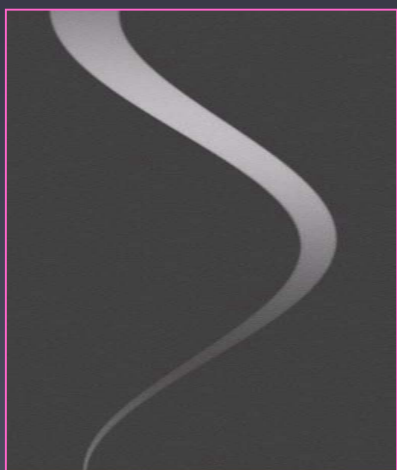
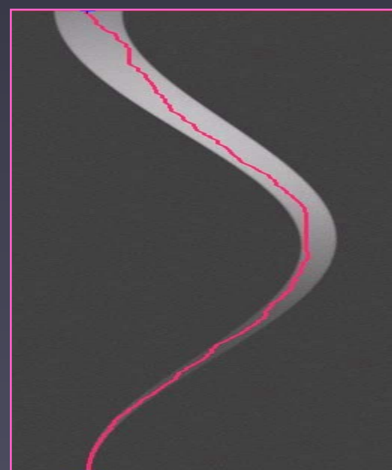
Accuracy of Automated Centerline Approximation Algorithms for LowerExtremity vessels in a CTA Phantom

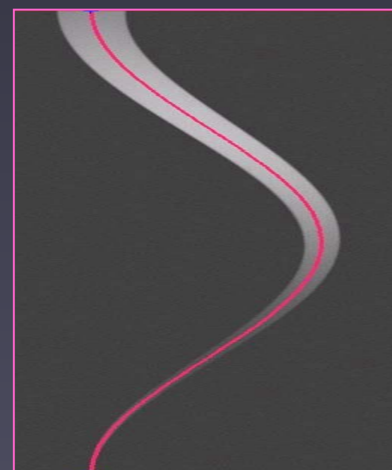
A. La Cruz, M. Straka, A. Köchl, Šrámek, E. Gröller, D. Fleischmann



Synthetic data



Vessel tracking



Vessel centerline

Institute of Computer Graphics and Algorithms
Vienna University of Technology

Purpose

- The vessel centerline is a prerequisite for the automated visualization (curved planar reformation) and quantification of arteries diseases.
- Furthermore, the vessel centerline can be used as an input function for 3D rendering, automated vessel measurement and analysis, and as a starting point for a geometric model of a vascular tree.
- The purpose of this work was to assess the accuracy of different algorithms for automated centerline detection in a phantom of peripheral arteries.

Video
CPR

Methods And Materials (1)

- We use a synthetic data set, which models a CTA phantom of peripheral arterial tree (iliac to pedal).
- Data dimension: 256x256x768
- Vessel diameter: From ~0.6mm to ~18mm
- Voxel size: 0.5x0.5x0.5mm
- Vessel density: 1350
- Background density: 1100
- A gaussian noise with sigma 0, 5 and 10 is used.

MIP of the data

Methods And Materials (2)

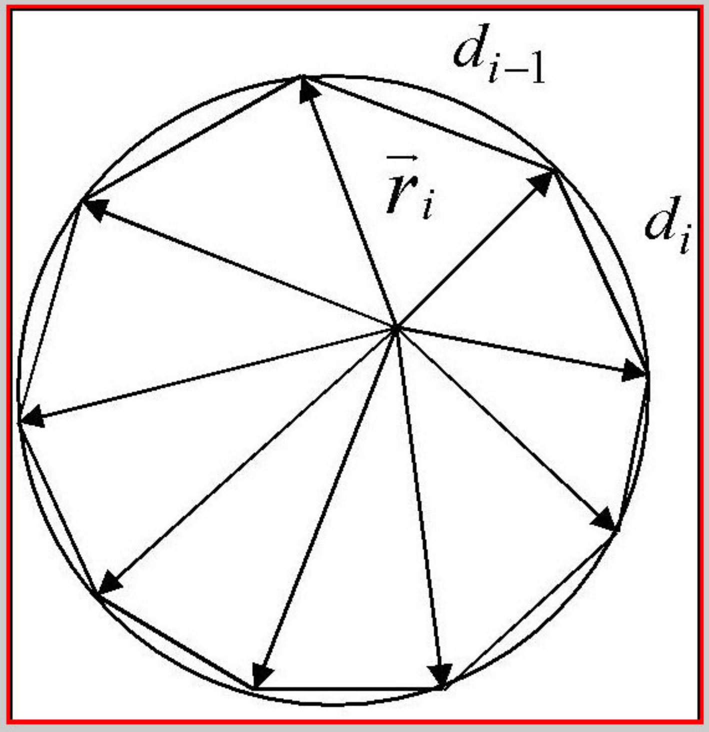
- First, a vessel tracking algorithm was used to find an initial vessel path [Kanitsar2002].
- Next, six different algorithms were used to determine the centerline of the synthetic data-set.
- They are ray-casting/thresholding (RCT), ray-casting/maximum gradient (RCMG), block matching (BM), ellipse fitting (EF), center of gravity (CoG), and randomized Hough transform (RHT).
- Centerline approximations were performed on planes perpendicular to the vessel tracking axis every 0.5mm approximately.
- The accuracy of each method was expressed as the error-distance between the derived centerline and the known centerline of synthetic data

