The challenges in optimizing angiographic system parameters

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Abstract

Computer vision algorithms such as depth estimation and segmentation may be used to extract useful data from images or videos captured by angiographic systems. These algorithms assist in identifying abnormal vessel structure that requires medical intervention. The accuracy of some of these algorithms, such as 3D reconstruction, depends on the accuracy of the system parameters. Therefore a preliminary step is required, in which the angio system parameters are optimized. In practice, this optimization is limited due to the dependencies of some of the parameters. In this paper we describe the parameter dependencies and discuss their effect on the optimization and on the algorithms that use it.

1 Introduction

A catheterization laboratory, or cath lab, is an examination room in a hospital or clinic with diagnostic imaging equipment used to visualize the arteries of the heart and the chambers of the heart and treat any stenosis or abnormality found. The angio system includes a moving bed and an arm, often shaped as the letter C, that includes an x-ray source at one end and an image intensifier at its other end. The C-arm may be rotated around the ISO-center in all directions.

Two or more images taken in various system positions may be used to reconstruct the shape of the vessels and their location ([1], [2]). Upon identifying a trace along a vessel in all views, the traces may be combined to calculate the shape and location of the vessel in the patient body. 3D Reconstruction algorithms use the location of the x-ray source and detector at each of the instances in which images were taken, to calculate the intersection of the rays and determine the 3D location of each point along the trace. The accuracy of the rays' location is highly important in this process, and it is derived from the system parameters as they are recorded at the metadata of image capture. The parameters include the rotation of the system in each of the three axes, the bed translation in each of the three axes, and the SID - the distance between the x-ray source and the detector, for each system position. The ISO-center location is an additional parameter. Some of these parameters are known with high accuracy, some with low accuracy, and some, such as the bed translations in the direction of the patient right/left hands and head/toes are unknown.

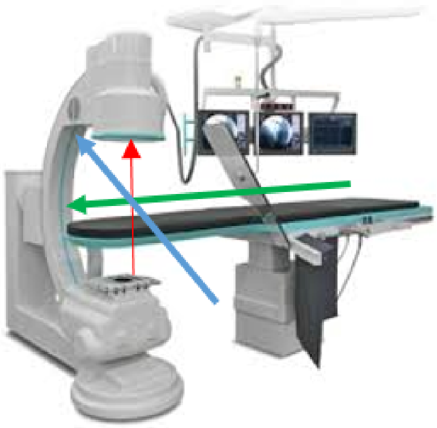

Figure 1: An angio system. The ISO center is located at the coordinates' origin. The plotted axes are the axes along which the bed may be translated and around which the C-arm may be rotated

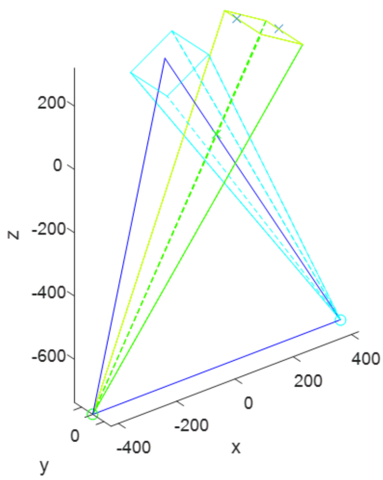

Figure 2: Simulation of two possible states of the angio system. The head of each pyramid is the x-ray source and the pyramids' bases are the detectors location. The intersection area of both pyramids includes the location of the patient's heart, in case the bed translation was equal in both positions. In this example, the C-arm was rotated once towards the left side of the patient and once towards the right, and was not rotated around the other axes. The blue triangle marks an epipolar plane.

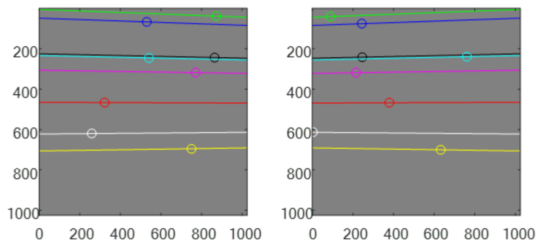

Figure 3: A set of matching points and the corresponding epipolar lines, that were simulated using the parameters of the example in Fig.2.

2 Parameter Optimization

In order to create an accurate 3D reconstruction, a preceding phase of parameter optimization is needed. The inputs of this phase are a few sets of matching locations in the various images and an initial guess of parameter values. At least n/2 pairs of matching points are needed for the optimization phase, where n is the number of parameters that need to be optimized. Since the matching points are also marked with limited accuracy, a bigger number of matching points, which are spread all over the image, rather than tight together, is favorable.

In the process of system parameter optimization, the 3D location of each pair of matching points is calculated and then back-projected to the images. The optimized set of parameters is the set that minimizes the cost function, which is the sum of distances between the original points and the related back-projections.

2.1 Epipolar Geometry

In any set of images that capture static objects from various views, matching points are located along epipolar lines. Epipolar lines are the intersection of the detectors' planes and the epipolar plane, which is the plane on which the two x-ray sources and the captured point on the object are placed. Figures 2 and 3 show a simulated example of two states of the C-arm, a set of matching points and related epipolar lines. For example, the match of the red point in the the left image of Fig. 3 can only be located along the red line in the right image. Symmetrically, the matching point of the right image's red point can only be found along the left image's red line.

