

Localizing a Guidewire in Three Dimensions during Endovascular Interventions Using Single-view Fluoroscopy and a Stereo Roadmap: Method and Feasibility Study

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1 Introduction

Interventional radiology is the medical specialty where instruments such as guide-wires and catheters are inserted into a patient's vasculature under image guidance. During a procedure, X-ray source-detector pair delivers live images of the anatomy and instruments based on X-ray attenuation.

In this context I want to introduce an algorithm which makes it possible to localize a monoscopically-visualized guidewire within a stereo roadmap or a 3D reconstruction of the vessel tree. Besides the algorithm itself I will introduce its validation and implementation within our application.

This application is intended to run in an interventional room, equipped with a Siemens X-ray system (Fig. 1). Diagnostic imaging capabilities of this system include 2D projections (Fig 2, left) and 3D reconstruction (Fig. 2, right) of the vasculature. However, during the intervention when the instruments are being guided by a physician this system is capable to produce only 2D fluoroscopic images (Fig 3). The goal is to display 2D fluoroscopic images within a pre-computed stereo roadmap or a 3D reconstruction.



Figure 1. Siemens Axiom Artis dBA.

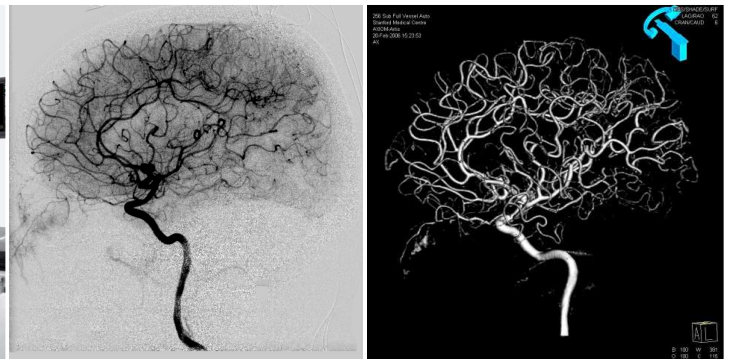


Figure 2. 2D projection and 3D reconstruction.

Having 3D data you might want to use some existing product which is capable to fade between 2D fluoroscopic image and a reconstructed 3D volume, e.g. Syngo iPilot (Fig 4). Another possibility is to use RoRo (Rotational Roadmapping). This application uses a rotational acquisition and proposes to do roadmapping directly on the 2D projections. Alternatively it can fade between 2D fluoro image and a stereo pair. Here we define a stereo pair as two DSA (Digital Subtraction Angiography) images acquired at slightly different angles (Fig. 5). The key feature of this approach is that it does not require 3D reconstruction, which sometimes could

be challenging due to the cardiac or respiratory motion or due to the presence of the metal objects inside the field of view.

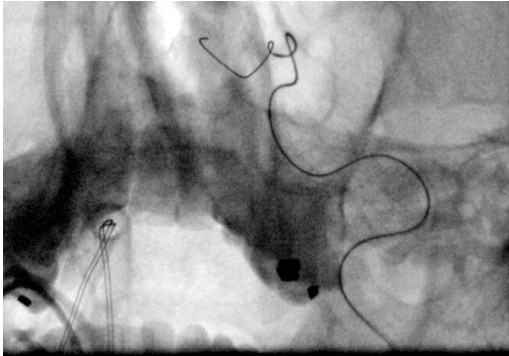


Figure 3. Guidewire on a fluoroscopic image.



Figure 4. Syngo iPilot output. Courtesy of Dr. Masaryk (Cleveland Clinic Foundation).

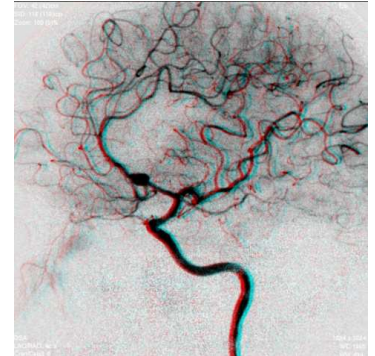


Figure 5. Blended stereo pair.

2 Problem Statement

We are given two DSA images of a stereo pair; let us denote them as left-eye and right-eye images. Also we are given a single 2D fluoroscopic image which corresponds to the left-eye image of the stereo pair. Let us denote it as a left-eye fluoroscopic image. Our goal is to find the right-eye fluoroscopic image in order to display a guidewire within a stereo roadmap. Once we have found the right-eye fluoro image we can produce a stereoscopic image of the guidewire by blending left- and right-eye fluoro images.

