2011

NERVE REGION SEGMENTATION FOR ULTRASOUND GUIDED LOCAL REGIONAL ANAESTHESIA (LRA)

Emmanuelle Thouin
Université d'Orléans - Laboratoire PRISME, France, emmanuelle.thouin@bourges.univ-orleans.fr

Nikolaos Xylourgos
Georgios Triantafyllidis and Georgios Papadourakis, nxylourgos@yahoo.gr

Alain Delbos
Medipôle Clinique du Sport- Toulouse

NERVE REGION SEGMENTATION FOR ULTRASOUND GUIDED LOCAL REGIONAL ANAESTHESIA (LRA)

Emmanuelle Thouin, Adel Hafiane and Pierre Vieyres, Université d'Orléans - Laboratoire PRISME, France, emmanuelle.thouin@bourges.univ-orleans.fr & adel.hafiane@ensi-bourges.fr & pierre.vieyres@bourges.univ-orleans.fr

Nikolaos Xylourgos, Georgios Triantafyllidis and Georgios Papadourakis, Applied Informatics and Multimedia Dept, TEI of Crete, Greece, nxylourgos@yahoo.gr & gt@epp.teicrete.gr

Alain Delbos and Eve Charest, Medipôle Clinique du Sport- Toulouse, France

Abstract

There is a great need for providing the anaesthesiology specialists with comprehensive tools to succeed safer routine local regional anaesthesia (LRA) practice into the operating room. To this goal, during the last decade, high resolution ultrasound images have been used to detect the nerve regions of a so-called "block" and provide the medical anaesthesiologist with the appropriate needle localisation. The goal is to provide the best path for the needle insertion, with respect to each patient's anatomy, to safely reach the relevant nerve region and distribute the anesthetic. In this context, this paper presents an approach for an automatic detection of the nerves, based on the analysis of high frequency ultrasound images; this will help the specialist to fully identify the required "block" for the local anaesthesia. The problem however is quite difficult: The appearance of nerves may vary depending on the nerve's size, the depth from the skin surface, the body region, and the probe frequency. Also, the general nerves structure, organised as a honeycomb structure, is very complex in term of ultrasound image analysis, as it is constituted of combined hypo- and hyper- echoic areas. A single segmentation approach is therefore not sufficient to address such kind of images; in this paper two segmentation schemes are proposed to identify and localise the the nerves. Results showing the detected nerve regions in ultrasound image prove the effectiveness of the proposed method.

Keywords: *ultrasound LRA nerve detection, ultrasound image segmentation, active contours, region growing*

1 INTRODUCTION

General anaesthesia is a medical act that eliminates the feeling of pain as well as the motor reflexes of a person in order to perform surgical operations. It is accompanied by a loss of consciousness and major functions (e.g. breathing), which often requires the patient to be intubated. Contrary to general anaesthesia, loco-regional anaesthesia (LRA) allows to anaesthetize specific parts of the body to perform minor or intermediate surgical acts. The patient remains conscious and does not lose respiratory functions. It is, therefore, an efficient and less intrusive technique, which offers patients a prompt post-surgical recovery and reduces hospital length of stay.

However, LRA is a complex patient-dependant technique, which requires a long learning process and years of practice in real operating room. Under the current protocol, the anaesthesiologist uses general anatomical references to decide the best possible puncture point from which he/she will insert the electric stimulated needle to search for the relevant nerve. This high skill protocol is not without risk and may generate nerve or lung puncture (paresthesia, pneumothorax), or anaesthetic injection in arteries.

We aim at providing the anaesthesiology specialists with a comprehensive tool to improve and provide safer routine LRA practice into the operating room [1] [2]. This assisting control will offer a real-time interactive tool to provide the best path for the needle, with respect to each patient's anatomy, to safely reach near the relevant nerve region and distribute the aesthetic [3] [4].

With the development of new high frequency ultrasound imaging, anaesthetists can now use echography to visualize and identify nerves from other anatomical parts (e.g.: arteries, muscles). However, the nerve detection ultrasound approach is not widely used yet in the LRA as it is an expert dependant technique; The lack of ultrasound experts makes it difficult to provide dual expertise, ultrasound analysis and anaesthesia, in routine in the pre-operating room.

In this context, this paper presents a preliminary framework for an automatic detection of the nerves based on the analysis of high frequency ultrasound images to assist the anaesthesiologist in its medical act; this will help the specialist to fully identify the required so-called "block" for the local anaesthesia. The nerves shown in ultrasound images and to be detected for LRA, can be described as hypoechoic (black) regions with hyperechoic (bright) perimeter constituting a Honeycomb pattern (many small circles with a hypoechoic centre and hyperechoic perimeter – see Fig 1a). Please notice that depending on the body part, this hoeycomb pattern may contain few (or even just one) hypoechoic circles (see Fig 1b).

a b

Figure 1. a) sciatic nerves regions (honeycomb pattern), b) interscalenic nerves area

For each of these patterns we employ efficient segmentation techniques in order to detect the required nerve region needed for the LRA practice.