2.2 Dependencies

It is derived from epipolar geometry that the cost function is more sensitive to system rotations and translations that are perpendicular to the epipolar plane than to ones along it. An example of this behavior can be viewed in Fig. 4. The cost function's gradient is modest in the direction of the epipolar lines, while it is significant in the perpendicular direction. As a result, there is no significant minimum in the epipolar lines direction, and the optimized parameters may be substantially different from the true ones.

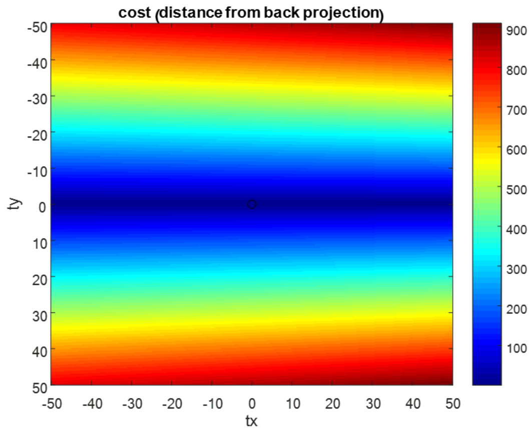

Figure 4: The cost function for the simulated system in Fig. 2, as a result of changes in the difference in bed translation in the patient right-left direction (tx) and head-toe direction (ty)

The same issue may be described from a different view: in order to decrease the distance between a point to the relative back-projection, either the bed translation or the rotation parameters may be changed in the desired direction, where one compensates for the other.

2.3 Possible solutions

When the cost function is very shallow near its minimum, as demonstrated in Fig. 4., increasing the number of matching points, and choosing ones that are well spread all over the images is obviously very essential. Unfortunately, in practice the locations that are used as matching points tend to lie on vessel bifurcations, therefore it is hard to locate a large number of matching points and even harder to locate matching points that spread on a large part of the image. In such case it might be useful to rotate the coordinates system such that one of its axes is along the coarse epipolar direction, where the weak cost gradient is expected. Then the optimization should be carried out in two phases: At first the system translation and rotation in the directions that are perpendicular to the epipolar line should be optimized. The translation and rotation along the weak axis, the axis along the epipolar line, should be estimated at the second step. Fig. 5 demonstrates the effect of optimization in one or two phases.

2.4 Influence on the following reconstruction

As a result of the shallow minimum along epipolar lines direction that was described above, the parameters estimation algorithm may not converge, and some of the values of the optimized parameters may be very different from their true value. Nevertheless, due to the fact that the effect is mainly in the direction of the epipolar lines, we found out that in most cases its effect on the final reconstruction is minor.

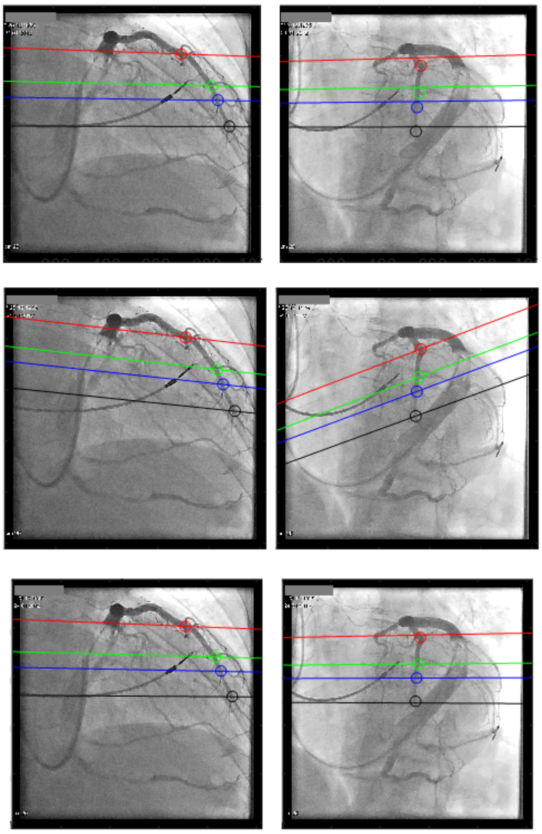

Figure 5: Optimization in one/ two phases: upper pair of images - the matching points and epipolar lines, as calculated with the original parameters, before optimization. Middle pair - epipolar lines as a result of optimizing the whole set of parameters at once. Bottom pair - epipolar lines as a result of optimization in two phases

3 Conclusion

When the system parameters in angio-system are optimized as a preliminary step for 3D reconstruction, there are dependencies, and the minimized cost does not have a clear and deep minimum along the epipolar lines direction. It is advisable to use as many spread matching points for the optimization, and to carry out the optimization in two phases.

References

[1] Kevin Sprague, Maria Drangova, Glen Lehmann, Piotr Slomka, David Levin, Benjamin Chow, et al. Coronary x-ray angiographic reconstruction and image orientation. *Medical physics*, 33(3):707–718, 2006.

[2] Jian Yang, Yongtian Wang, Yue Liu, Songyuan Tang, and Wufan Chen. Novel approach for 3-d reconstruction of coronary arteries from two uncalibrated angiographic images. *Image Processing, IEEE Transactions on*, 18(7):1563–1572, 2009.