Methods And Materials (3)

Centerline Approximation Methods

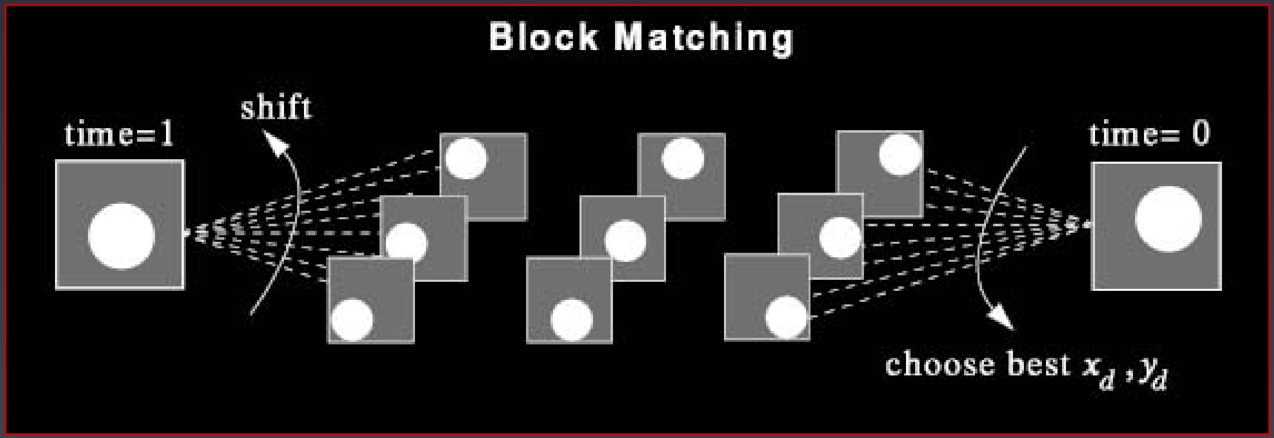
Ray Casting (RC)

The ray casting method works by tracing several rays (r_i) from one point inside the vessel to the outside. In this work we present two ray casting techniques that differ by the ray stopping criterion. We denote one technique as ray casting with thresholds (RCT), which uses a threshold interval to define the vessel boundary. The second technique uses the maximum gradient (RCMG) information. A point is considered to be at the vessel border if at this point a gradient maximum is found along the ray. After the processing of several rays over the vessel, an approximation of its center is estimated as the center of gravity of detected border points (d_i).



Ray Casting

Methods And Materials (4)



Block Matching (BM)

This method is applied incrementally for two successive cross-sections of the initial vessel path. It looks for the best matching between two vessel cross-sections by applying a shift on the original cross-sections. The consecutive cross-section is shifted to several new positions and matched with the previous cross-section. The best matching result is selected to better center the vessel path.

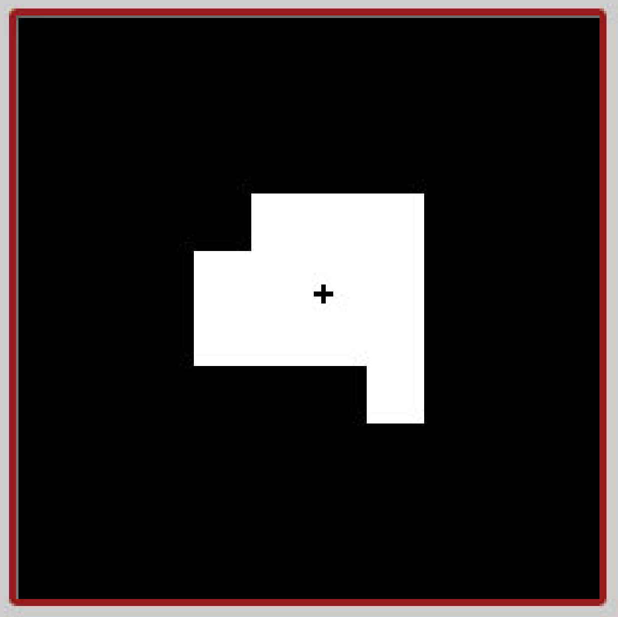
Methods And Materials (5)