2 DETECTION OF NERVES

First, the nerves organized as honeycomb structure will be detected by using snakes. The principle of the snakes or active contours [5] is to use curves that move in the image space and whose deformations are governed by external and internal energies delimited by the curve.

Let be x(s) be the curve equation

$$x(s) = [x(s), y(s)], s \in [0,1] \tag{1}$$

$$E = \int_0^1 \frac{1}{2}(\alpha |x'(s)|^2 + \beta |x''(s)|^2) + E_{ext}(x(s))ds \tag{2}$$

where a is a elasticity factor and b a rigidity contour factor.

The external energy depends on the image characteristics and drives the contour to the desired position in the image; among the most used one is the image gradient:

$$E_{ext}(x, y) = -|\nabla(G_\sigma(x, y) * I(x, y))| \tag{3}$$

G_s is a Gaussian filter, *I* the image grey level at the coordinate (x, y) and * is the convolution operator. The Gaussian filter enables the reduction of the speckle noise in the ultrasound image. To reach the best contour, we need to minimize the total snake energy which turns into solving the following Euler Lagrange equation:

$$\alpha x''(s) - \beta x'''(s) - \nabla E_{ext} = 0 \tag{4}$$

which can be described as the following force equation:

$$F_{\text{int}} + F_{ext}^{(p)} = 0 \tag{5}$$

where

$F_{\text{int}} = \alpha x''(s) - \beta x'''(s)$ and $F_{ext}^{(p)} = -\nabla E_{ext}$.

The internal force F_{int} tends to limit stretching and bending and the external force F_{ext} pushes the snake towards the edges of the object of interest. The outline must evolve to an equilibrium position that results in zero change of the total energy. The main drawback of the traditional snake is the poor convergence in concave boundaries. This can hinder the nerve region detection. Hence the Gradient Vector Flow (GVF) method can address this issue.

Xu et al [6][7][8] has presented GVF which has a process to solve the convergence of the snake approach when encountering concave situations. GVF is a vector field

$$V(x;y) = (u(x;y); v(x;y)) \quad (6)$$

which allows the minimization of the following energy function:

$$\varepsilon = \iint \mu(u_x^2 + u_y^2 + v_x^2 + v_y^2) + |\nabla f|^2 |V - \nabla f|^2 dxdy \quad (7)$$

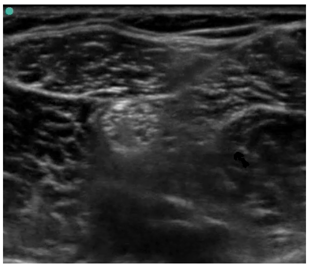
where $f(x, y)$ is the image *edge map* corresponding to:

$$f(x, y) = |\nabla I(x, y)|^2$$

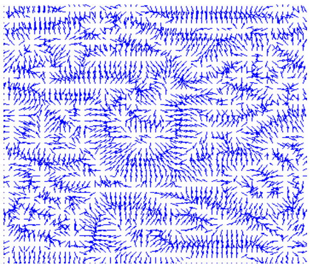
$$f(x, y) = |\nabla (G_\sigma(x, y) * I(x, y))|^2$$

In homogeneous regions where $I(x, y)$ is constant, f and ∇f converge to zero, and no information is available on close or distant contours.

Figure 2 presents an example of the GVF external forces on the sciatic nerve image.



a



b

Figure 2. a) input image sciatic nerve of the popliteal region, b) corresponding GVF external forces

The energy function allows for a smooth result in the absence of constraints. When $|\nabla f|$ is low, energy is dominated by the first term yielding slowly varying field. On the contrary when $|\nabla f|$ is large, the second term of the energy equation dominates the integral. This forces the field to be slowly varying in homogeneous region and making vector *V* close to the edge map when it is large. The parameter m is a control parameter that should allow a trade off between the two terms of the integral. This parameter must be set proportionally to the noise in the image.

Detecction of nerves shown as simple hypoechoic circles

The flowchart of the proposed technique is shown at Figure 3. At the beginning, a segmentation of seeded region growing is applied. Afterwards, a threshold method is employed in order to process accordingly the output of segmentation and then the centroids of the resulted regions are detected. Finally, after all regions are located and the objects are recognized, the respective detected black region is the required nerve region.

