Real-time Matching of Angiographies with In Situ Heart Image Sequences

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Abstract

Coronary angiography has become an important tool in modern medicine by providing an additional modality for heart disease diagnostics. Even though the recorded images (or image sequences) are digitally available, their analysis is very elementary in nature in most cases: the surgeon studies the angiograms before the operation, and operates without having them available in the operation room. It is up to the surgeon's memory to accurately remember the relevant details like locations of stenosis or occlusion. To improve both the analysis and the on-site availability of angiograms, but also to drastically increase the usefulness of the angiogram as a diagnostical modality, we present a novel approach which combines several advanced techniques into a single tool allowing real-time augmentation of in situ beating heart image sequences with the corresponding angiogram. The software toolset we developed so far contains the removal of specularities from the glossy heart surface and the reconstruction of the original image colors, color based coronary artery segmentation in beating heart image sequences, angiogram segmentation and symbolic representation, OpenGL based augmentation and visualization, Mass-Spring-NURBS-based soft tissue simulation. Future work will focus on developing robust matching techniques and on integrating the software tools into an operation room suitable hardware setup.

1: Introduction

During cardiac procedures (especially in minimally invasive interventions) finding the targeted vessel(s) is often complicated by accumulated adipose tissue on the external surface of the heart. The preoperative coronary angiography provides a precious diagnostic procedure, whose digital image sequences illustrate the exact position of the arteries. Coronary angiography is an X-ray examination of the blood vessels or chambers of the heart. A very small tube (catheter) is inserted into a blood vessel in the patient's groin or arm.

The tip of the tube is positioned either in the heart or at the beginning of the arteries supplying the heart, and a special fluid (called a contrast medium or dye) is injected. This fluid is visible by X-ray, and the pictures that are obtained are called angiograms. In most cases not only images, but whole image sequences in form of X-ray beating heart "movies", even from different perspectives, are made. Figure 1(right) shows a frame of such a movie. Often an angiogram is necessary before deciding whether a coronary disease needs more treatment or not. Once made, angiograms help the surgeon finding the targeted vessels for a surgical procedure. But in todays hospital practice the surgeon has no possibility to analize pre-operatively recorded material while operating, unless the angiograms are made during the surgical procedure in a specially equipped operation room. Our vision is to provide a set of operation room suitable hardware and software tools which allow the analysis of angiograms in a user friendly manner. The software functionality consists on a highest level of a (preferably exact) match of previously recorded angiograms with the visible coronary arteries and an augmentation by a semi-transparent crossfade-view of the angiogram. Figure 1 shows the problem: the visible part of the artery on the left side has to be matched with the highlighted part on the right side, allowing to find even covered runs of the arteries (the enclosing lines were drawn by hand for illustration purposes). For a more natural looking augmentation the corresponding angiogram should behave like a "second skin" on the heart surface, which implies the requirement of dynamic soft-tissue modeling.

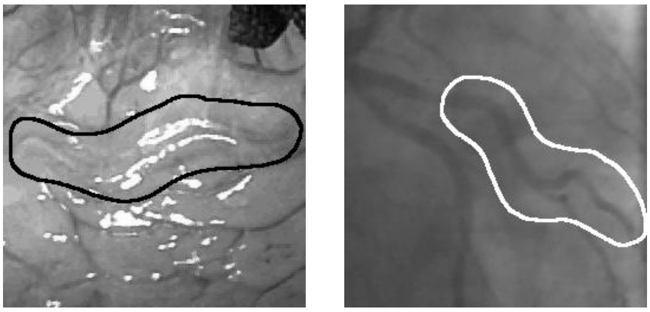

Figure 1. In situ heart image and corresponding angiogram

2: Materials and Methods

Understandably it is not possible to develop and test in a clinical environment, thus all research activities were performed outside of the hospital. Therefore the image material used (angiographies and the live heart image sequences) were provided in digitised form by the German Heart Center Munich. The heart images are in a 720x576@24bit RGB format, while the angiograms are available as 512x512@8bit grayscale. Matching coronary arteries to their respective angiograms requires both segmenting the images and bringing the results in a symbolic representation which facilitates the matching process.

2.1: Coronary artery segmentation

The segmentation of coronary arteries first implies the restoration of the source images "damaged" by specular reflections. Specular reflections occur as a result of light reflections on glossy surfaces, but due to their high intensity a thresholding operator is in most cases sufficient to localize them. Figure 2 shows a magnified view of a specularity and the result of thresholding followed by a dilation operator.