Center of Gravity (CoG)

The center of gravity can be defined as the equilibrium point where the entire weight of the object is concentrated.

First a threshold filter is applied to get a binary image and eliminate background from vessel information.

The center of gravity of the remaining points is used to improve the approximation of the vessel center.



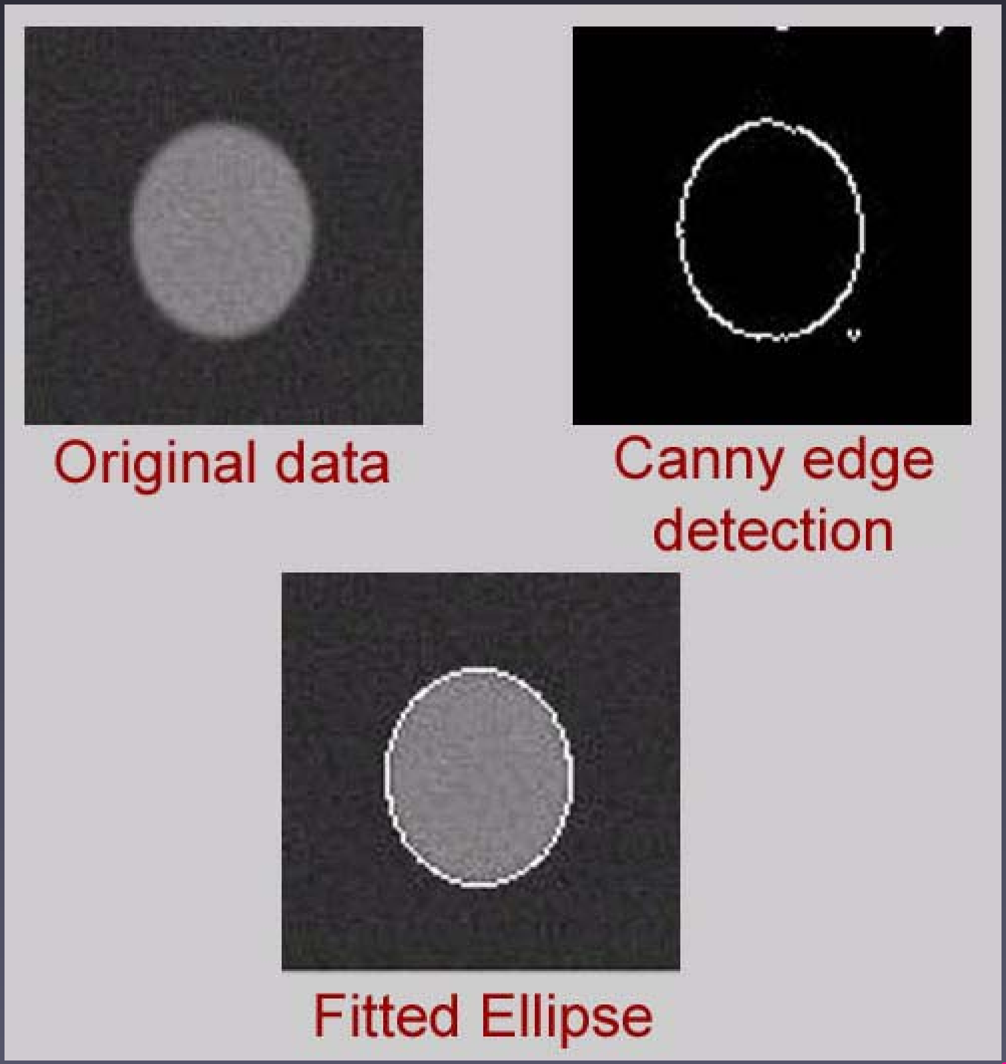
Center of gravity of white pixels

Methods And Materials (6)

Ellipse Fitting (EF)

Blood vessels have a tubular shape, which can be defined by a set of ellipses along their axes.