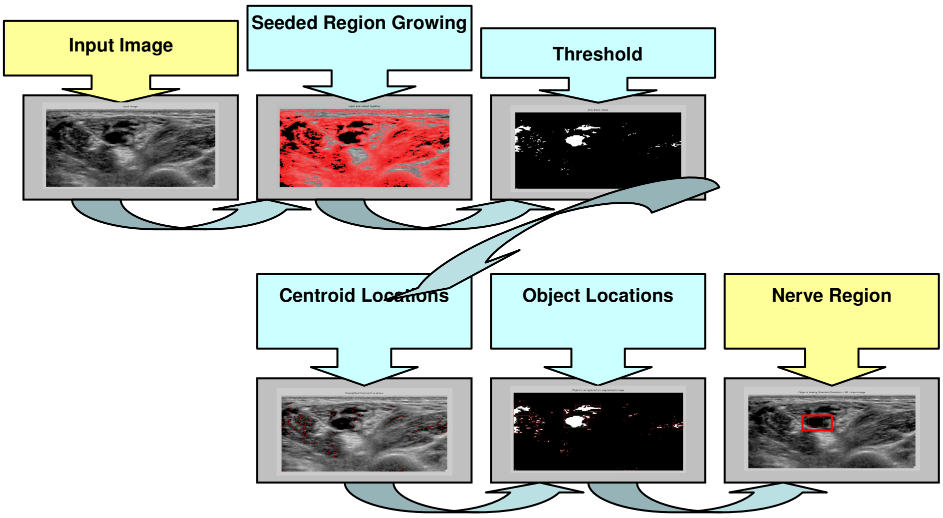


Figure 3. Proposed scheme for detecting nerves shown as hypoechoic cirlces

Experimental results

Our method has been implemented using Matlab and tested with an ultrasound image of the sciatic nerve of the popliteal region (see Figue 4) which presents a honeycomb structure. The snake was originally set as a circle.

The GVF method is suitable to detect nerves regions as the sciatic nerves, but in some parts of the body the nerves regions may present different ultrasound structures (few or even just one hypoechoic circles), as depicted in Figure 1 a and b. Therefore the detection of the nerve region may require a different analysis strategy. The region growing algorithm can be used in this case as a simple and efficient method for images such as Figure 1b.

Experimental results also show that the nerves shown in ultrasound images as black regions (hypoechoic circles) can be easily identified using the scheme of Fig.3. The red rectangles in the ultrasound images of Figure 5 shows the detected nerve regions

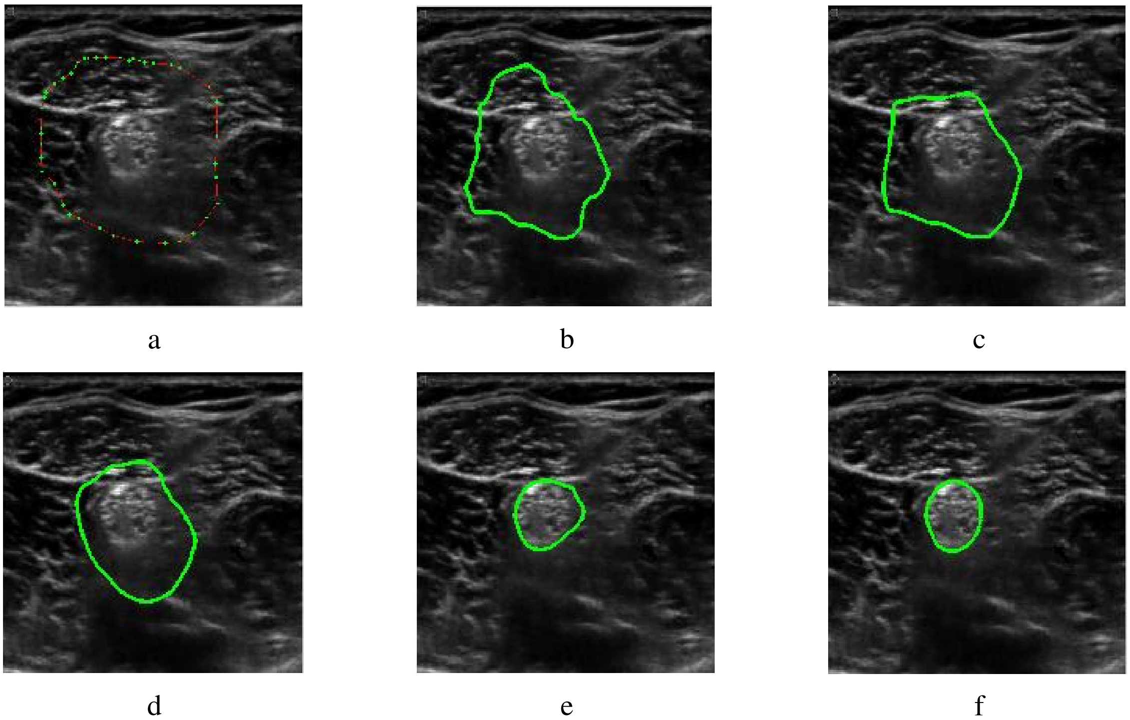


Figure 4. Ultrasound image of the sciatic nerve of the popliteal region segmented by the GVF method using s= 7 ; a=35, b= *0 .8 , m=0.2 .(a)- original contour. (b,c,d,e)- contour evolution. (f)- final segmentation.*

