A Survey on Automatic Femoral Artery Segmentation

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Abstract: The goal is to create an assistant for ultrasound guided femoral nerve block. By segmenting and visualizing the important structures such as the femoral artery, we hope to improve the success of these procedures. This article is the first step towards this goal and presents novel real-time methods for identifying and reconstructing the femoral artery, and registering a model of the surrounding anatomy to the ultrasound images. The femoral artery is modelled as an ellipse. The artery is first detected by a novel algorithm which initializes the artery tracking. This algorithm is completely automatic and requires no user interaction. Artery tracking is achieved with a Kalman filter. The 3D artery is reconstructed in real-time with a novel algorithm and a tracked ultrasound probe. A mesh model of the surrounding anatomy was created from a CT dataset. Registration of this model is achieved by landmark registration using the centre points from the artery tracking and the femoral artery center line of the model. The artery detection method was able to automatically detect the femoral artery and initialize the tracking in all 48 ultrasound sequences.

***Index Terms* - Artery segmentation, artery tracking, real-time, regional anaesthesia, ultrasound..**

I. INTRODUCTION

The use of regional anaesthesia (RA) is increasing due to the benefits over general anaesthesia (GA) such as reduced morbidity and mortality, reduced post operative pain, earlier mobility, shorter hospital stay, and lower costs. Despite these clinical benefits, RA remains less popular than GA. One reason for this is that GA is far more successful and reliable than RA. Ultrasound has been employed to increase the success rate of RA. However, ultrasound-guided RA can be a challenging technique, especially for inexperienced physicians and in difficult cases. Good theoretical, practical and non-cognitive skills are needed in order to achieve confidence in performing RA and to keep complications to a minimum. Studies indicate that RA education focusing on illustrations and text alone is not sufficient. The RASimAs1 project (Regional Anaesthesia Simulator and Assistant) is a European research project which aims at providing a virtual reality simulator to improve the training of doctors performing RA, as well as an assistant to lessen the cognitive burden and help performing RA procedures.

This article focuses on creating an assistant for ultrasound- guided RA to block the femoral nerve. In this application, the femoral artery is an important structure used to locate the femoral nerve. A study by Gruber *et al.* showed that in 77.5% of the cases the femoral nerve was located within 5 mm of the femoral artery. The rest were located more than 5 mm lateral of the artery. This article presents novel methods for identifying and reconstructing the femoral artery from ultrasound images, and registering a model of the surrounding anatomy to the images. The idea is that the registered model together with the segmented artery will help locate the femoral nerve. The hypothesis that this assistant helps identifying the femoral nerve is not validated in this article. However, the assistant will be clinically tested and evaluated in future work at three different clinical sites as part of the ongoing RASimAs project. The accuracy of the femoral artery segmentation and model registration is evaluated in this article.

Several methods for segmentation of the cross-section of vessels in 2D ultrasound have been reported, using methods such as level sets, fuzzy -means clustering and evolutionary algorithms. These methods focus on segmenting a single image. However, in this work the goal is to segment the femoral artery in real-time on a sequence of ultrasound images. Abolmaesumi *et al.* and Guerrero *et al.* presented methods for vessel segmentation and tracking in ultrasound images using an extended Kalman filter. Their methods were fast and accurate, but had to be manually initialized with a seed point inside the vessel.

The contributions of this article are:

- A real-time automatic artery detection method. This method eliminates the need for manual initialization.
- A real-time vessel tracking method of the femoral artery.
- A real-time vessel 3D reconstruction method and this proposed method can also reconstruct bifurcations.
- A real-time vessel registration method which registers a model of the femoral region anatomy to the ultrasound images. The method is automatic and provides anatomical reference to the operator.

II. LITERATURE SURVEY

Abdel-Dayem[1] proposed an algorithm for the segmentation of the lumen and bifurcation boundaries of the carotid artery in B-mode ultrasound images. It uses the hipoechogenic characteristics of the lumen for the identification of the carotid boundaries and the echogenic characteristics for the identification of the bifurcation boundaries. The image to be segmented is processed with the application of an anisotropic diffusion filter for speckle removal and morphologic operators are employed in the detection of the artery. The obtained information is then used in the definition of two initial contours, one corresponding to the lumen and the other to the bifurcation boundaries, for the posterior application of the Chan-vese level set segmentation model. A set of longitudinal B-mode images of the common carotid artery (CCA) was acquired with a GE Healthcare Vivid-e ultrasound system (GE Healthcare, United Kingdom). All the acquired images include a part of the CCA and of the bifurcation that separates the CCA into the internal and external carotid arteries. In order to achieve the uppermost robustness in the imaging acquisition process, i.e., images with high contrast and low speckle noise, the scanner was adjusted differently for each acquisition and according to the medical exam.

In this paper, A. R. Abdel-Dayem and M. R. El-sakka[2] have proposed a new scheme for extracting the contour of the carotid artery using ultrasound images. Starting from a user defined seed point within the artery, the scheme uses the fuzzy region growing algorithm to create a fuzzy connectedness map for the image. Then, the fuzzy connectedness map is thresholded using a threshold selection mechanism to segment the area inside the artery. Experimental results demonstrated the efficiency of the proposed scheme in segmenting carotid artery ultrasound images, and it is insensitive to the seed point location, as long as it is located inside the artery.

