Discovering Shortest Path between Points in Cerebrovascular System

Shweta Suran Vishwajeet Pattanaik Dr. D. Malathi
Department of Computer Science and Engineering, SRM University, Chennai, India
+91-8375041539 +91-788012822 +91-8144468136
shwetasuran10@gmail.com vpattanaik@gmail.com malathi.d@ktr.srmuniv.ac.in

ABSTRACT
Cerebrovascular system is a complex network of vessels that supply vital nutrients and oxygen to the brain. Like any other body part it is vulnerable to bleeding, infection, blood clot and other forms of damage. These damages in brain functioning require brain surgery. The main problem with such surgeries on brain blood vessels is that in most cases, place of operation cannot be accessed directly. Therefore alternative entry points and paths have to be discovered. The proposed system is designed to help doctors/surgeons find the shortest distance between two points in brain blood vessel system, using image processing and path finding techniques over MRA images.

Categories and Subject Descriptors
I.4.9 [**Image Processing and Computer Vision**]: Applications.

General Terms
Algorithms, Measurement, Design, Reliability, Experimentation, Theory.

Keywords
Cerebral blood vessels, Magnetic Resonance Imaging (MRI), Magnetic Resonance Angiography (MRA), Segmentation, Thresholding, Skeletonization, Path finding, Dijkstra's algorithm, Digital Imaging and Communications in Medicine (DICOM).

1. INTRODUCTION
Brain injury is a catastrophic problem and leads to several small and large cerebral blood vessel damages. These damages could lead to abnormal mass of blood vessels, bleeding in brain, blood clots, stroke, lack of blood flow, blood vessel rupture, etc. When approaching a cerebral blood vessel during surgery, it is not always possible to operate the exact place directly. Sometimes surgeons have to find the alternate paths to reach the part of the blood vessel that needs to be operated. New imaging technologies can produce detailed images of the brain blood vessels and help physicians diagnose and treat medical conditions related to blood vessels; tests like: Magnetic Resonance Imaging (MRI), Magnetic Resonance Angiography (MRA) and Computed Tomography (CT). MRA is particularly meant to show vessels; whereas MRI is used to image various parts of the body like joints, soft tissues, muscles, blood vessels and internal organs [1]. MRA is an MRI technique that provides the visualization of cerebral blood flow in the vessels and is used to identify the presence and level of dissection in the brain.

I-CARE 2014, October 09 - 11 2014, Bangalore, India

http://dx.doi.org/10.1145/2662117.2662122

For surgical planning of brain, segmentation of MRA images helps in finding the structure and configuration of the cerebral blood vessels. Segmentation is the process of subdividing the image into interpretable regions [2, 5]. It improves the visualization of cerebral blood vessels in the brain and easily detects changes in the vessel. Thresholding is one the simplest segmentation techniques used. It separates object from its background [3], making it easily identifiable.

MRA of cerebral brain vessels is a complex geometry of vessels; its skeletonization highlights regular lines and shapes that look like skeleton. It is used to extract the blood vessel centerlines which help analyze the pattern of the blood vessels. It reduces redundant pixels [7] and helps identify the properties of the cerebral blood vessels such as radius, asymmetry in blood vessels, paths and branch number. Skeleton does not remove the end points neither does it break connectivity in the pixels [7]; therefore it is extensively used in path finding and precise location of the damaged cerebral blood vessels.

Based on the segmentation and skeletonization of MRA images the path finding methodology of the proposed system would determine the shortest path between two chosen points, allowing the surgeons to make quick judgments in the surgery. The proposed systems employs Dijkstra's algorithm for path finding; which finds the shortest path between nodes within the graph [6]. This system would help neurosurgeons identity shortest routes between points to reach damaged vessels in the cerebrovascular system. Neurosurgeons can use this projected path to operate the damaged vessels or can find more paths through alternate points.

