse in pixels). This curve (artery sectional area in dependence on time) is the cardiac cycle with direct relationship to the blood pressure and artery elasticity.
3 Experimental results

The output curve is a measure of the quality of processing mainly in sense of noise appearance. An example of such typical curve (without any post processing) acquired by presented method can be seen in Fig. 7. Some other algorithms has been tried to use for solving the problem. Hence, a comparison of their outputs and characteristics is suitable when we are evaluating the quality of the proposed method.

At first place can be mentioned a very simple method of so called flood filling. Its simplicity leads to “escaping” of filled area out of the searched inner part of an artery as can be seen in Fig. 8. The “escapes” can be removed by some post processing using morphological techniques but there is still a distortion or noise in output curve.

Fig. 8 Result of simple flood filling algorithm (selected red (bright) area in smoothed image) with clearly perceptible “escape” from the inner part of the artery.

The problems with unclear artery border are partially removed by the complex algorithm [4] using artificial immune system method for decision if the analyzed pixel is inside or outside of an artery and Hough transformation.
for initial artery circle finding. Unfortunately the algorithm is very computationally expensive and artery circle has to pulse in one position in image so that the analyzed area will not to “escape” from the initial artery circle. Moreover, many testing video sequences showed that there is often an artery movement in an image. Presented technique based on optical flow method removes problems both with the movement and unclear artery edges. The results contain not a noise even by strong artery circle movement.

The proposed algorithm has been tested on tens short sequences, which has approximately about 5 seconds (160 frames), with usable results for cardiac cycle curve analysis.

The ultrasound video-sequence was acquired on a volunteer’s carotis communis, using the Sonix OP Smart Ultrasound system with linear probe.

4 Conclusion

A semi-automatic method for cardiac cycle extraction from B-mode ultrasound video sequence using the optical flow technique has been presented. The method acquires a curve of artery sectional area in dependence on time. The curve can be used for non-invasive analysis of blood circulatory system parameters. The method needs only one manual initialisation step of rough denoting of the artery border localisation in the first frame of analysed video sequence. The tests show its reliability regarding various image quality, sensor movement and possibility of processing of boundless artery image. Using of the method is very simple without any further parameter settings.

The utilization of presented method can be seen in wide area of analysis of medical ultrasound video sequences. Physicians can strictly noninvasively (even without inflatable cuffs) get a cardiac cycle curve (which is proportional to blood pressure curve) from arbitrary place in a blood circulatory system.

Future work will be aimed to the evaluation of accuracy regarding the ground truth data, other existing methods or a processing of long-time video sequences.

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