An ellipse is approximately fitted to a set of points. This set of points is the result of a pre-processing step, which involves an edge detector (Canny edge detector).

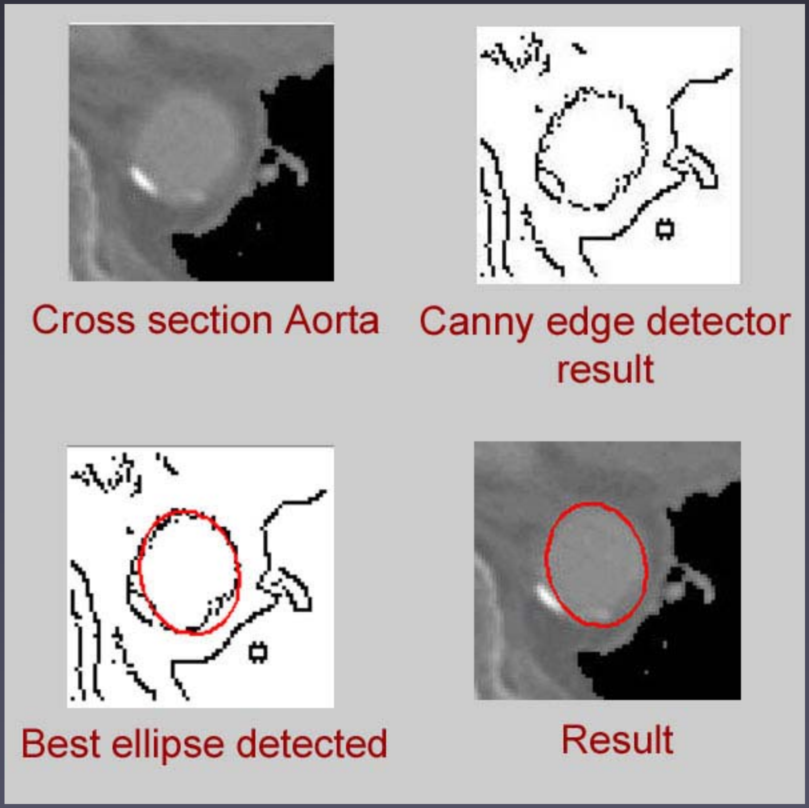


Methods And Materials (7)

Randomized Hough Transform (RHT)

Given a subset of border points of the vessel (after the Canny edge detector has been applied).

- Iterate the following three steps until a determined number of times.
  - Select three points.
  - Define the parameter of one ellipse passing through these three points.
  - Increment a score for each ellipse found.
- Select the ellipse with the maximum score. This should be the ellipse best fitting the vessel.



Cross section Aorta

Canny edge detector result

Best ellipse detected

Result

Results (1)

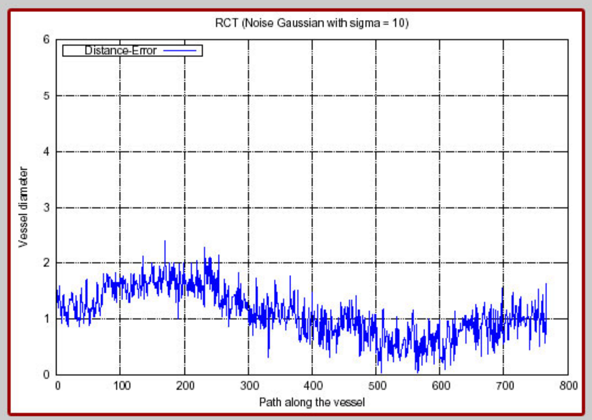
- Six algorithms for centerline estimation were evaluated generating a graph which describes the error of the distance between the center estimated by the method and the center of the synthetic data which is known.
- The Y-axis represents the error-distance, which should be closer to 0 for good approximations. The X-axis represents each slice along the vessel. The slice 0 has a diameter ~18mm and slice 768 has a diameter ~0.7mm

Results (2)