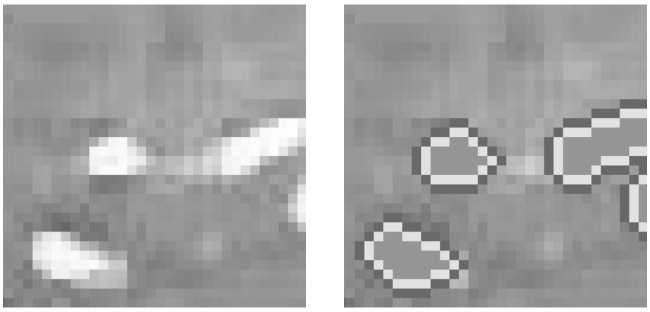

Figure 2. Eightfold zoom of a specular reflection

Dilating the thresholded areas is necessary due to artefacts in form of a 1-2 pixel wide dark contour around a specular reflection, which also has to be removed. The underlying image colors are then reconstructed using a fill-in technique based on chaincoding. Chaincoding is a reliable and fast approach for representing arbitrary plane curves ([2]). The idea is to first detect and chaincode the 1 pixel wide outer bound of a specularity, then traverse the chaincode and replace each pixel with an averaged color of his neighbours. This is then repeated, from the outside to the inside, until the whole specular reflection is processed. Both mean and median operators are suitable for averaging, while a mean operator will inevitably introduce new colors. Figure 3 shows the results of the specular reflection removal using the green channel (of the 3-channel RGB image) for thresholding with the threshold value 210 and a mean operator for averaging. The main advantage of our approach is, that is surpasses real-time (30 frames per second on an Athlon 1.6 GHz) requirements on high resolution color images and is faster than other known approaches ([1]). Due to the high quality image restoration a color based approach can be used for the coronary artery segmentation in the beating heart image sequences. Chaincoding is then used again to bring the segmented arteries in a symbolic representation ([3], [4]).

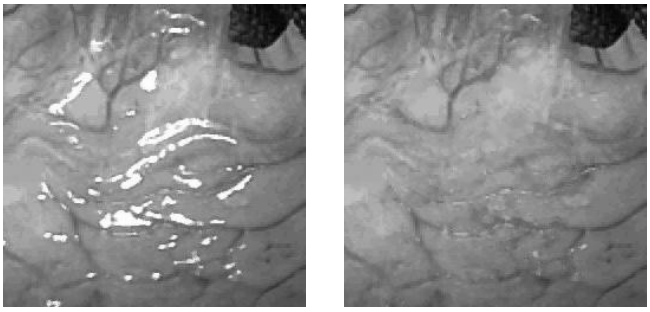

Figure 3. Specular reflection removal

2.2: Angiogram segmentation

The robust segmentation of angiographies (fig. 4-left) is still a challanging task. We found that an edge-based approach is best suitable for the grayscale angiogram images, and use an efficient implementation of a Gauß/Sobel filter combination to detect not only the runs of the vessels (fig. 4-middle) but also their thickness (fig. 4-right). Unfortunately the edge-based approach with this filter combination doesn't meet real-time requirements, which is insofar not a serious drawback as the angiogram segmentation can be done in a batch process. The contours of the segmented vessels are then chaincoded using the same technique as for the arteries in the live heart images. For the symbolic representation of the segmented parts features of the chaincoded representation are used, which additionally advantages the matching process with the (also chaincoded) coronary arteries. Having the thickness of the arteries, an automatic stenosis detection is also possible, for example by searching for minima in the thickness function.

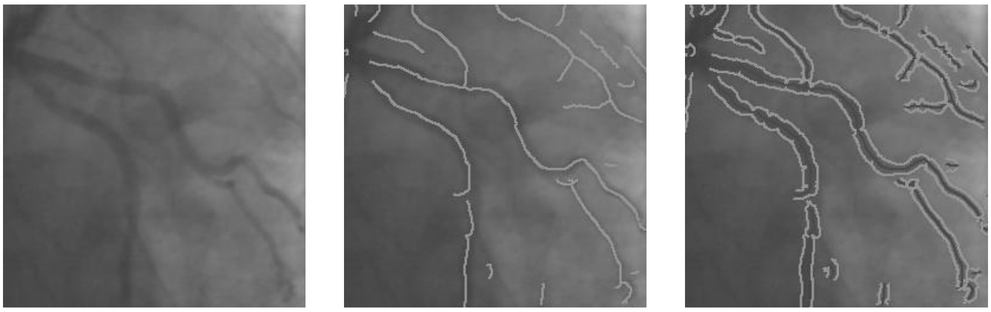

Figure 4. Angiogram segmentation

2.3: Matching

To find the best fitting angiogram to the currently visible part of a coronary artery, a similarity search is necessary. Having both modalities (angiogram and heart image) in a symbolic representation enables us not only to find a best match but also to compute the transformation parameters (axis for flipping, translation and rotation angle) necessary to be applied to the angiogram. In our case for example flipping the angiography horizontally and rotating it 35 degrees clockwise, which of course can be done automatically, gives the desired results (fig. 5-left). As already mentioned it is not possible to do a real-time angiogram segmentation, thus the features used for the similarity search must provide fast comparison operators. Our further research will mainly focus on this issue, since there is room for improvement, for instance using beside the chaincoded representation also spline based storage.

