Efficient 3D Reconstruction of Vessels from Multi-views of X-Ray Angiography

Xinglong Liu[1] Fei Hou[1] Shuai Li[1] Aimin Hao[1] Hong Qin[2]

[1]State Key Laboratory of Virtual Reality Technology and Systems, Beihang University, China

[2]Stony Brook University, Stony Brook, USA

1. Motivation and Challenges

Intra-operative X-Ray is essential during some surgeries. The 2D X-Ray images have many shortcomings such as viewing angle dependence, etc.

We develop an efficient vessel reconstruction system from multiple X-Ray views considering consistency and continuity and help doctors understand the spatial configuration of coronary arteries of specific patients during operation.

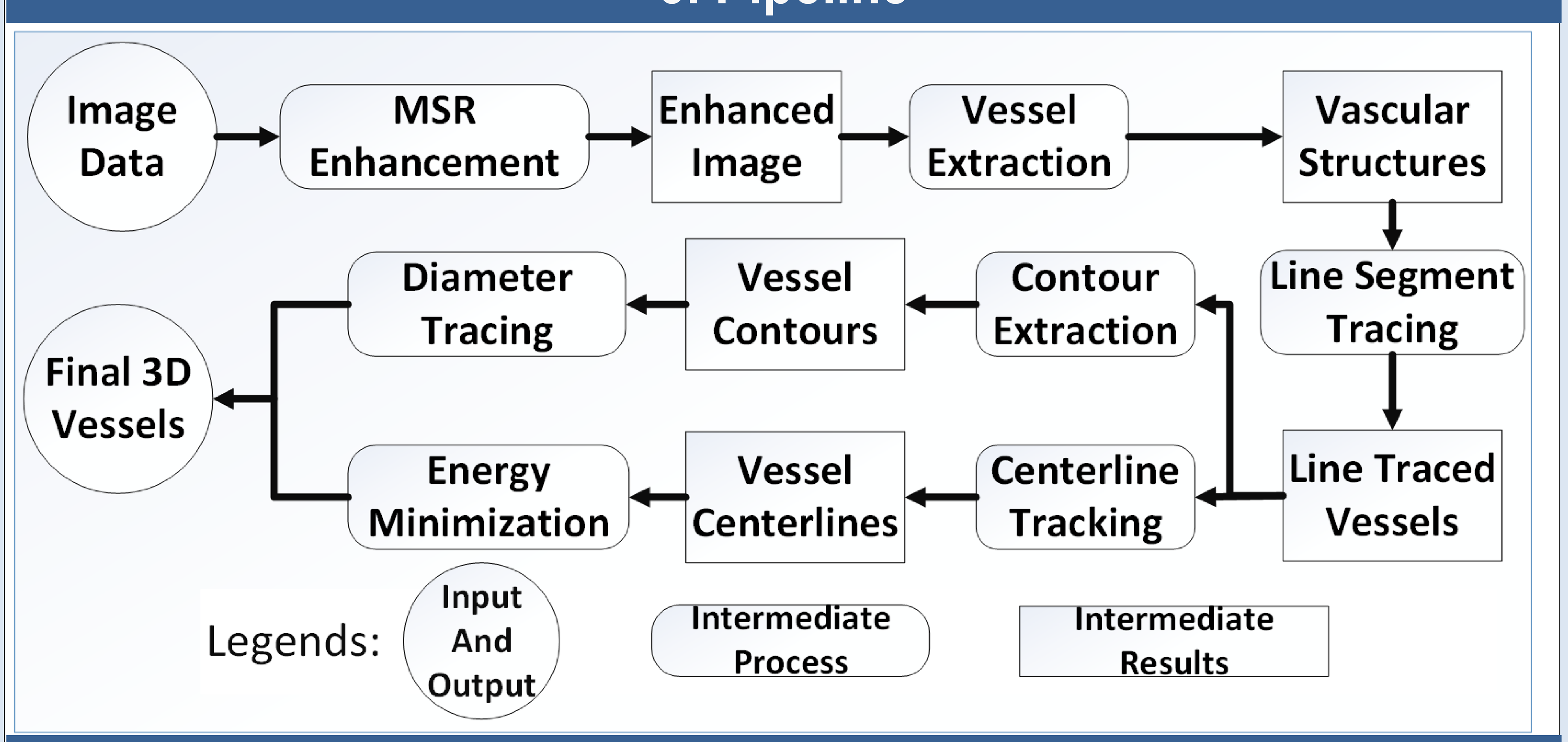
2. Contributions

(1) We divide the spaces between the X-Ray iso-center and the detector into slices. We sample 3D space points and project them to the image space considering consistency and continuity with their neighbors.

(2) We formulate the 3D reconstruction as a global energy optimization problem and solve it using belief propagation.

(3) We implement a CUDA edition of Hessian-based vessel filter and centerline tracking method and gain great time efficiency.

3. Pipeline



4. Data Acquisition and Preprocessing

We use two types of data,

- **Synthetic data** from our simulation system.
- **Real data** from clinical angiogram.