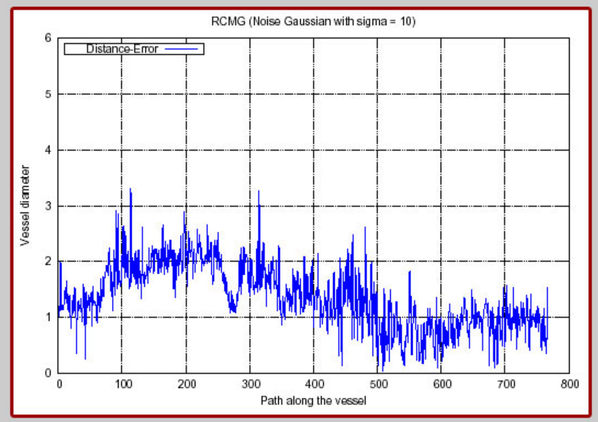
Method	~ Mean of error (avg.) (mm)	Time consume (~seg)	Comments
RCT	1.11 ± 0.4	~1.7	Threshold depending. However, we get a good approximation along all different vessel diameters
RCMG	1.82 ± 0.9	~1.85	Threshold depending. However, we get a good approximation along all different vessel diameters
CoG	0.8 ± 0.4	~1.53	Good performance, good approximation along all different vessel diameters
BM	0.99 ± 0.63 for diameter vessels < 5mm	~ > 190,000	Require optimization. Better results on small vessels (< 5mm) than large vessels (> 5mm)
FE	0.56 ± 0.22	~ 3.7	Depend on the result of the canny edge detector. Sometimes it can not approximate any ellipse
RHT	5.23 ± 6.89	~ > 100,000	There is not enough points to define an ellipse around the vessel with this method

Results (3)

- RCMG, RCT has similar results along different vessel diameter (as can be see in the graph).
- CoG keep a mean of the error significantly smaller (0.8mm)

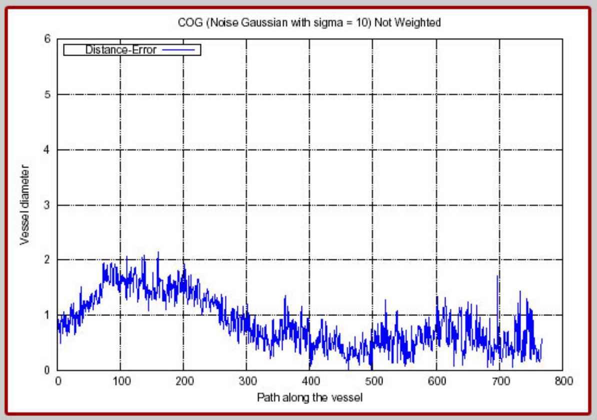


Ray casting using thresholds (RCT)



Ray casting using Maximum Gradient (RCMG)

- The RCT method uses two threshold values. These values define a valid interval of intensity to identify vessels.



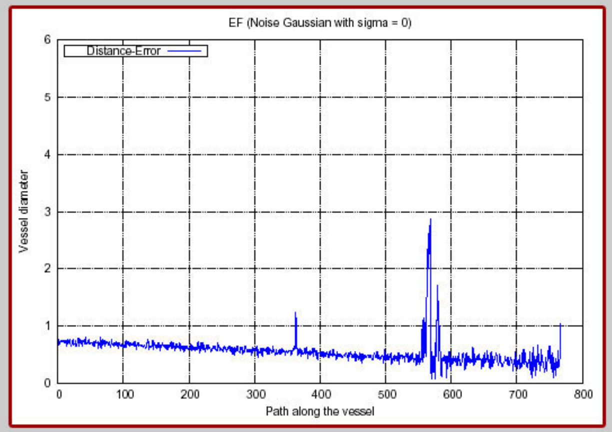
Center of Gravity (CoG)

Results (4)

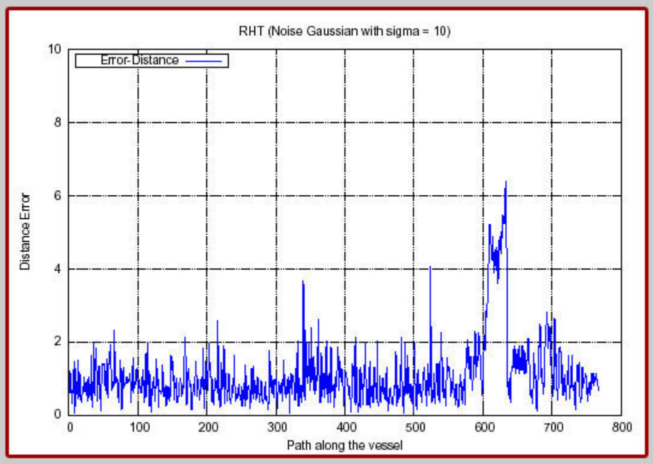
- BM demonstrated unacceptable performance in large vessels (>5mm). For small diameter (< 5mm), BM shows an error significantly smaller with a mean of error 0.99mm and standard deviation of 0.63mm.
- EF and RHT methods use as a pre-processing the Canny edge detector. The Canny edge detector gives as result a binary image with borders defined by points. This method uses two threshold values. With lowers values for these thresholds we get binary images with a spread set of points around the borders, with higher values important data might be lost. Therefore the EF and RHT methods are highly dependent on the Canny edge detector. These methods are not robust enough.