2. DICOM TO JPEG CONVERSION
DICOM (Digital Imaging and Communications in Medicine) is a standard for handling, storing, printing, and transmitting information in medical imaging. Although DICOM images have found extensive recognition in medical practices, they have two major drawbacks: DICOM image have large file sizes and special software is required for viewing them on personal computers. There are a number of formats described to store images. The more popular formats used in daily practice include JPEG (Joint Photographic Experts Group), JPEG 2000, TIFF, GIF, and PNG formats. Unlike DICOM images, images saved in these formats can be viewed on any personal computer without the need for dedicated viewers. Image files saved in these formats lack bulky header information and usually contain 8-bit information. Consequently these files require less storage space and demand less resource to transfer over a network or via the Internet. DICOM files require enormous space for storage compared to JPEG format; JPEG images on the other hand are easy to handle and provide significant quality.

The proposed system is designed to function over both DICOM and JPEG images. In case the system is fed a DICOM MRA image, it first converts the image into JPEG format before proceeding to the next step. The DICOM/JPEG MRA images used in the simulation were attained from various online datasets available for research and teaching purposes [8, 9].

3. SEGMENTATION OF CEREBRAL BLOOD VESSELS

Segmentation is used to distinguish between an object of interest and the rest of the image [1]. Segmentation through thresholding is determined by a single value known as threshold. Threshold denotes an integer value between 0 – 255 i.e. the intensity scale. Any pixel value above the threshold is changed to 1 whereas any pixel value below the threshold is changed to 0.

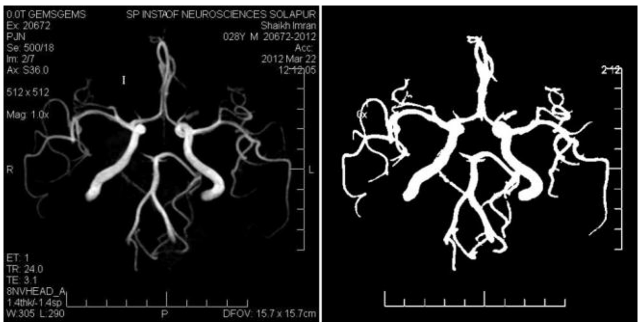

Figure 1. Comparison of original MRA (left) vs. segmented MRA (right)

The simulation for the proposed system reads the image as a 2 – D matrix; value stored at each node represents the black/white intensity of the pixel on an intensity scale of 0 – 255. The user interface of the proposed system allows to user to test various threshold until the most suitable is achieved. In most simulations the appropriate threshold was found to be between 20 and 30. Figure 1 compares a 2 – D MRA used for the simulation of the proposed system before and after thresholding. The proposed system interprets these MRAs as 2 – D matrixes with each node representing the intensity of the respective pixel, each node being an unsigned integer data type. At this state the segmented MRA is transformed into a binary image.

4. SKELETONIZATION

The process of extracting the skeleton of an image is known skeletonization. Skeletonization on the segmented MRA is done by thinning. Thinning is the layer by layer erosion of the image [3, 7]. Skeletonization of the image extracts the center lines of the cerebral blood vessels without changing the topology of the image. The outline of the structures of the brain blood vessels becomes clearer after skeletonization. The skeleton of the blood vessels can then be interpreted as a graph for path finding.

5. PATH FINDING

Once the skeleton of the blood vessels has been extracted from the segmented image, the skeletonized MRA is now interpreted by the system as a graph. Each white pixel in the image is considered as a node. It is assumed that nodes that are connected to each other have edges between them, whereas the ones that are not connected do not have edges between them. Interpreting the image as a graph allows the usage of any shortest path finding algorithm, making the proposed methodology adaptable. The simulation for the proposed system utilized Dijkstra’s algorithm as it’s an effective single-source shortest path finding algorithm for graphs [6]. The algorithm finds the shortest path from a single source point to all other points in the skeleton of the image. It stops only when the shortest path is found.

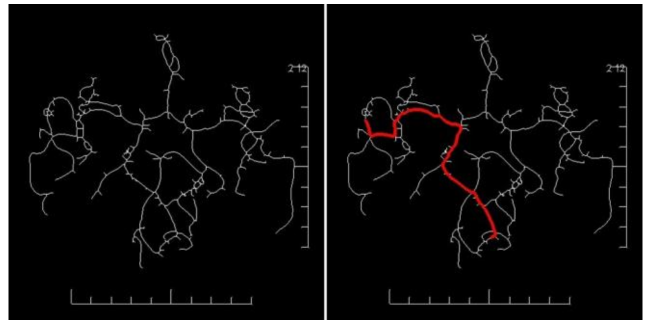

Figure 2. Skeletonized MRA before (left) and after (right) path finding

As demonstrated in Figure 2, the thin lines represent the skeleton of the MRA whereas the thick line represents the shortest path between two selected points in the skeletonized MRA. In case the chosen point lie outside the skeleton the proposed system would give the nearest possible solution.

