Real-Time Tracking of Aortic Valve Landmarks Based on 2D-2D Fluoroscopic Image Registration

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Abstract:

Transcatheter aortic valve implantation (TAVI) is routinely performed under 2D fluoroscopic guidance. The target position for placement of the stented aortic valve prosthesis is defined by aortic valve landmarks, e.g. coronary ostia. This paper presents a real-time tracking method of these landmarks in 2D fluoroscopic image sequences to improve the positioning of the implant during TAVI. The proposed tracking method is based on the Insight Toolkit (ITK) registration framework. Minimal user-interaction is required to define 2D landmarks in a reference image. The reference image is automatically detected to present all image features, when the aortic root is filled with a contrast agent. Preliminary results showed a good tracking of the landmarks even without the contrast agent in 14 fluoroscopic image sequences.

Keywords: Transcatheter aortic valve implantation, Fluoroscopy, Real-time tracking, Image registration

1 Problem

Transcatheter aortic valve implantation (TAVI) has evolved as a routine procedure for high-risk patients with severe aortic valve stenosis [1]. For exact placement of the stented aortic valve prosthesis, knowledge and visualization of anatomic aortic valve landmarks such as the coronary ostia, the commissures, the three lowest points of the leaflets cusps, and annular calcification are essential [2].
Under 2D X-ray fluoroscopic guidance, balloon expandable aortic valve prosthesis such as the SAPIEN valve (Edwards Lifesciences, Irvine, USA) is carefully positioned, and finally deployed under rapid ventricular pacing [1]. The target position of implantation is one-third to one-half of the prosthesis above the mid-level of the aortic annulus, avoiding the obstruction of coronary ostia. This prosthesis cannot be repositioned after deployment. The exact placement of the prosthesis is therefore crucial.
Fluoroscopy presents a good intra-operative imaging modality to provide accurate information on the target area of implantation. However, the contrast in fluoroscopic images is generally low. The motion of the aortic root including the valve is complex due to heart and respiratory motion. Moreover, limited doses of the contrast agent must be injected to visualize the aortic root with the landmarks in seconds to define the exact positioning of the prosthesis. Using additional equipment such as optical system for tracking the landmarks may also complicate the surgical workflow. Therefore, medical image registration is more appropriate for landmark tracking in 2D fluoroscopic images.
Medical image registration is the process to geometrically align two images which were acquired from the same patient at different times or with different devices. A real-time alignment of 2D fluoroscopic images acquired at different times can be used to determine the landmark displacement in each image of sequence.
In this paper, an intra-operative tracking method of the aortic valve landmarks, i.e. the coronary ostia and two lowest points of the aortic valve cusps, is presented based on image registration procedure to assist in the positioning of the prosthesis under 2D fluoroscopy.

2 Methods

The Insight Toolkit (ITK) [3] has been used for intensity-based 2D-2D rigid fluoroscopic image registration. The basic components of the ITK registration framework are two input images, an image transformation, a metric, an interpolator and an optimizer. The two input images are a fixed image and a moving image. A translation transformation maps the fixed image space into the moving image space by resolving the translational misalignment between images, in order to overlap the same objects in both images. An optimizer is required to explore the parameter space of the transform in search of optimal values of the metric. Mutual information registration by Mattes et al. [4] has been used as a metric to compare how well the two images match each other. An interpolator will finally evaluate the intensities of the moving image as non-rigid positions.

Fig. 1 shows the flowchart of the proposed tracking method of aortic valve landmarks in 2D fluoroscopic image sequences. For the TAVI, the automatic landmark detection is a difficult task, because the aortic root is not visible in the fluoroscopic image unless the contrast agent is injected. Therefore, detection of a reference image that includes the required features of aortic root is needed. The proposed tracking algorithm automatically detects the reference image in which the aortic root including the stenotic valve is filled with a contrast agent based on histogram analysis of the fluoroscopic images [5]. Once the reference image is detected, the image sequence is frozen to provide a manual initialization of the valve landmark locations.

Afterwards, tracking of aortic valve landmarks is automatically started as follows: The input fluoroscopic image and the reference image are preprocessed using the median filter, in order to reduce the image noise. Each image of the sequence is presented as a fixed image and the reference image including the landmarks is presented as a moving image for the ITK registration framework. The registered reference image determines a new translation of the current features in each image of sequence, defining the new displacement of valve landmarks. Finally, these landmarks are overlaid on the current image of the sequence to visualize the target area of implantation.

