The Usage of Optical Flow Algorithm to the Problem of Recovery Contour of the Left Ventricle of the Human Heart on the Ultrasound Image Data

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Abstract. Cardiologist builds contour bounding area of the left ventricle (LV) in each frame of the ultrasound video sequence usually in a manual mode. The article describes results of application of semi-automatic algorithm using the optical flow. The visual and qualitative characteristic of contouring results of this algorithm are obtained. This algorithm is used to select the contour on ultrasound images.

Keywords: Contouring, left ventricle, optical flow, ultrasound images

1 Introduction

Contemporary research methods greatly simplify investigations in the medicine area. Diagnosis takes much less time and is more informative if an ultrasound image data are used for this purpose. The heart disease diagnosing on the basis of echographic imaging (echocardiography) is one of the challenges for cardiologists.

Analysis of ultrasonic image sequence allows one to investigate the heart muscle dynamics. The left ventricle (LV) of the heart is of the great interest for cardiologists, since most of various heart diseases and pathologies change, primarily, its state.

Existing devices of ultrasound heart research use tools that help doctors to calculate different indicators, which are necessary for the diagnosis of many diseases. To assess the state of LV, the cardiologist puts the contour bounding the region of the left ventricle on every frame of the ultrasonic images sequence, as a rule, in the manual mode.

Today, there are many different ultrasound scanners, each of which is equipped with any tools of LV contouring (Philips, Aloka Hitachi, Toshiba, Siemens, General Electric, and others.). However, analysis of commercial proposals of companies listed above showed that there are no devices for echocardiography with built-in software on the market, which could allow one to carry out the LV contouring in fully automatic mode. Thus, the problem of fully automatic algorithm delineation of LV is important.

2 Problems formulation

To solve the problem of delineation of LV on the ultrasound images, the usual methods of digital image processing do not fit. The techniques such as segmentation, filtering, contrast enhancement, and morphological transformation do not give positive results of contour allocation [1, 4, 5, 7, 8].

Thus, to solve the problems of delineation, it was decided to investigate the method of optical flow [2, 3, 6]; and it is needed to write a program that will allow cardiologists to build a contour only on the first frame of the video sequence. The contour should be build automatically starting form the second frame.

For example, in articles [9, 10] to track the areas on 3D echographic sequences, optical flow techniques, such as the "block flow" and "Real-time 3-dimensional echocardiographic" (RT3DE) were used. Since we apply the two-dimensional images, it has been already decided to use the Kanade-Lucas-Tomasi software-based algorithm.

3 Semi-automatic contour extraction algorithm on the video sequence

Many current flow search algorithms based on the Lucas and Canada idea [11–14]:

1. Lucas-Kanade considered just the offset point, without distortion.
2. Tomassi-Kanade is a reformulation of the Lucas-Kanade. Offset is calculated by an iterative solution of a built system of linear equations.
3. Shi-Tomassi-Kanade is an affine distortion of the point neighborhood taken into account.
4. Jin-Favaro-Soatto is a modification of the Shi-Tomassi-Kanade considering affine illumination changes of point neighborhood.

In this paper, the algorithm based on a Kanade-Lucas-Tomasi algorithm for tracking points on the first frame was used. Video records of fourteen patients are used as input data. The method uses image pyramid. Each image of sequence excepting the first is obtained as convolution of the previous image with the following filter:

$$\left[1/4\ 1/2\ 1/4\right] * \left[1/4\ 1/2\ 1/4\right]^T. \tag{1}$$

The algorithm used the following parameters:

1. BlockSize [61x61] is the neighborhood around each point, which is monitored;
2. NumPyramidLevels, 5 is the fifth level of the pyramid that can handle large displacements of points between frames.

The value of BlockSize defines the area where the point is monitored. If this value is too small, some points may be lost or displaced causing the incorrect contouring. Example of the BlockSize parameter is shown in Fig.1.

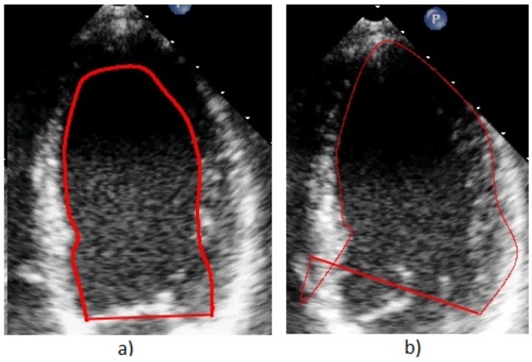

Fig. 1. BlockSize parameter application, a) the last frame under the value of [11x11], b) the last frame under a value of [61x61].

The value of NumPyramidLevels parameter determines what size of the object displacement should be tracked. Without this option a dramatic valve shift causes the displacement of the tracking point. Example of NumPyramidLevels is shown in Fig.2.

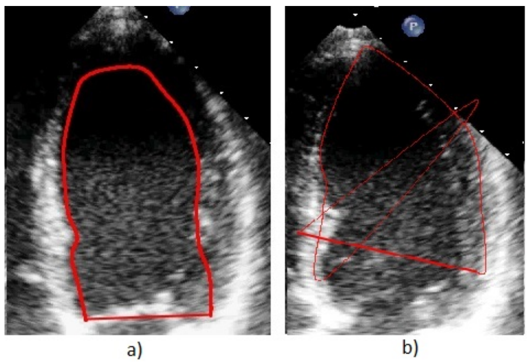

Fig. 2. The NumPyramidLevels parameter usage, a) the last frame 0 value of the parameter, b) the last frame with 5 value of the parameter.

It experimentally has been found, that contours constructed by this method is satisfactory only in the first cycle of the heartbeat on the video sequence. Therefore, it was decided to allocate the first cycle of the video sequences and process only it. The oscillogram, which is present on all videos, is used to determine the first cycle (Fig. 3). R peaks were used to highlight one cycle of heartbeats.