The authors, P. Abolmaesumi, M. Sirouspour, and S. Salcudean[3] presented the development of a novel, fully-automatic tracking and segmentation system to extract the boundary of the carotid artery from ultrasound images in real-time. The center of the carotid artery is tracked using the Star algorithm. The stability of the Star algorithm has been improved by using a temporal Kalman filter. A spatial Kalman filter is used to estimate the carotid artery boundary. Since the method does not employ any numerical optimization, convergence is very fast. The stability and accuracy of the method is demonstrated by tracking the carotid artery over a 30 second sequence of ultrasound images taken during a carotid artery examination. An application of the tracking method to ultrasound image servoing is also presented.

The authors, P Abolmaesumi and M. R. Sirouspour[4] presented a novel segmentation technique for extracting cavity contours from ultrasound images. The problem is first discretized by projecting equispaced radii from an arbitrary seed point inside the cavity toward its boundary. The distance of the cavity boundary from the seed point is modeled by the trajectory of a moving object. The motion of this moving object is assumed to be governed by a finite set of dynamical models subject to uncertainty. Candidate edge points obtained along each radius include the measurement of the object position and some false returns. The modeling approach enables us to use the interacting multiple model estimator along with a probabilistic data association filter, for contour extraction. The convergence rate of the method is very fast because it does not employ any numerical optimization. The robustness and accuracy of the method are demonstrated by segmenting contours from a series of ultrasound images. The results are validated through comparison with manual segmentations performed by an expert. An application of the method in segmenting bone contours from computed tomography images is also presented.

The authors, W. S. Beattie, N. H. Badner, and P. Choi[5] discussed in their paper that postoperative cardiac morbidity and mortality continue to pose considerable risks to surgical patients. Postoperative epidural analgesia is considered to have beneficial effects on cardiac outcomes. The use in high-risk cardiac patients remains controversial. No study has shown that postoperative epidural analgesia decreases postoperative myocardial infarction (PMI) or death. All studies are underpowered to show such a result, and the cost of conducting a large trial is prohibitive. We performed a metaanalysis to determine whether postoperative epidural analgesia continued for more than 24 h after surgery reduces PMI or in-hospital death. The available databases were searched for randomized controlled trials of epidural analgesia that was extended at least 24 h into the postoperative period. The search yielded 17 studies, of which 11 were randomized controlled trials comprising 1173 patients. Meta analysis was conducted by using the fixed-effects model, calculating both an odds ratio and a rate difference. Postoperative epidural analgesia resulted in better analgesia for the first 24 h after surgery.

The authors, M. Bozorgi and F. Lindseth[6] have showed that multi-volume visualization is important for displaying relevant information in multimodal or multitemporal medical imaging studies. The main objective with the current study was to develop an efficient GPU-based multi-volume ray caster (MVRC) and validate the proposed visualization system in the context of image-guided surgical navigation. Ray casting can produce high-quality 2D images from 3D volume data but the method is computationally demanding, especially when multiple volumes are involved, so a parallel GPU version has been implemented. In this method MVRC, imaginary rays are sent through the volumes, and at equal and short intervals along the rays, samples are collected from each volume. Samples from all the volumes are composited using front to back α-blending. Since all the rays can be processed simultaneously, the MVRC was implemented in parallel on the GPU to achieve acceptable interactive frame rates.

III. METHODOLOGY

This section first describes the artery model used to detect and track the femoral artery. Next, the artery detection, tracking and 3D reconstruction methods are presented. Finally, the registration method is described.

The modules used in this paper are:

- Artery model.
- Artery detection.
- Artery tracking.
- 3D Artery reconstruction.

3.1 Artery model

The artery cross-section in the ultrasound images is modelled as an ellipse with major and minor radii a and b. The cross-section of arteries will not necessarily have the exact shape of an ellipse. However, in the application of RA exact delineation of the artery border is not required.

3.2 Artery detection

In this section, a novel fully automatic artery detection method is presented which is used to initialize the artery tracking algorithm described in the next section. First, the image is blurred using convolution with a Gaussian mask and then the image gradients are calculated. For a given radii a and b , the artery score is calculated as the average dot product of the outward normal and the corresponding image gradient on the ellipse. Before the dot product is calculated, the image gradient is normalized so that it has unit length. This normalization makes this artery detection method invariant to the contrast of the image, and only the direction of the gradients influences the score.

The ellipse with the highest score is selected for each pixel. The best score and the values and is stored for each pixel. The ellipse with the highest score of all pixels is selected and used to initialize the tracking.

3.3 Artery tracking

Artery tracking in the ultrasound images is achieved with a Kalman filter. The Kalman filter estimates a state using a set of noisy measurements over time. The proposed Kalman filter estimates both the position and shape of the artery cross-section which changes over time as new image frames are received. The state is predicted for the next image frame using a motion model along with the covariance error matrix.

3.4 3D Artery reconstructions

The ultrasound probe is tracked using the electromagnetic tracking system SonixGPS. This enables 3D reconstruction of the artery tracked in the 2D ultrasound images. Each centre coordinate from the artery tracking is converted into a 3D coordinate using the transformation provided by the electromagnetic tracking system. 3D reconstruction is done by adding a sphere to a volume at the 3D coordinate. Finally, a real-time marching cubes algorithm is used to generate a surface mesh of the volume and visualize it. These steps are all performed for each new tracked centerpoint.

IV. CONCLUSION

In this survey, the performance of many algorithms such as level sets, fuzzy c-means clustering, star algorithm and evolutionary algorithms to segment and visualize interested objects in ultra-sound images have been assessed and it is found that these methods focus on segmenting a single image. However, the methodology presented in this survey can be used segment femoral artery in real time on a sequence of ultra-sound images. This methodology can be able to automatically and accurately track the femoral artery in ultrasound images and use this to reconstruct the artery in 3D and register it to a model of the surrounding anatomy in real-time.

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