We select one image from each view within mostly the same cardiac cycle and use them to reconstruct the vessels. To enhance the images, we apply **multi-scale retinex** method.

5. Vessel Extraction

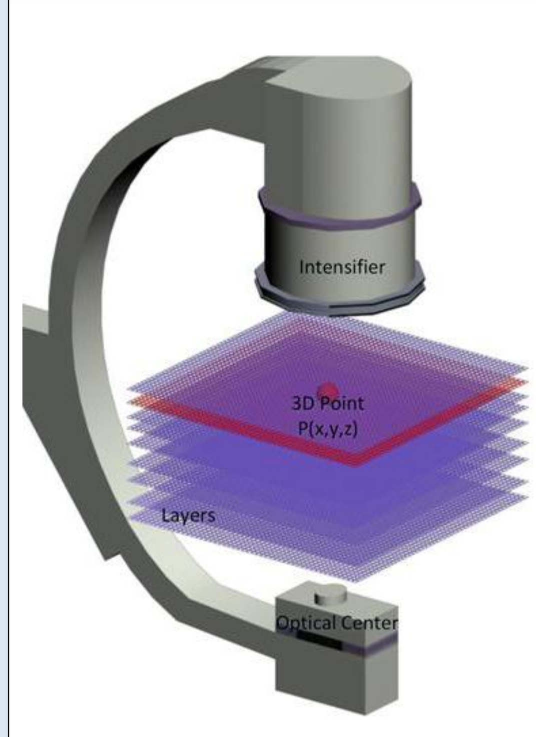
This step is done by two procedures,

- We use the approach relying on a **multi-scale Hessian matrix** to extract the vascular structures.
- We compute the connectivity of the entire image using a cross template to filter tiny line segments.

6. Centerline Tracking

Using the binary images of vascular structures, we apply the centerline extraction method using **multi-stencils fast marching (MSFM).** Also, we obtain the vessel contours to compute the diameters at each centerline point.

7. 3D Reconstruction of Coronary Arteries



The elements of our method include,

- Using **three** view images of the **same cardiac cycle**
- One image with **least foreshortening and overlapping** as reference image
- The 3D space between optical-center and intensifier is divided into **3D slices** $l = (l_1, l_2, \dots l_k)$

Then, for a given pixel p on I_1 , the pair $(p,\ l_i)$ uniquely identifies a point in 3D space. Therefore,

$$3D\ reconstruction\ is\ to\ assign\ l_i\ to\ each\ p\ on\ I_1$$

An **energy minimization problem** considering **connectivity** and **topological** structures. We use **Belief Propagation(BP)** to solve this problem.