2.4: Augmentation techniques

In order to achieve a more realistic augmentation we plan to use a Mass-Spring-NURBS based soft tissue simulation as a framework for the angiographic view. Figure 5 (left) shows the intended view, initially without an underlying soft-tissue model, where the live heart image sequence is augmented by a semi-transparent crossfade-view of the angiogram. This is done by mapping both the heart image and the corresponding angiogram respectively to an OpenGL textured "canvas". The canvas is in case of a heart image a simple textured polygon, whereas for the angiogram a textured NURBS surface. The result of our preliminary work on the simulation part is shown in figure 5 (right), where a textured NURBS surface is applied to a mass-spring grid. The mass points are at the same time control points of the freeform surface. The arrangement and the number of the mass/control points is not random, since they are closely related to the parameters (knot sequence, order) of the surface. The interconnection between masses by springs is done using a Delaunay triangulation, where the masses are arbitrary points in 3D cartesian space and the sides of the resulting triangles are the springs. The most challenging task is to fix the mass/control points to the underlying heart surface. We are investigating several techniques to do this, and natural landmarks seem to be most promising.

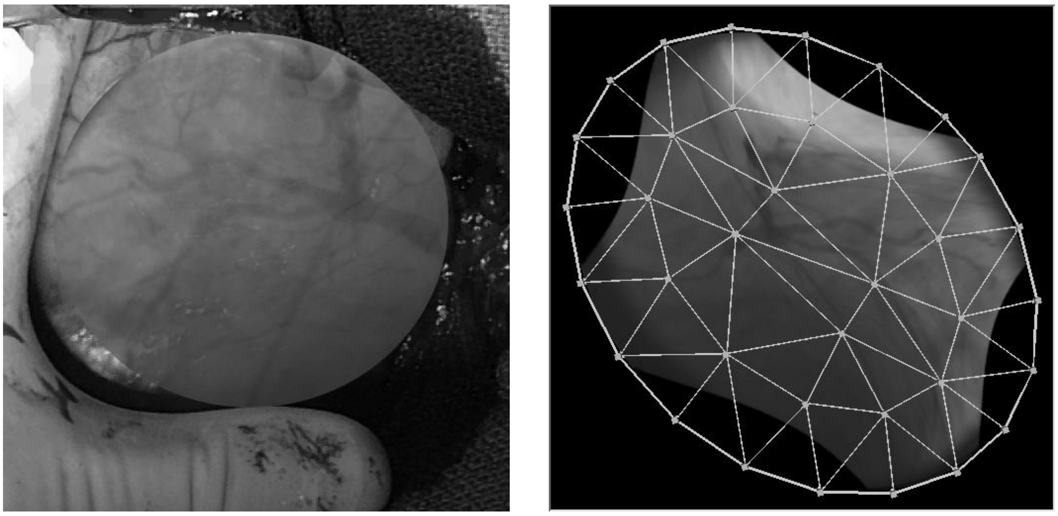

Figure 5. Augmentation and Mass-Spring-NURBS Model

3: Conclusion and Outlook

We presented in this paper an approach which facilitates the exact identification of the target artery on the heart surface in conventional or endoscopic cardiac procedures. The integration into existing surgical infrastructure is quite easy, since it can be used without additionally acquired images or intraoperative angiography. Potentially not only traditional endoscopic procedures could benefit from this technology, but also robot-assisted interventions. Most parts of the system are already implemented, nevertheless further work on two important issues is needed: making the matching process more reliable and finding the best solution to fix the mass/control points to the underlying heart surface. A corresponding operation room suitable hardware setup serving as a visualization platform would increases instant as well as long-term acceptance and facilitate the acclimatisation period. Such a hardware setup could be an LCD touchscreen equipped on the backside with a camera, mounted on a backdrivable robotic-arm like system, which can be positioned over the patient's chest, giving an augmented view of the beating heart.

4: Acknowledgements

This work was supported by the German Research Foundation (DFG) in the Collaborative Research Center SFB 453 on "High-Fidelity Telepresence and Teleaction".

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