6. EXPERIMENTAL RESULTS

The proposed methodology as illustrated through Figures 1 and 2, describes how image processing techniques such as segmentation and skeletonization can help surgeons identify optimal paths for cerebrovascular surgeries. The simulation of the proposed was tested using seven different MRA samples. The system performed flawlessly for each MRA.

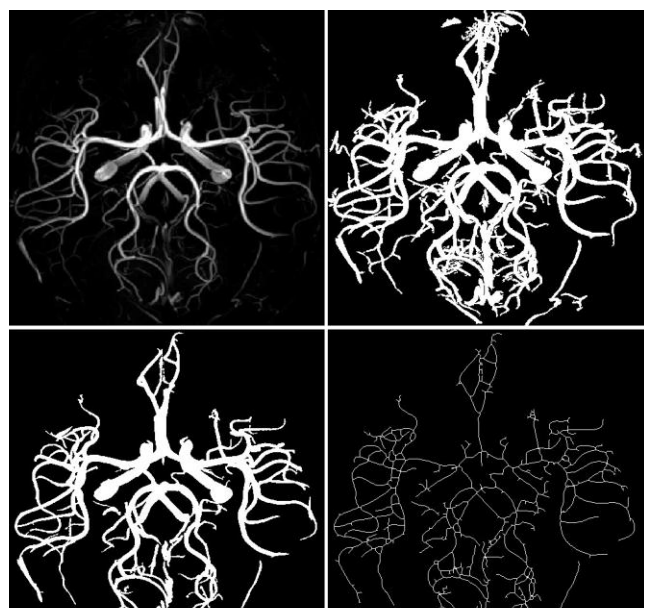

Figure 3. Various transitions during simulation: Original MRA (top-left), Segmented MRA at threshold = 10 (top-right), Segmented MRA at threshold = 20 (bottom-left), and Skeletonized MRA (bottom-right)

Figure 3 illustrates various transitions the MRA goes through during simulation: the Original MRA, the MRA segmented at a threshold of 10, the MRA segmented at a threshold of 20, and finally the skeletonized form of the MRA.

The interface of the proposed system allows the user to customize or change the threshold value whenever required as different MRAs might have different qualities; the threshold apt for one MRA might not provide appropriate results over a different MRA.

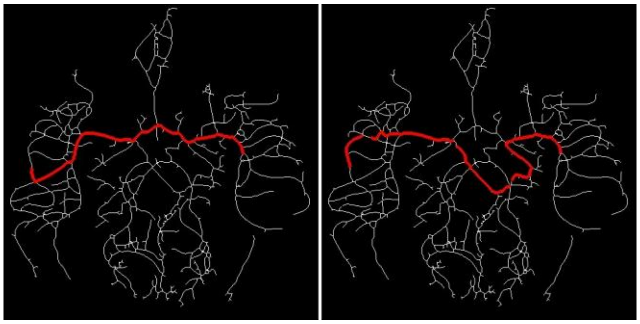

Figure 4. Shortest path between 2-points in a Skeletonized MRA without constraints (left) and with user defined constraints (right)

The interface of the suggested system also lets the user decide if a nerve shouldn't be used during path finding. The user can choose to break down a larger path by breaking it down into intermediate points. He/she can then find paths over smaller gaps or distances, decide which nerves to use and which ones to be ignores or skipped. Figure 4 illustrates two paths between the same pair of points. The path without constraints simply finds the shortest path between the chosen points, while the path with constraints is comprised of 4 smaller paths as chosen by the user.

In real-time scenario the proposed system can be used prior to surgery, a neurosurgeon can easily find the shortest path between point to reach the damaged place in the cerebral blood vessel system hence reducing risks by reducing interference in the form human choices. Using the proposed methodology neurosurgeons can freely draw out interesting regions and fast judgements.

