SELF-ACTING CORONARY ARTERY IDENTIFICATION IN ENDOSCOPIC HEART SURGERY

E.U. Schirmbeck*, I. Nagy**, H. Mayer**, A. Knoll**, R. Lange* and R. Bauernschmitt*

*Deutsches Herzzentrum München, Klinik für Herz- und Gefäßchirurgie, Technische Universität München, Germany
**Technische Universität München, Fakultät für Informatik, Lehrstuhl für Robotik und Echtzeitsysteme, München, Germany

schirmbeck@dhm.mhn.de

Abstract: The benefits of minimally invasive cardiac surgery are manifold, including less trauma to tissue and consequently less pain, shorter hospital stay and faster recovery. Nevertheless problems remain in the complex operative procedure with long instruments and small aditus to the operating field. In coronary artery bypass graft operations the exact identification of the target artery on the heart surface in an endoscopic or minimally invasive incision, respectively, persists complex. The combined presentation of the real endoscopic camera view and additional preoperative diagnostic images (e. g. coronary angiography) in one augmented-reality-model facilitates the identification and classification of the coronary arteries on the heart surface. We present a novel approach which combines several advanced techniques into a single tool allowing real-time augmentation of endoscopic beating heart image sequences with the corresponding angiogram assisting the surgeon in classifying the arteries rapidly and reliably.

Introduction

Cardiac surgical procedures are still among the most demanding and invasive therapeutic techniques in modern medicine. The development of minimally invasive heart surgery offers the possibility of less traumatizing surgery. Particularly the robotically assisted procedures seem to be very promising, allowing the surgeon a greater range of motion and a magnified view of the heart. The exact identification of the target arteries in endoscopic or minimally invasive heart surgery still remains difficult due to the limited view through the endoscopic camera. The preoperative coronary angiography illustrates the position and the course of the coronary arteries.

The goal is to provide a set of operation room suitable software tools which allow the analysis of angiograms in a user friendly manner. The software functionality consists of an exact match of pre-operatively recorded angiograms with the visible in situ coronary arteries with a semi-transparent cross-fade view of the angiogram.

The visible part of the coronary tree as shown in figure one on the left hand 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 are highlighted by hand for illustration purposes).

For more realistic augmentation the corresponding angiogram should act like a "second skin" on the heart surface, which implies the requirement of dynamic soft-tissue modelling. This complex task is subdivided into several subtasks.

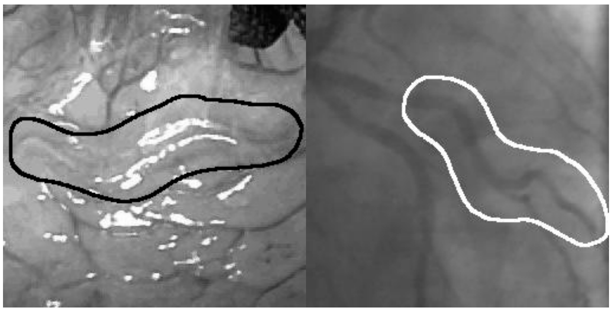

Figure 1: View of the heart surface and corresponding angiogram

Materials and Methods

The angiograms and the in situ heart image sequences are digitally available. The heart images are in a 720x576 24 bit RGB format, while the angiograms are available as 512x512 8bit greyscale images. Matching coronary arteries to their corresponding angiogram requires segmenting the images and presenting the results in a symbolic illustration, which facilitates the matching process.

Coronary Artery Segmentation

The segmentation is performed to distinguish the coronary arteries from the background in a colour-based technique. The significant parts of the heart surface, which are up for segmentation, are damaged by specular reflection. Specular reflections occur as a result of light reflections on glossy surfaces. Due to their high intensity a thresholding operator is sufficient to localize the glossiness. In 24 bit RGB images almost each of the available colour channels (red, green, blue) can be used for thresholding, even a computed 8 bit greyscale channel is suitable. Dilating of the thresholded areas is required caused by artefacts in form of a 1-2 pixel wide dark contour around a specular reflection (fig. 2). The underlying image colours are reconstructed using a fill-in technique based on chain coding.