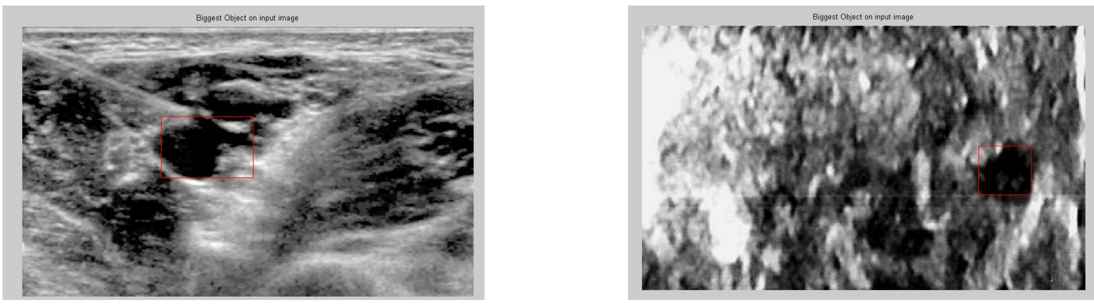


Figure 5. Results of the proposed detection scheme for nerves shown as hypoechoic cirlces

3 CONCLUSIONS AND FUTURE WORK

The goal of this paper is to employ efficient image segmentation algorithms which identify nerves (according to the respective patterns) in ultrasound scans. This task of locating the nerves regions in ultrasound is a very difficult problem since the appearance of nerves may vary depending on the nerve's size, the depth from the skin surface, the body region, and the probe frequency. Also, the general nerves structure, organised as a honeycomb structure, is very complex in term of ultrasound image analysis. Althought these difficulties, the proposed approaches have shown a good detection of the nerves regions in agreement with the expert's ground truth.

The real time processing however is still to be improved especially for the GVF method using for instance the parallel programming with GPU. This will be a strong requirement for in vivo future applications. One of the future works is to combine the two proposed methods as a hybrid approach to handle any nerve regions segmentation. These preliminary results demonstrate the relevance of the two segmentation methods; they have to be further explored in various nerves areas and tested in a significant number of patients, before being validated for automatic needle insertion during LRA.

References

[1] F. Pierrot, E. Dombre, E. Degoulange, L. Urbain, P. Caron, S. Boudet, J. Gariepy and J. Megnien. "Hippocrate: A safe robot arm for medical application with force feedback". Medical Image Analysis (MedIA). Special Issue on Medical Robotics and Computer Assisted Surgery, 3(3), pp. 285-300, 1999.

[2] Arbeille P, Capri A, Ayoub J, Kieffer V, Poisson G. "Use of a robotic arm to tele operated abdominal ultrasound". Am J Roentgenology; AJR; 188: 317-322. 2007.

[3] P. Abolmaesumi, S. Salcudea, W. Zhu, M. Sirouspour, and S. DiMaio. "Image-guided control of a robot for medical ultrasound". In IEEE Trans. Robotics and Automation, vol. 18, pp. 11-23, 2002.

[4] L. Hong, T. Dohi, M. Hashizume, K. Konishi, and N. Hata. "An ultrasound-driven needle insertion robot for percutaneous cholecystostomy". In Physics in Medicine and Biology, vol. 49, no. 3, pp. 441-455, 2004.

[5] M. Kass, A. Witkin, D. Terzopoulos. Snakes: Active contour models. International Journal of Computer Vision, pp. 321-331, 1988.

[6] C.Xu, J.L. Prince, Gradient vector flow: a new external force for snakes, Proc. IEEE Conf. On Comp. Vis. Patt. Recog., 1997, pp. 66-71 .

[7] C. Xu, J.L. Prince, Snakes, shapes, and gradient vector flow, IEEE Transactions on Image Processing 7 (3) (1998) 359-369.

[8] C. Xu, J.L. Prince, Gradient vector flow deformable models, In I. Bankman (Ed.), Handbook of Medical imaging, Academic Press, pp. 159-169.