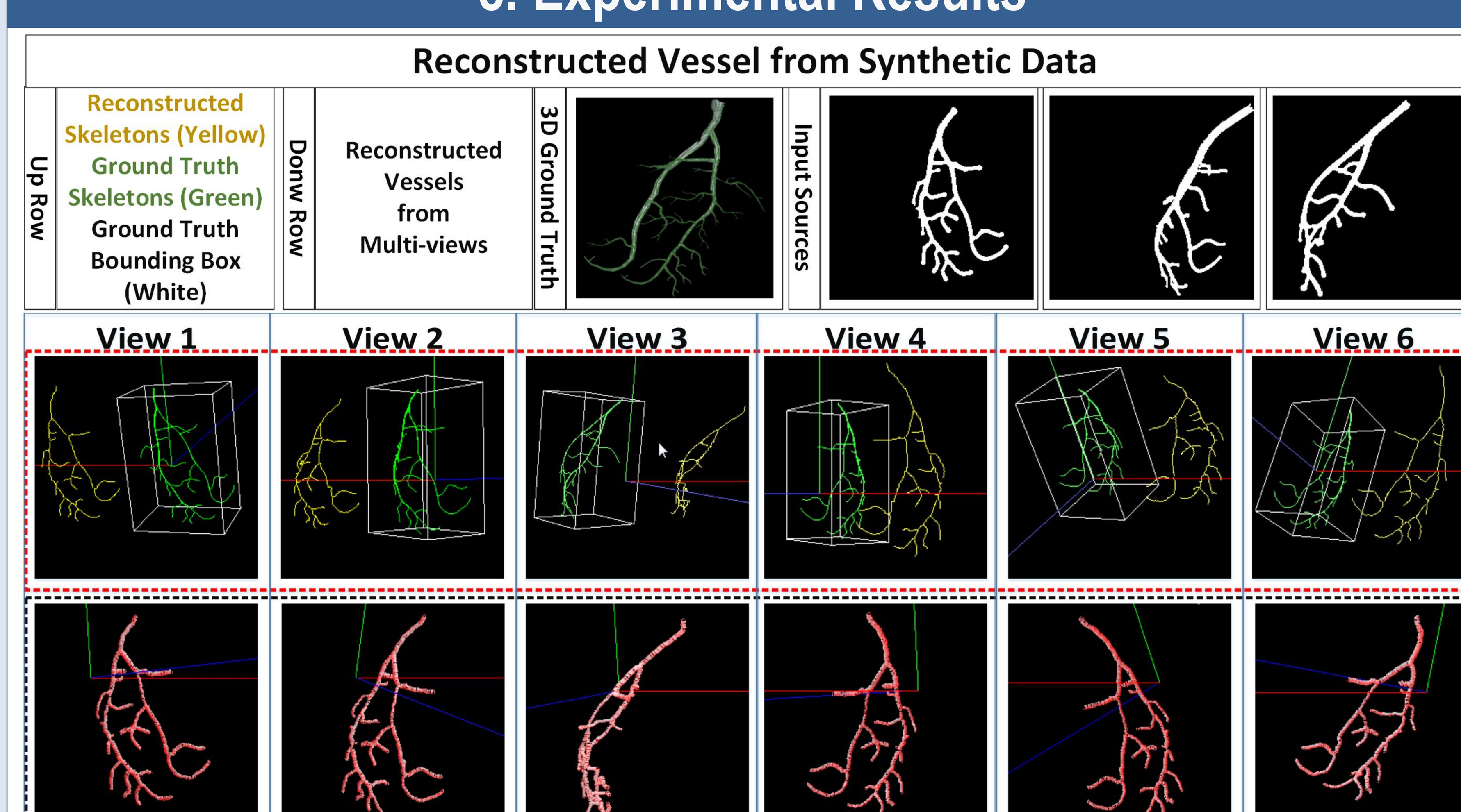
Energy Equation, $E(f) = \sum_{p\in P} D_p(f_p) + \lambda \sum_{p,q\in N} V_{p,q}(f_p, f_q)$

- $V_{p,q}(f_p, f_q)$ is the **Euclidean distance** between point p, q
- $D_p(f_p)$ is the **color consistency**.