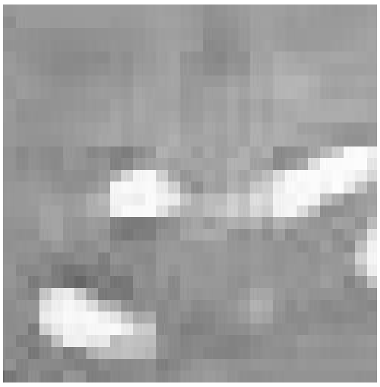

Figure 2a: Eightfold zoom of a specular reflection

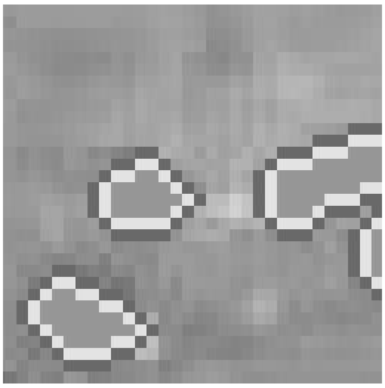

Figure 2b: Thresholded areas (dark contour)

First the one pixel wide outer bound of a specularity is detected and chain coded followed by replacement of each with an averaged colour of his neighbours outwards to inwards up to the whole specular reflection is processed. Due to the high quality image restoration a colour based approach is applied for coronary artery segmentation in the beating heart image sequences. By chain coding the segmented arteries obtain a symbolic representation which is a reliable and fast approach for representing arbitrary plane curves [1,2,3,].

Angiogram Segmentation

An efficient implementation of a Gauß/Sobel filter combination detects not only the runs of the vessels (fig. 3-left) but also their thickness (fig. 3-right). Features of a chain coded representation show additional advantages of the matching process with the (likewise chain coded) coronary arteries for the symbolic representation of the segmented parts [4,5].

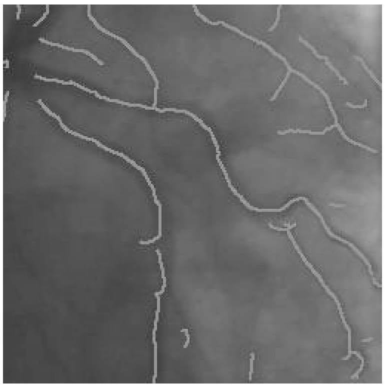

Figure 3a: Angiogram segmentation of the course of the coronary arteries

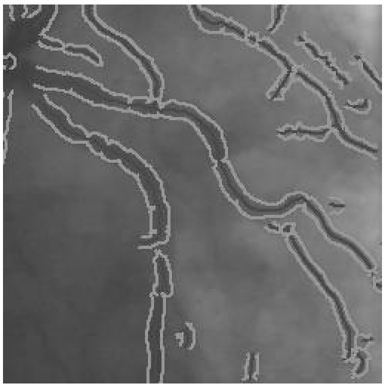

Figure 3b: Angiogram segmentation with the outline figure of the coronary arteries

Matching

To find the best fitting angiogram to the currently visible part of a coronary artery, a search of similarity is obligatory. Both modalities (angiogram and heart image sequence) in a symbolic representation enable to find the best match to compute the transformation parameters [6] (axis for flipping, translation and rotation angle).

Augmentation Techniques

In order to achieve a more realistic augmentation a Mass-Spring-NURBS based on soft tissue simulation avails as framework for the angiographic view [7]. The heart image and the corresponding angiogram are mapped to an OpenGL textured ”canvas” [8]. The canvas of the heart image is a simple textured polygon;

the angiogram represents a textured NURBS surface. Figure 4b illustrates a textured NURBS-surface to a mass-spring grid. The mass points are simultaneously control points of the freeform surface.

The arrangement and the number of the mass/control points are 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: the masses are arbitrary points in 3D Cartesian space and the sides of the resulting triangles are springs. The most challenging task is to fix the mass/control points to the underlying heart surface on natural landmarks.

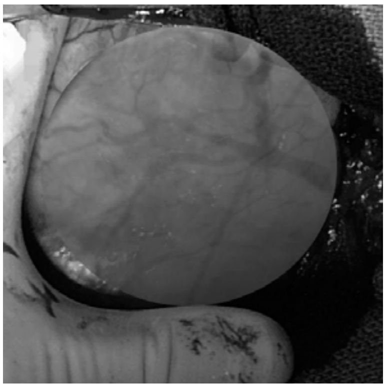

Figure 4a: Augmentation of the heart surface with the angiogram

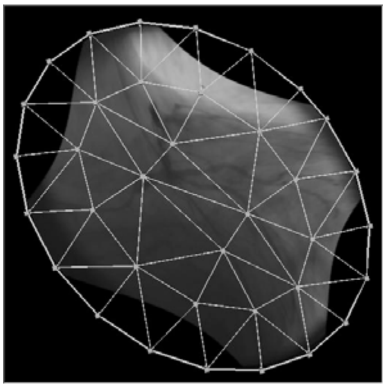

Figure 4b: M-S-NURBS model of the surface

Results

The elementary basis for coronary segmentation is to eliminate the specularity of the heart surface. Figure 2 shows a magnified view of a specularity and the result of thresholding using green channel based thresholding with the threshold value 210 and a mean operator for averaging followed by a dilation operator. Figure 5 shows the results of the specular reflection removal; the approach surpasses real-time (30 frames per second) requirements on high resolution colour images (512 x 512 24 bit RGB).