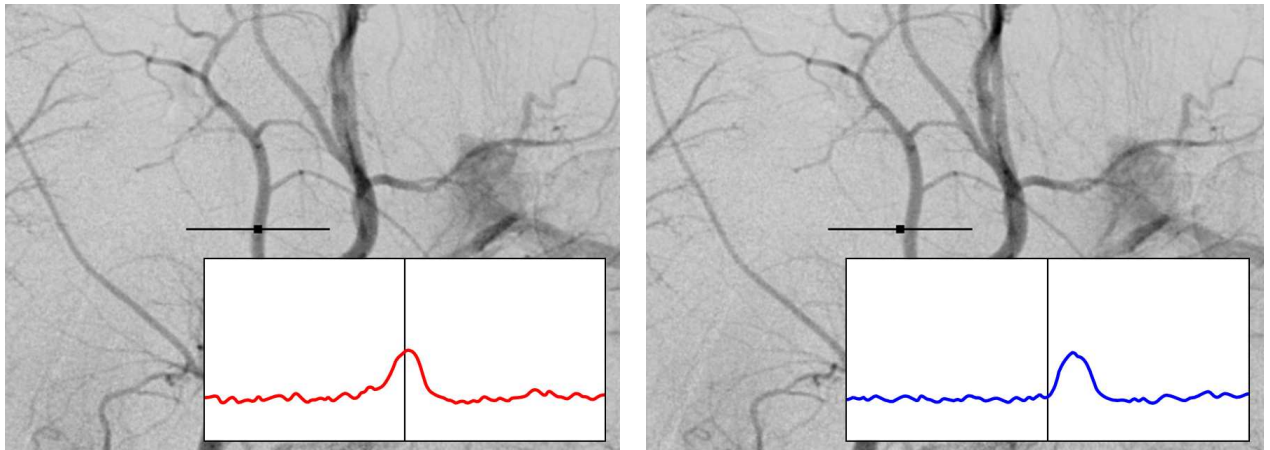


Figure 6. A point and two profiles, acquired along the same line segments.

3 Algorithm

First, select a point on the left-eye image of the stereo pair, and then acquire an intensity profile along a horizontal line segment which goes through this point (see Fig. 6, left). After that we acquire an intensity profile along the same horizontal line segment, but on the right-eye image of the stereo pair (see Fig. 6, right). The goal is to determine the distance between two peaks, i.e. we need to match these two profiles (Fig. 7). Let's denote this distance as a stereo shift. Before matching the profiles we apply window function (Fig. 8) in order to remove other peaks caused by the nearby vessels. We determine the stereo shift using the two

following techniques. In the first one, referred as Maximum Difference (MD) we find such S which minimizes the maximum difference between two profiles, i.e.

$$S_{MD} = \operatorname{argmin}_s \max_x |p_{left}(x) - p_{right}(x + s)|$$

In the second one, referred as Cross Correlation (CC) [1], we find such S which minimizes the following expression.

$$S_{CC} = \operatorname{argmin}_s \left| 1 - \frac{\int p_{left}(x)p_{right}(x+s)dx}{\int p_{left}^2(x)dx} \right|.$$

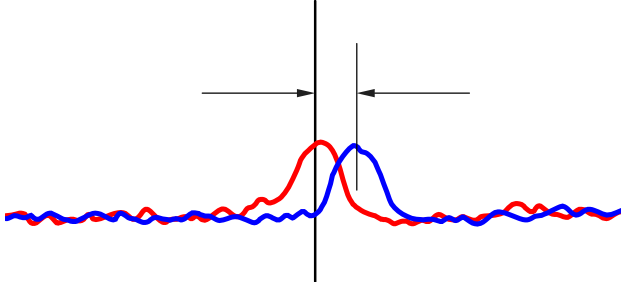


Figure 7. Left- (red) and right-eye (blue) profiles together.

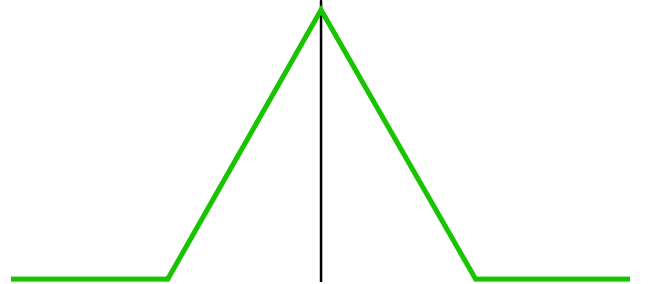


Figure 8. Window function.