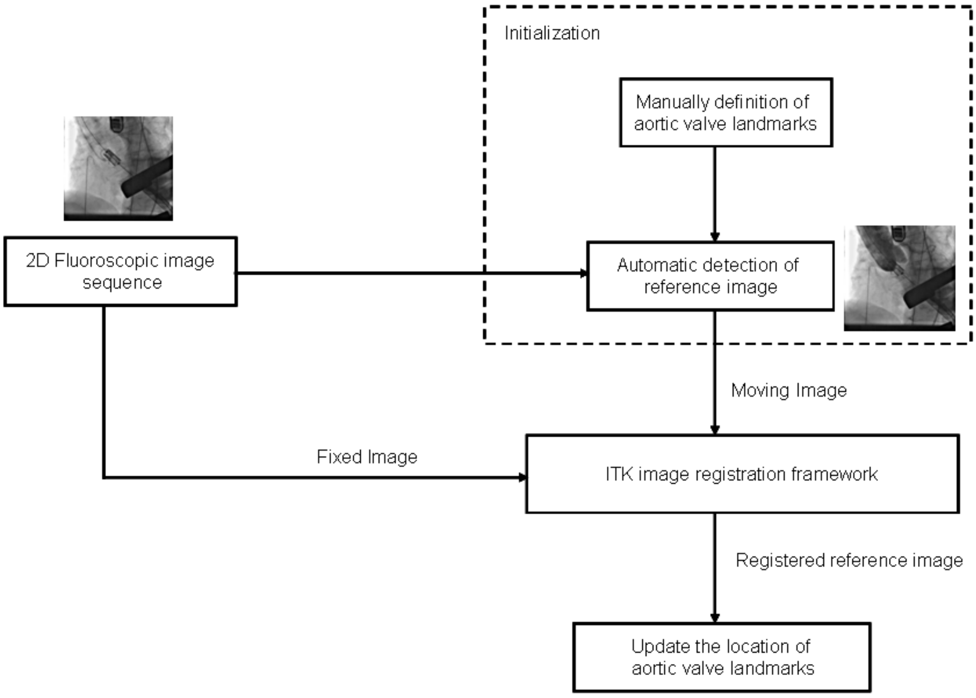

Fig. 1: Flowchart of the proposed aortic valve landmarks tracking method by using 2D-2D fluoroscopic image registration.

The evaluation of the registration-based tracking procedure is a difficult task, especially for the registered images with no injected contrast agent. Also, a ground-truth image data is not available. All image sequences were therefore visually and qualitatively inspected to verify the registration quality for landmarks tracking. The quality of registration was classified as defined in [6]:

- Excellent: the best quality with no visible discrepancy between both images.
- Good: small misalignment between the images in the range of 1 to 9 pixels.
- Moderate: high misalignment between the images in the range of 10 to 20 pixels.
- Poor: registration with significant misalignment.

3 Results

The proposed tracking method has been tested on 14 fluoroscopic image sequences of the TAVI. The tested images are 1024×1024 pixels in size. All image sequences were acquired using an angiographic C-arm system (Axiom Artis, Siemens AG, Healthcare Sector, Forchheim, Germany) at the Heart Center Leipzig, Germany.

The proposed method has been implemented using C++ and open source libraries which are the ITK and the Visualization Toolkit (VTK) [7]. Total processing time of the registration-based tracking algorithm is 100 ms per frame.

Fig. 2 shows a sample of landmarks tracking in two sets of fluoroscopic images using 2D-2D intensity-based registration. The reference fluoroscopic images are automatically detected to manually define the aortic valve landmarks as depicted in Fig. 2(a, b). The features from the reference image (moving image) are matched to the most intense features of the input images of the sequence (fixed image) in the presence of a contrast agent (see Fig. 2(c, d)) and without a contrast agent as shown in Fig. 2(e, f). The evaluation results of registration are summarized in Table. 1.

