DIRECT MODEL BASED NEEDLE TRAJECTORY GENERATION FOR ULTRASOUND GUIDED REGIONAL ANAESTHESIA

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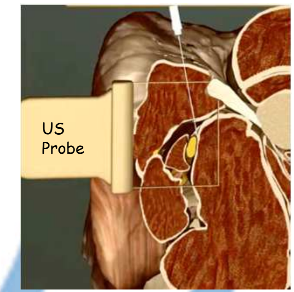
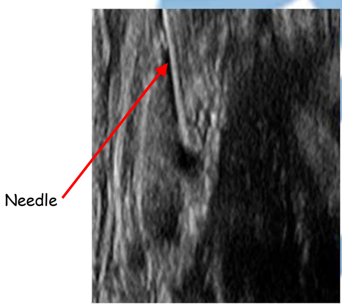
1 Ultrasound-guided regional anaesthesia (UGRA)

Ultrasound-guided regional anesthesia (UGRA) has rapidly become popular for performing RA blocks. Compared to standard general anesthesia, the increasing interest in regional anesthesia (techniques and drugs) is considered as crucial for early postoperative recovery. Moreover, the ratio time efficiency of anesthesia /quantity of drugs injected is really interesting with this method.





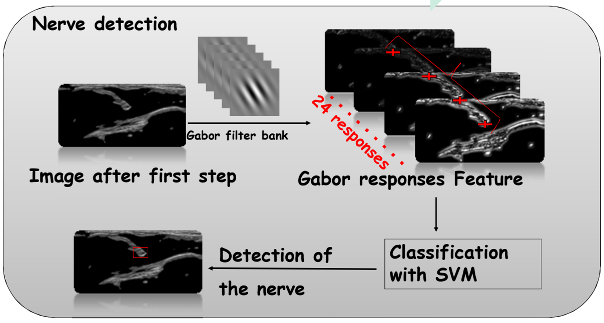
2 DANIEAL Project

Many anaesthetists lack experience with UGRA as it requires complex hands coordination: during the needle insertion, done with one hand, the anaesthetist has to position, with the other hand, the ultrasound probe in order to maintain the nerve position in the US image, to visualize the needle tip and to ensure the perineural spread pattern.

Two recent studies on robot-assistance in RA have shown that this technology leads to a decrease in inter-individual performance variability and improves significantly the learning curve of junior trainees. The aim of DANIEAL is to provide anesthetists with a novel minimally invasive collaborative human/robot platform to significantly improve routine practice as well as the training process of UGRA. In the first stage of the project, the objectives are to automatically detect targets (nerves) in the US image. These targets are to be reached by the end of the tip of the needle to deliver the anesthetic drug. We have developed a direct model based trajectory generator for the needle to be guided to these targets.

3 Automatic nerve detection in the ultrasound image

The objective is to detect the nerve automatically using image processing and machine learning algorithms. We have developed a two-step method to detect the nerve region. The first step consists in a segmentation of the hyperechoic foreground tissues to distinguish the hyperechoic tissues from non useful information. The second phase extracts the nerve area in the foreground using support vector machine (SVM) and Gabor descriptor.



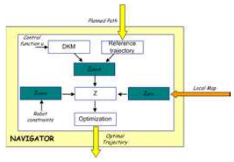
Experiments were conducted over 173 ultrasound images of the median nerve and provided identified areas for the anesthetist to define target points around it.

4 Needle tip trajectory generation

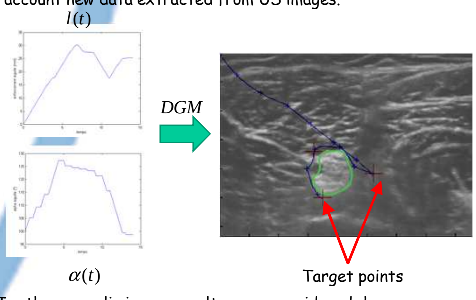
Our approach was to work on a direct model based trajectory generator in order to be adaptable to any robotic needle holding system and to be able to integrate easily various constraints and tissues deformation models.

The objective was to generate online trajectories:

- to reach target points defined by the anesthetist where to deliver the anesthesia drug,
- which are safe that is to avoid collision with nerves and other obstacles,
- to comply with the constraints of the needle holding system.

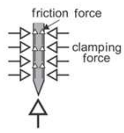


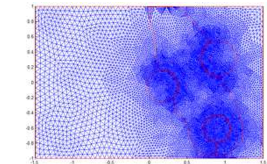
Injecting control functions in the direct (geometric, kinematics or dynamics) needle system model generate trajectories. A criterion is computed to evaluate each trajectory and a trajectory optimization is processed every sampling time, taking account new data extracted from US images.

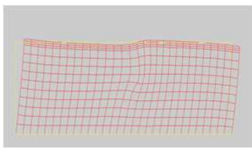


In these preliminary results, we considered homogeneous tissues without taking into account their deformations. However, it is necessary to model these tissues deformations while inserting the stiff needle by taking into account elasticity and viscosity in order to:

- generate realistic needle trajectories in its dynamic environment,
- reach delivery points (targets) behind obstacles.







We are currently working on the choice of the most adapted visco-elastic model among all the existing ones (Kelvin Voigt, Maxwell, Kelvin Boltzmann etc…) and on finite elements discretization to provide accuracy while respecting real time constraints.

5 Perspectives

As the nerves present in various body areas exhibits heterogeneous textural properties, we have focused on the texture analysis to detect a nerve within an US image and worked more specifically on the median nerve. Gabor filter bank have been used to compute the texture descriptors. The experimental evaluation on real data, showed that this method enables a better detection of the nerve region compared to the tested state-of-the-art techniques. In the future work, we will explore the possibilities to extend the detection to other types of nerves.

These first results of automatic nerve detection have been used as an entry point to evaluate real time trajectory generation methods. Preliminary results for needle navigation validate the direct model needle trajectory generation for obstacle avoidance in soft tissues environments. This approach generates safe trajectories that fulfil the constraints on the needle kinematics and deliver the anaesthetic agent on identified target points chosen by the medical expert in the US image and around the nerve itself. This method is adaptable to the environment dynamics by managing the prediction horizon and sampling times.

The work in progress consists in taking into account the environment deformation according to the needle trajectory during the computation of the trajectory itself to improve the position accuracy to reach target points.

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