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

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1. Motivation and Challenges

Intra-operative X-Ray is essential during some surgeries, such as percutaneous coronary intervention. The 2D X-Ray images have many shortcomings such as viewing angle dependence, magnification factor, etc. Current 3D reconstruction methods are mostly relying on the registration between image pairs and generally hard to enforce constraints such as consistency and continuity.

2. Contributions

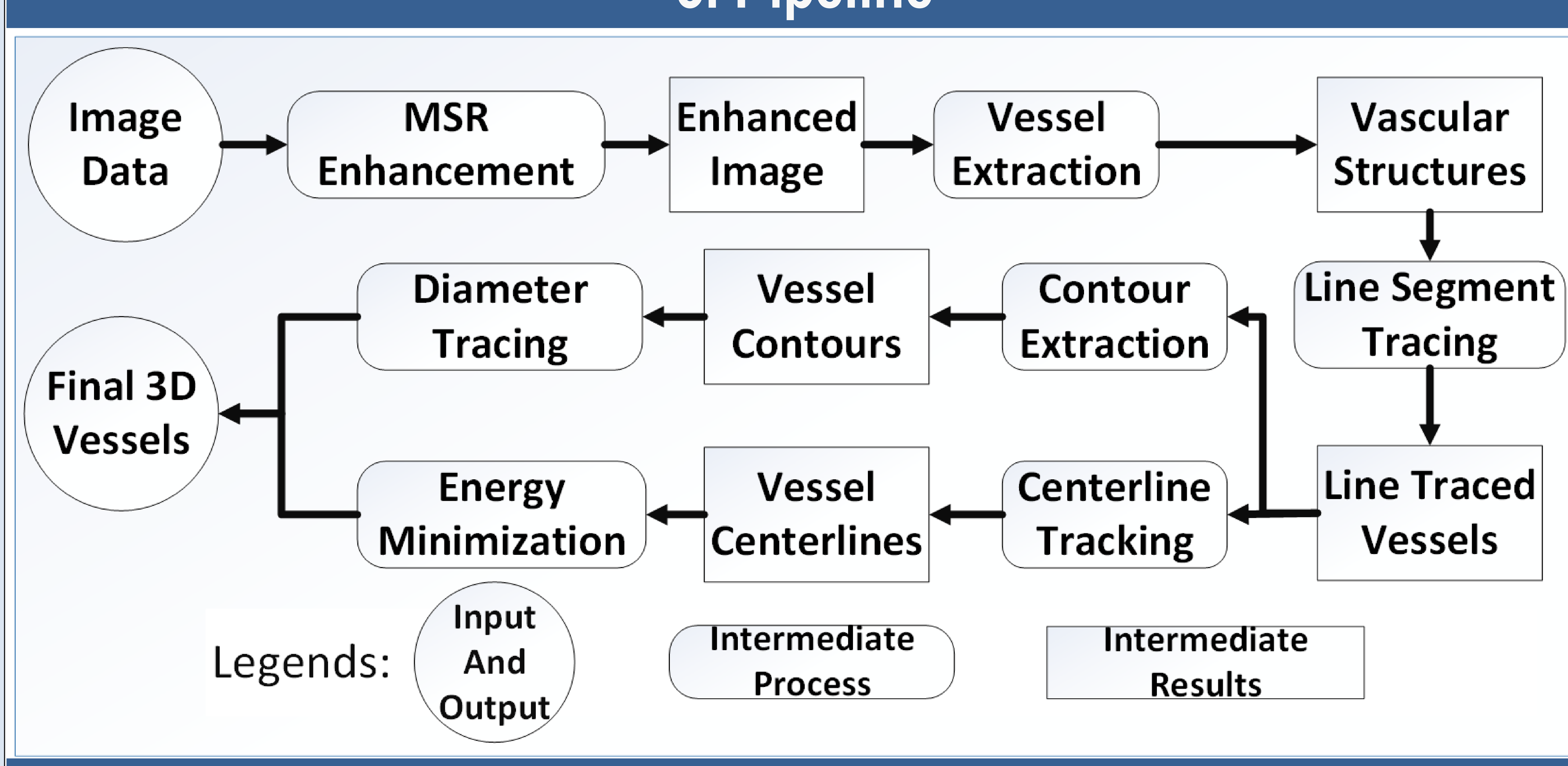
(1) We use the MSR enhanced images to obtain more detailed vessels from blurry angiograms.