Figure 5a: Specular reflection

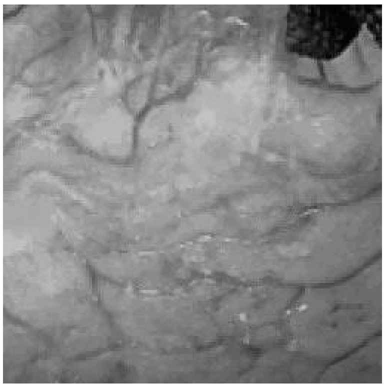

Figure 5b: Removal of specular reflection

By flipping the angiography horizontally and rotating at 35 degrees clockwise, which is done automatically, the best fitting angiogram to the section of the real heart surface is found (fig. 4a).

The intended view is shown in figure 4a, initially without an underlying soft-tissue model, where the live heart image sequence is augmented by a semi-transparent cross fade-view of the angiogram.

Discussion

A virtual soft tissue simulation is implemented which represents the exact identification of the target coronary artery on the heart surface in the endoscopic cardiac procedure [9]. Real-time matching of angiographies with in situ heart image sequences permits an exact classification of coronary arteries.

For real-time applications this approach of removal of specular reflection is faster than other known approaches [10].

Endoscopic procedures are extended by this technology, as well telemanipulated assisted interventions. The bigger part of the system is implemented, nevertheless further upgrades on two important issues queue: a refining of the matching process and the advancement of fixing the mass/control points to the underlying heart surface. A corresponding operation room suitable hardware-setup like a platform of visualisation would increase the long-term acceptance and intra-operative workflow.

Conclusions

The new tool-set of augmented real-time live camera images extends the intra-operative view to identify exactly the coronary arteries. The surgeon is assisted by an approach to enhance and ameliorate the success of an endoscopic operation without requiring any additional image acquisition or intra-operative angiography.

Acknowledgement

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References

[1] FREEMAN H. (1961): ´Techniques for the digital computer analysis of chain-encoded arbitrary plane curves`. Proc. Natl. Elect. Conf., 17, pp. 421-432

[2] KUHL F.P., WEBER J., O'CONNOR D. and GIARDINA C.R. (1980): ´Fourier series approximation of chainencoded contours´. Proc. of the 1980 Electro-Optics Laser Conference and Exposition, Boston, MA

[3] KUHL F.P and. GIARDINA C.R. (1982): ´Elliptic Fourier features of closed contours´. *Computer graphics and image processing*, 18, pp.236-258

[4] TOLEDO R., ORRIOLS X., RADEVA P., Binefa X., VITRIA J., CANERO C., VILLANUEVA J.J.(2000): ´Eigensnakes for Vessel Segmentation in Angiography´. International Conference on Pattern Recognition, Barcelona, Spain, 2000, 4, p.4340

[5] YIM P.J. CHOYKE P.L, SUMMERS R.M. (2000): ´Greyscale skeletonization of small vessels in magnetic resonance angiography´. *IEEE Transactions on Medical Imaging*, 6, pp. 568- 576

[6] COTTIN S., DELINGETTE H., AYACHE N. (1999): ´Real-Time Elastic Deformations of Soft Tissues for Surgery Simulation´. *IEEE Transactions on Visualization and Computer Graphics* 1999, 5(1), p. 62

[7] KÜHNAPFEL U., CAKMAK H.K., MAASS H. (2000): ´Endoscopic Surgery Training using Virtual Reality and deformable Tissue Simulation. *Computers & Graphics*, 24, pp. 671-682

[8] WERNECKE J. (1999): ´Programming Object-Oriented 3D Graphics with Open Inventor´ in Addison Wesley (Ed) ´The Inventor Mentor´

[9] BANERJEE S., CROOK A.M., DAWSON JR, TIMMIS A.D. and HEMINGWAY H. (2000): ´Magnitude and consequences of error in coronary angiography interpretation (the ACRE study)´. *Am. J. Cardiol.*, 1; 85(3), pp. 309-14

[10] GRÖGER M., SEPP W., ORTMAIER T. and HIRZINGER G. (2001):´Reconstruction of Image Structure in Presence of Specular Reflections´, in Radig B. and Florczyk S. (Eds.): ´DAGM 2001´, LNCS, (Springer-Verlag Berlin Heidelberg), pp. 53-60