On Figure 9 green and magenta curves correspond to the MD and CC algorithms respectively. These functions both depend on the shift value. Easy to see that the shift value which minimizes both functions corresponds to the number we need to shift the right profile in order to match it to the left one.

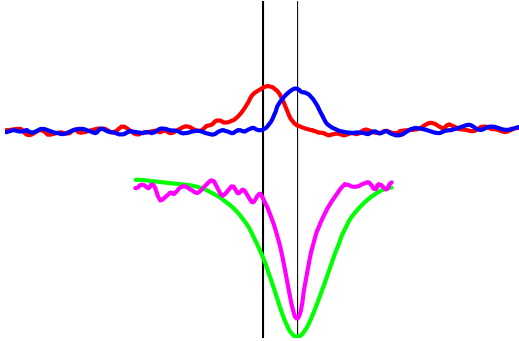


Figure 9. Sample output.

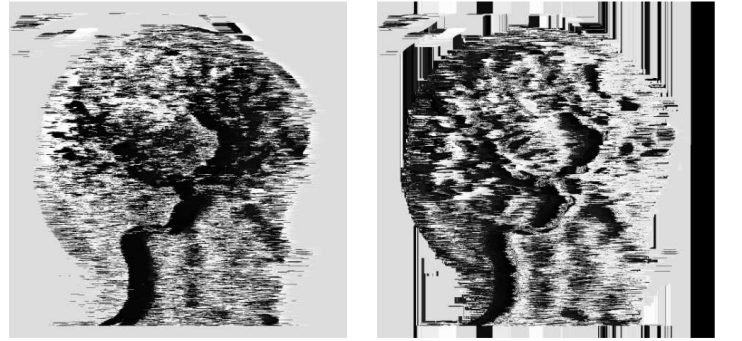


Figure 10. Examples of displacement maps: MD (left) and CC (right). Shift value is marked by color.

4 Implementation

After physician selected a working view we pre-compute all the possible shift values for the corresponding stereo pair, and then we compute a displacement map (Fig. 10), i.e. for every pixel of the left-eye image we extract left and right intensity profiles, and then determine the shift value and save the result into the look-up table. Having selected an appropriate working angle physician acquires live fluoro sequence. Consider a single frame from this sequence. We apply fluoro mask to this image and binarize it, and perform noise filtering. Next, every non-black pixel of the left-eye fluoro image is shifted according to the displacement map. Now we can display a guidewire within a stereoscopic image of the corresponding vessel tree (Fig. 11).

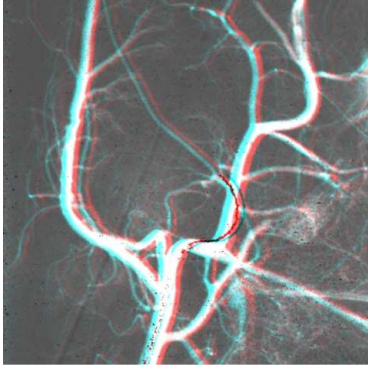


Figure 11. Stereo guidewire.

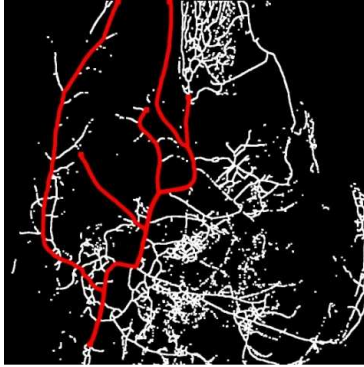


Figure 12. Six paths on an skeletonized image.



Figure 13. Computed guidewire (blue) and the ground truth (green).

5 Validation

To test this concept we need to compare our results to the ground truth. However, we do not have the ground truth in this case, since we cannot acquire two live fluoro sequences from two slightly different angles simultaneously. However, we can get around it by employing the following idea. Consider a stereo pair, let's skeletonize both images and label skeletonized right-eye image as the "ground truth". From the left image we extract six central paths which go through the major vessels (Fig. 12, 14).