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

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

(4) 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

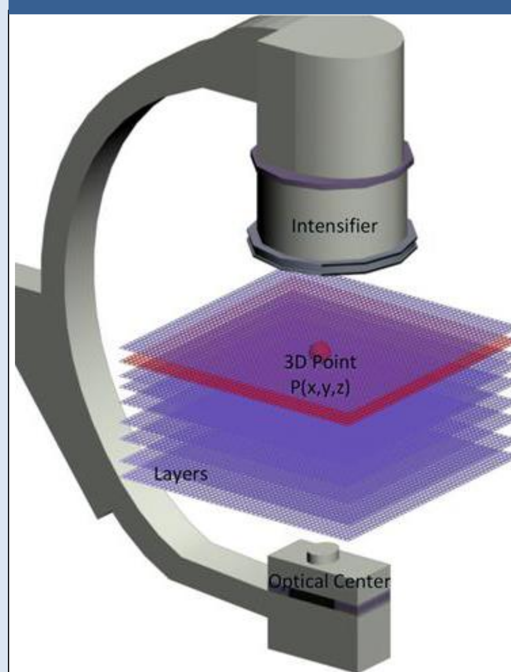
This step is done by two procedures,

- We firstly use the approach relying on a **multi-scale Hessian matrix** to extract the vascular structures.
- Then, 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 foundation of our method is,

- We use **three** views' images
- Images at the **same cardiac cycle**
- One image with **least foreshortening and overlap** as reference image I_1
- The 3D space between optical-center and intensifier is divided into **3D slices** $l = (l_1, l_2, \ldots l_k)$