$$D_p(f_p) = \frac{1}{(n-1)} \sum_{i=2}^{n} P_i(x,y),\ P_i(x,y) = \begin{cases} W_h, & p(x,y) \in I_i \\ W_l, & \mathcal{N}(p(x,y)) \notin I_i \\ W_a, & \text{otherwise} \end{cases}$$

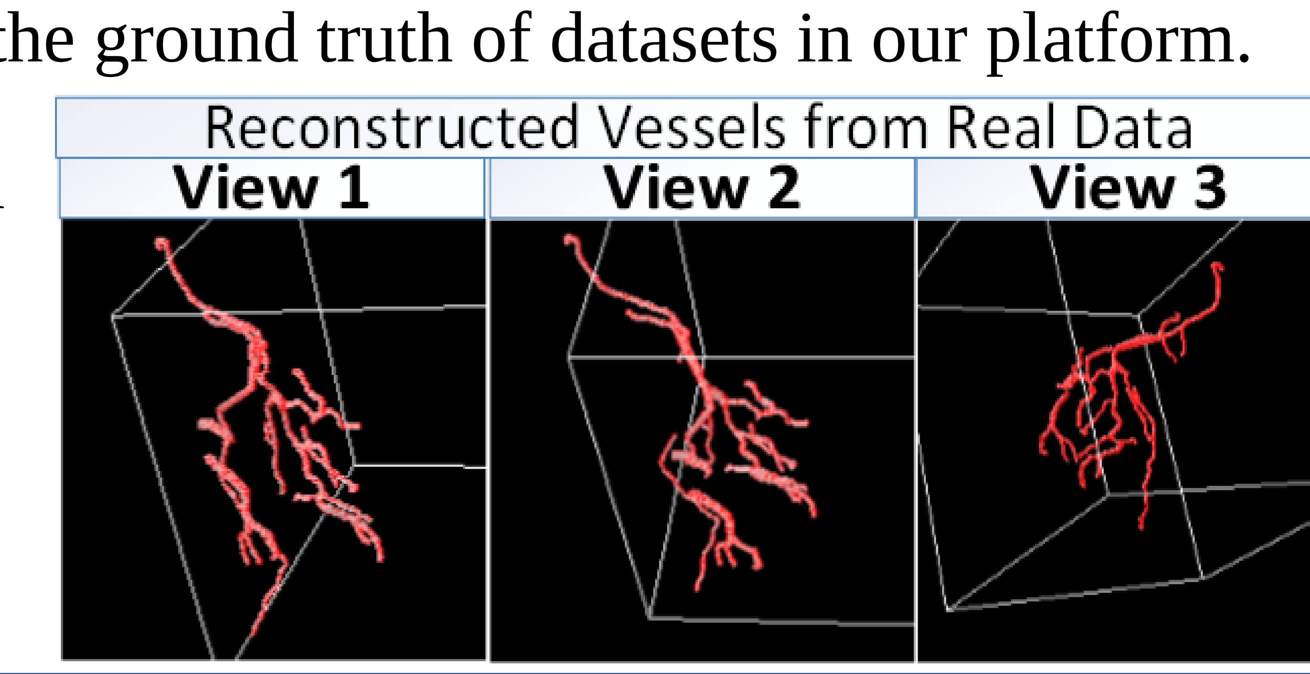
$$W_a = \frac{1}{N} \sum_{i=1}^{N} V_i(x,y), \qquad V_p = V_{p-1} + \alpha\, minD_{p,q}(f_p, f_q) + (1-\alpha) V(p_{min})$$

8. Experimental Results



The yellow lines indicate the reconstructed skeleton and the green lines are the ground truth of datasets in our platform.

For real clinical data, the views and results can be found on the right.



9. Acknowledgments

This work is supported by National Natural Science Foundation of China (No. 61190120, 61190121, 61190125, 61300067, and 61300068) and National Science Foundation of USA (No. IIS-0949467, IIS-1047715, and IIS-1049448).