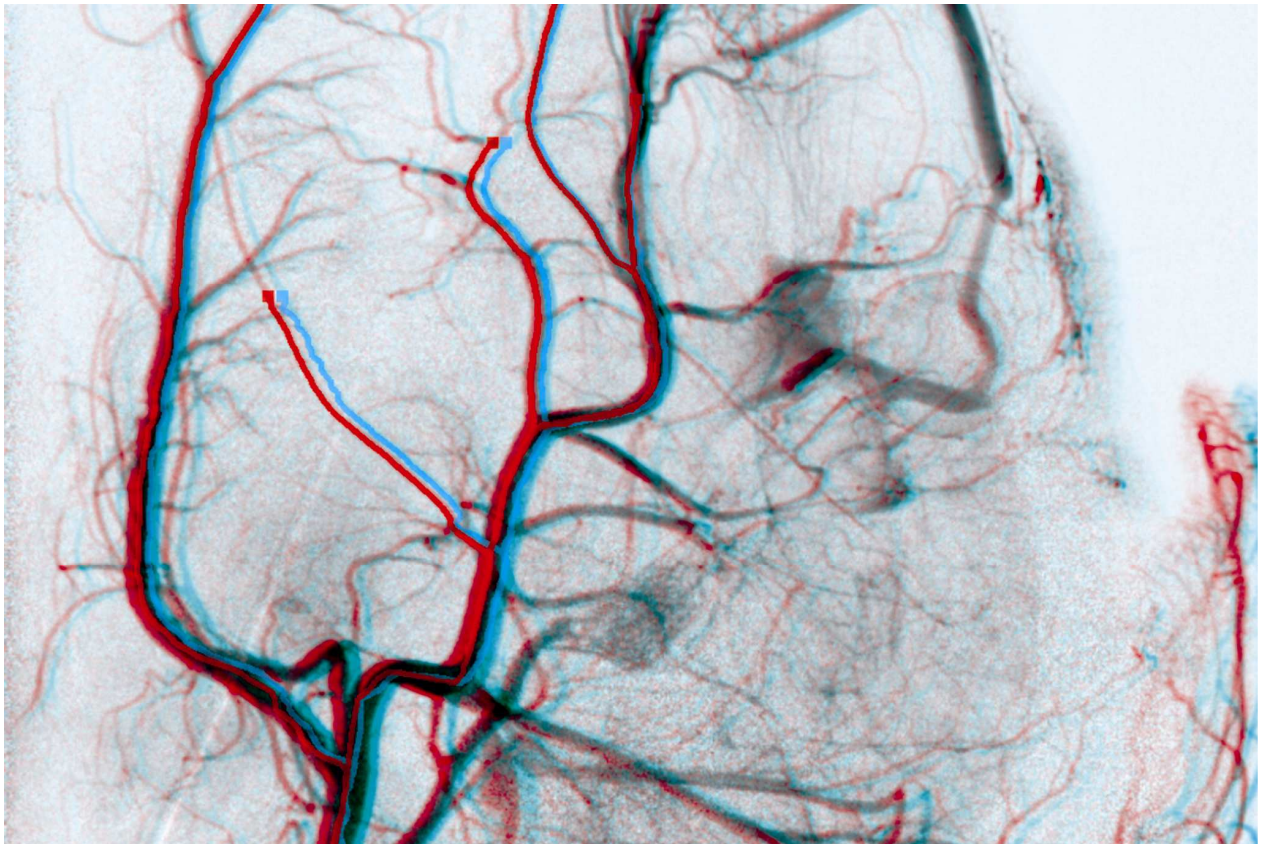


Figure 14. Simulated (red) and computed (blue) guidewire visualized within a stereo roadmap.

Here is how we perform the validation process. We use this path and the corresponding stereo pair to compute its location in the right-eye image. Then we compare the computed image to the ground truth (Fig 13). We calculate the score for every path as a number of points which overlap the corresponding skeletonized path in the right-eye image (considered as the “ground truth”). We should mention that two points are considered overlapping if their centers are within 0.5 mm from each other (this number is specific to the dataset and depends on the pixel thickness). On Table 1 you can see how both algorithms performed on one of our datasets.

#	Maximum Difference	Cross Correlation
1	86/98 (88%)	86/98 (88%)
2	88/90 (98%)	78/90 (87%)
3	183/197 (93%)	150/197 (76%)
4	58/65 (89%)	55/65 (85%)
5	149/152 (98%)	124/152 (82%)
6	54/61 (88%)	44/61 (72%)

Table 1. Comparison of MD and CC algorithms.

6 Conclusion

First of all, we think that it is feasible to find the location of a guidewire in the right-eye image of a stereo roadmap, given its location in the left-eye image. Secondly, stereoscopic visualization of the vessel tree and the guidewire looks “convincing” and, finally, we can process live fluoroscopic image sequence in real time.

7 Acknowledgements

We gratefully acknowledge support from Siemens Medical Solutions.

8 References

- [1] D. Ballard, C. Brown, *Computer Vision*. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1982.