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

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

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

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

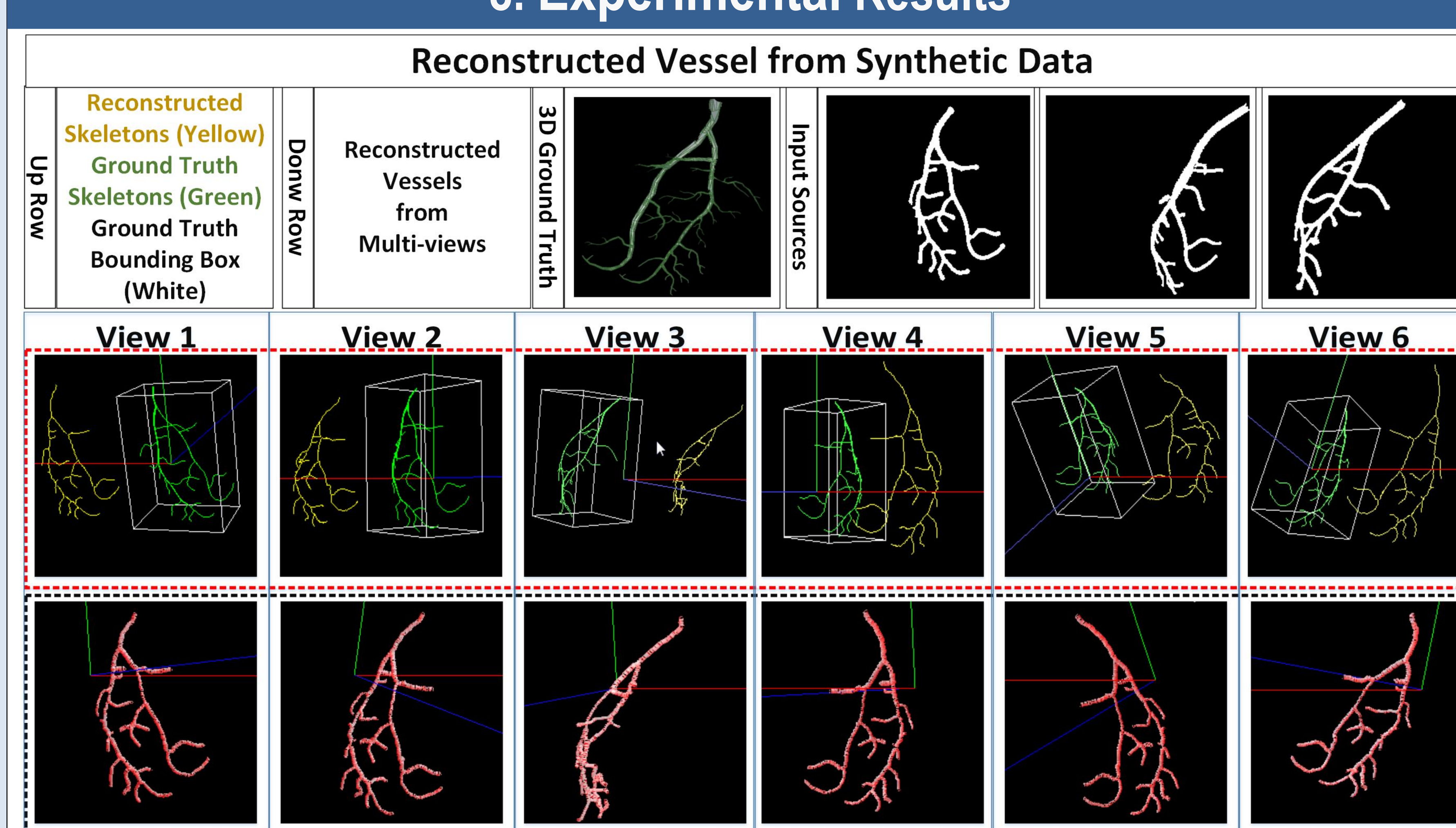
We define,

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

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

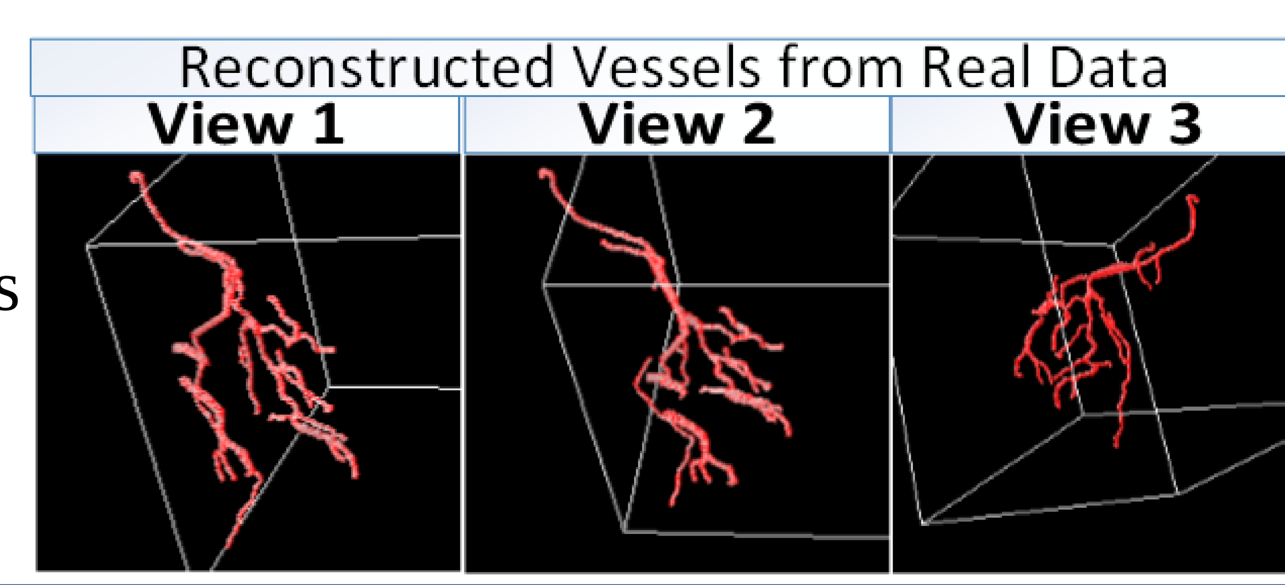
$$W_a = \frac{1}{N} \sum_{i=1}^{N} V_i(x,y) \qquad V_p = V_{p-1} + \alpha\, minD_{p,q}(f_p, f_q) + (1-\alpha) V(p_{min})$$

8. Experimental Results



The yellow lines indicate the reconstructed skeleton .The green lines are the ground truth got in our platform.

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



9. Acknowledgment

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