Figure 4 shows the volume change of the left ventricle during the cardiac interval.

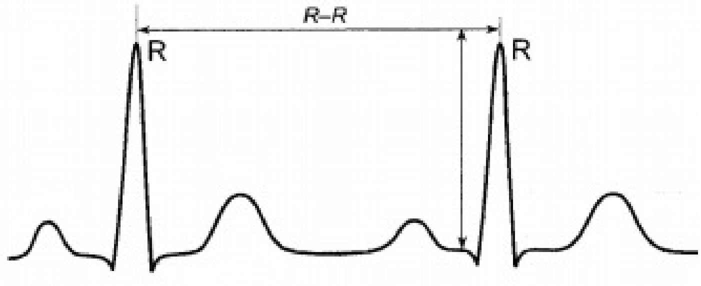

Fig. 3. ECG segment.

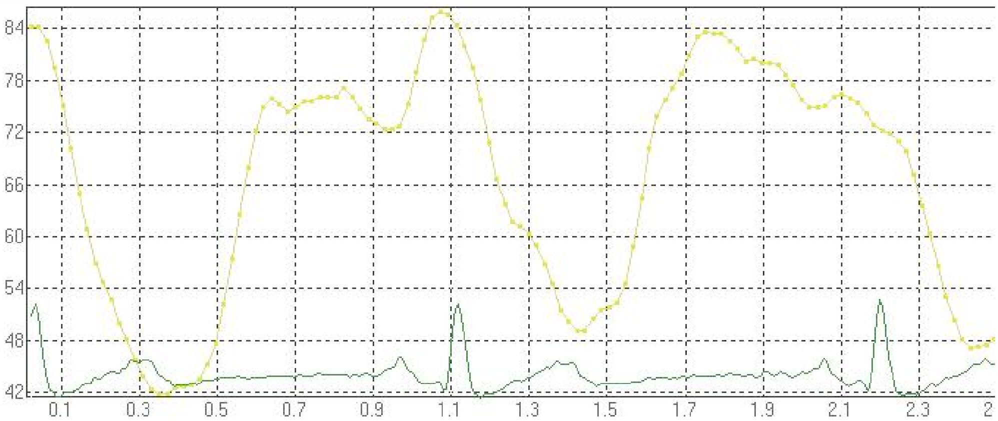

Fig. 4. LV volume changes (yellow), ECG signal (green).

To assess the quality of contouring, the following parameters were counted:

– precision

$$Precision = \frac{S_\cap}{S_{cont}}, \tag{2}$$

where $S_\cap$ is the intersection of square of area, limited by expert contour, and area, formed from classified pixels, S_{cont} is the square of the area formed from the classified pixels;

– recall

$$Recall = \frac{S_\cap}{S_{exp}}, \tag{3}$$

where S_{exp} is the area of the region bounded by the expert contour;

– F-measure

$$F = \frac{2 * Precision * Recall}{Precision + Recall}; \tag{4}$$

– the feature of the mass center motion of the left ventricle has been used as a quality criterion of the LV contour construction; next, for each patient the area of the respective ellipses was calculated that compared with the area of the left ventricle in diastole (the contour of the first frame of the cardiac cycle)

$$K = \frac{S_{ellipse}}{S_{diast\_cont}}, \tag{5}$$

where $S_{ellipse}$ is the area of the ellipse bounding CM LV, S_{diast_cont} is the area of the region contour in diastole.

Quantitative estimates of these parameters are presented in Table 1.

Table 1. The quality contouring parameters.

Patient	K	Recall	Precision	F
1	0.21 %	0.94	0.98	0.96
2	1.58 %	0.96	0.98	0.97
3	2.68 %	0.96	0.97	0.96
4	0.13 %	0.95	0.99	0.97
5	0.16 %	0.98	0.98	0.98
6	0.10 %	0.93	0.98	0.95
7	0.08 %	0.99	0.98	0.98
8	0.41 %	0.94	0.95	0.94
9	0.25 %	0.92	0.94	0.93
10	0.09 %	0.99	0.98	0.98
11	0.26 %	0.97	0.99	0.98
12	0.23 %	0.94	0.97	0.95
13	0.33 %	0.95	0.98	0.96
14	0.16 %	0.98	0.99	0.98

Table 1 shows that the area of the ellipse covering CM does not exceed 3 % of the left ventricle area in diastole that indicates the accuracy of the contours construction.

A similar contouring problem was solved by machine learning - the decision tree method [15]. The authors offer completly automated algorithm for solving the problem. Table 2 shows a comparison of the semi-automatic and automatic contouring methods results.

Table 2. Compare contouring methods.

Criteria	Decision tree	KLT
Recall	0.77±0.01	0.96±0.02
Precision	0.92±0.02	0.98±0.01
F	0.84	0.97

Table 2 shows that the KLT algorithm gives significantly better results compared to the decision tree method. However, the KLT method requires participation of the doctors.

For a more qualitative assessment of this algorithm, the expert evaluation is required. With this purpose, the program allowing cardiologists to use this algorithm and to have the assessments of the construction quality has been created.

4 Conclusion

This paper studied the optic flow method as a semi-automatic contouring algorithm. The Kanade-Lucas-Tomasi algorithm is applied to tracking points of the contour on the video sequence. The parameters of the algorithm are analyzed and those were choosen, that allow more accurate delineation of the left ventricle.

The visual and qualitative characteristic of contouring results are obtained using this algorithm. The program was developed that allows cardiologists to use this algorithm and provide the assessments of the construction quality.

Based on the results of the contour construction, it is possible to conclude that this algorithm could preferally be used in the solution of the LV contouring problem.

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