7. CONCLUSIONS AND FUTURE WORKS

The intension of the proposed method is to find the shortest path between points within a cerebral blood vessel system using its MRA. The system effectively identifies shortest paths between selected points. The simulation for the proposed system was designed as a proof of concept. Features to create blockages or dead ends within the cerebrovascular system might be added in the later versions of the system. Since the skeletonized image is in binary format, hence obstacles can be created by changing the required co-ordinates from 0 to 1.

The system would help neurosurgeons operate over damaged parts of cerebrovascular system with minimum risk of human error in path finding. Hence, increasing the rate of success of such operations drastically.

The proposed method used single slide MRA images, enabling only a 2 – Dimensional view of the cerebrovascular system. The next stage of the research would be to use multiple slide MRA images to generate a 3 – Dimensional view of the brain blood vessel system, providing a more detailed and accurate view of the blood vessel system. The 3 – Dimensional MRA would be generated using slides of MRAs, each slide acting as a 2 – Dimensional matrix and the position of the slides with respect to first slide would be treated as the 3rd – Dimension. The rest of the process would remain the same. More path finding and searching algorithms need to be tested with the suggested system so as to verify whether it is a generalized solution or not.

8. REFERENCES

[1] Ahmed Faisal, Sharmin Parveen, Shahriar Badsha and Hasan Sarwar. 2012. An Improved Image Denoising and Segmentation Approach for Detecting Tumor From 2-D MRI Brain Images. In IEEE International Conference on Advanced Computer Science Applications and Technologies (Kuala Lumpur, Nov. 26 – 28, 2012). 451 - 457. DOI= 10.1109/ACSAT.2012.35

[2] Albert C. S. Chung. 2006. Image Segmentation Methods for Detecting Blood Vessels in Angiography. IEEE 9th International Conference on Control, Automation, Robotics and Vision, (Singapore, Dec. 5 - 8, 2006). 1 - 6. DOI= 10.1109/ICARCV.2006.345331

[3] Erhan Bas, Nastaran Ghadarghadar and Deniz Erdogmus. 2011. Automated Extraction of Blood Vessel Networks from 3D Microscopy Image Stacks Via Multi-Scale Principal Curve Tracing. In Biomedical Imaging: From Nano to Macro, 2011 IEEE International Symposium (Chicago, IL, March 30, 2011 - April 2, 2011). 1358 – 1361. DOI= 10.1109/ISBI.2011.5872652

[4] Qi Aipeng. 2010. An Improved Skeletonization Algorithm of Color Cerebral Vascular Image based On Color Level Set Mode. IEEE International Conference on Networking and Digital Society (Wenzhou, May 30 – 31, 2010). 500 – 503. DOI= 10.1109/ICNDS.2010.5479458

[5] Sathish Kumar, S., Amutha, R. 2012. Edge Detection of Angiogram Images Using the Classical Image Processing Techniques. In IEEE International Conference on Advances in Engineering, Science and Management. (Nagapattinam, Tamil Nadu, March 30 – 31, 2012). 55 - 60. ISBN: 978-81-909042-2-3.

[6] Verscheure, L., Peyrodie, L., Le Thuc, V., Dewalle, A.S., Maouche, S. and Vermandel, M. 2010. Dijkstra's Algorithm Applied To 3D Skeletonization of the Cerebral Vascular Tree: Evaluation and Application to Symbolic Description. In Engineering in Medicine and Biology Society (EMBC), Annual International Conference of the IEEE (Buenos Aires, Aug. 31, 2010 - Sept. 4, 2010). 3081 - 3084. DOI= 10.1109/IEMBS.2010.5626112

[7] Yufei Chen, Klaus Drechsler, Weidong Zhao and Cristina Oyarzun Laura. 2011. A Thinning-based Liver Vessel Skeletonization Method. In International Conference on Internet Computing and Information Services (Hong Kong, Sept. 17 – 18, 2011). 152 - 155. DOI= 10.1109/ICICIS.2011.

[8] DICOM MRA/MRI Image source: http://www.osirix-viewer.com/datasets

[9] JPEG MRA Image source: http://www.neuroradiologycases.com