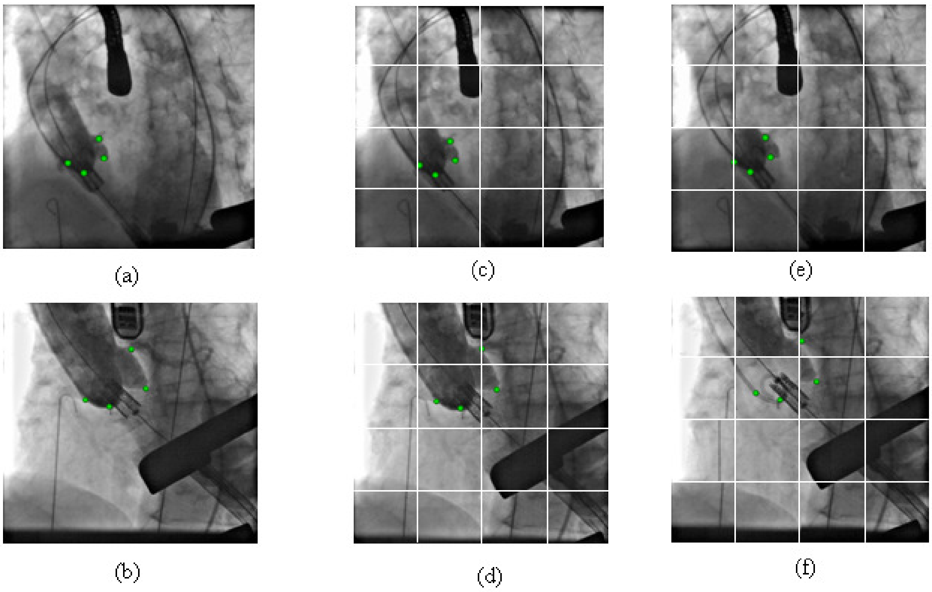

Fig: 2: (a, b) the reference images of two different fluoroscopic image sequences including the manual definition of aortic valve landmarks, i.e. coronary ostia and two lower points of aortic valve cusps, the figures (c and e, d and f) show that the landmarks are successfully tracked in a sample of two images for each fluoroscopic sequence, the figures also depict checkerboard registration results as alternating blocks from the reference image and the input image of sequence with a contrast agent (c, d), and without a contrast agent (e, f).

Table. 1: Evaluation of the registration-based tracking of landmarks results

Image Sequence No.	Number of frames	Registration quality			
		Excellent	Good	Moderate	Poor
1	53	11 (20.75 %)	28 (52.83 %)	14 (26.42 %)	0 (0.00 %)
2	47	10 (21.28 %)	26 (55.32 %)	7 (14.89 %)	4 (8.51 %)
3	76	17 (22.37 %)	33 (43.42 %)	25 (32.89 %)	1 (1.32 %)
4	53	7 (13.21 %)	22 (41.51 %)	21 (39.62 %)	3 (5.66 %)
5	40	5 (12.5 %)	13 (32.50 %)	12 (30.00 %)	10 (25.00 %)
6	50	20 (40.00 %)	25 (50.00 %)	5 (10.00 %)	0 (0.00 %)
7	64	24 (37.5 %)	36 (56.25 %)	4 (6.25 %)	0 (0.00 %)
8	52	16 (30.77 %)	33 (63.46 %)	3 (5.77 %)	0 (0.00 %)
9	47	12 (25.53 %)	19 (40.43 %)	16 (34.04 %)	0 (0.00 %)
10	54	8 (14.80 %)	26 (48.15 %)	17 (31.48 %)	3 (5.56 %)
11	47	8 (17.02 %)	20 (42.55 %)	19 (40.43 %)	0 (0.00 %)
12	77	18 (23.38 %)	48 (62.33 %)	11 (14.29 %)	0 (0.00 %)
13	58	13 (22.41 %)	23 (39.66 %)	17 (29.31 %)	5 (8.62 %)
14	67	11 (16.42 %)	29 (43.28 %)	24 (35.82 %)	3 (4.48 %)

4 Discussion

An intra-operative tracking method of aortic valve landmarks has been presented based on 2D-2D fluoroscopic image registration. A qualitative evaluation of the registration performance showed that the quality of registration-based tracking of landmarks algorithm is good with 1 to 9 pixels errors in most tested images of each fluoroscopic sequence as illustrated in Table 1. The misalignment of registered images detected in 7 of 14 fluoroscopic image sequences in the range of 1 to 10 images per sequence, because the input fluoroscopic images without a contrast agent and large motion of the aortic root may affect significantly the accuracy of 2D-2D intensity-based registration procedure. However, the alignment of fluoroscopic images is still valid and optimized by using the capabilities of the ITK registration framework.

The proposed registration-based tracking method of aortic valve landmarks may provide a helpful tool for assisting the TAVI under 2D fluoroscopic guidance. To minimize the user-interaction and increase the accuracy of initialization, we plan to extract 3D landmarks from CT or Dyna-CT images and register them to a 2D fluoroscopic reference image. Tracking of native annular calcification may be also another promising method for image registration in the future.

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5 References

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