Results (5)

- However, with an empiric selection of a good threshold value (in this case; lower value = 768 and high value = 1536 of density), the FE method keeps a mean of the error in ~0.56mm but fails many times as you can see in the graph.
- RHT requires more points. The diameter of the peripheral vessels are between ~20mm and ~2mm approximately. Therefore, only rather small resolution vessel cross-sections are available. The RHT requires more points around the border to produce better results.
- Around the slices 550 and 650, the data is darker than other parts, this was created to model a real dataset, where some area can be diffuse. As we can see, in this area RHT and FE show a bigger error.



Fitting Ellipse (FE). Peaks show where the method fail, because of the Canny edge detector



Randomized Hough Transform (RHT). Peaks show where the method fail, because of Canny method

Conclusion (1)

- This work presents an evaluation of different techniques used to approximate the center of peripheral arteries.
- A synthetic data is used in order to evaluate the accuracy of each method.
- CoG method presents less sensibility to noise than the others.
- RCT, RCMG and CoG methods present the best approximation to the center.
- BM makes a search of the best position to match two images, which can take longer, this can be optimized, in order to improve the performance and accuracy, optimizing the searching process.

Conclusion (2)

- With the RHT in small diameter vessels there ire not enough points to extract the ellipse parameters with good quality.
- RCT, RCMG and CoG methods provide the most efficient centerline approximation over a wide range of vessel diameters.
- RCT method uses an interval defined by two threshold values, this interval is defined empirically. Higher values for this interval would include intensity values from other tissues and lower values would not content all the vessel voxels. The method might benefit from knowledge based and locally determined threshold adaptations (e.g. from attenuation values along the initial path).

Conclusion (3)

- The EF method depends to higher degree on the pre-processing step, which is a boundary detector algorithm.
- The RHT method also depends to a higher degree on the pre-processing step, and is computationally expensive. For small diameter it is quite difficult extract the ellipse parameters because there are not enough points to accurately define the most appropriate ellipse.

References

- A. Kanitsar, R. Wegenkittl, P. Felkel, D. Fleischmann, D. Sandner, E. Gröller. Computed tomography angiography: a case study of peripherl vessel investigation. In IEEE Visualization 2001, pp. 477-480.
- A. Kanitsar, D. Fleischmann, Wegenkittl R., Felkel P., E. Gröller. CPR - Curve Planar Reformation. In IEEE Visualization 2002 (Oct 2002), pp. 37-44.
- O. Wink, W. Niessen, M. Viergever. Fast delineation and visualization in 3d-angiographic images. IEEE Transactions on Medical Imaging (2000).
- C. Q. Davis, Z. Z. Karu, D. M. Freeman. Equivalence of subpixel motion estimators based on optical flow and block matching. In International Symposium on Computer Vision (1995), pp. 7-12.
- H. Van Assen, M. Egmont-Petersen, J. Reiber. Accurate object localization in gray level images using the center of gravity measure; accuracy versus precision. IEEE Transactions on Image Processing 11, 12 (December 2002), 1379-1384.
- A. Fitzgibbon, R. Fisher. A buyer's guide to conic fitting. In british Machine Vision Conference (1995), pp. 513-522.
- R. A. MacLaughlin. Radomized hough transform: Improved ellipse detection with comparation. In Pattern Recognition Letters 19 (1998), pp. 299-305.

Authors

- A. La Cruz, MSc., Ao. Univ. Prof. DI. Dr. techn. E. Gröller
  - The Institute Of Computer Graphics and Algorithms, Technical University, Vienna.
  - email: alacruz@cg.tuwien.ac.at
  - web page: http://www.cg.tuwien.ac.at/staff/AlexandraLaCruz.html
- DI. M. Straka, DI. dr. techn. M. Šrámek
  - Commision for Scientific Visualization, Austrian Academy of Sciences, Vienna
- Dr. A. Köchl
  - Vienna General Hospital
- Ao. Univ. Prof. Dr. med. D. Fleischmann
  - Stanford University