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Using a 3D Needle –Tissue Interaction Loading basis to optimize the design of an instrumented needle

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1. Introduction

Many medical interventions are based on the insertion of needles to perform a diagnostic or therapeutic act. Such percutaneous insertions into soft tissues are one of the most common minimally invasive procedures. CT-guidance (Computerized Tomography) is a well-established technique for percutaneous procedures in order to obtain the needle and target positions. It enables to view any part of the body in three-dimensions and with typically higher definition than other imagery modalities.

During a CT-guided percutaneous procedure, the patient is moving in and out of the scanner in order to verify the good trajectory of the needle. It has to be noticed that the trajectory of the needle may be complex and not straight since the needle is brought to deform because of its interactions with inhomogeneous tissues and organs. That can involve a certain number of tests necessary to the installation of the needle which does not follow the planned trajectory. Furthermore, the amount of irradiation during procedures under CT-scan (patient and medical staff) can be high.

Methods in passive (imaging) [Dimairo, 2006] and active (instrumentation of the device) [Park, 2010] tracking of medical devices have been developed to improve the realization of the gesture.

Works in progress [Yang, 2010] raise the problems of incorporating strain microgauges on the needle. These microgauges provide information regarding the local deformations of the needle. In this paper, we describe a method enabling to optimally position the strain microgauges of an instrumented needle using a 3D loading basis, in order to explain the interaction forces applied on the needle during an intervention.

2. Methods

A needle model was developed [Robert, 2013a] to reconstruct the needle shape of a deformed needle from strain microgauges.

To find the optimal location of the microgauges, an optimization function was determined:

$$(y_{tip} - S_{tip})^2 \quad (1)$$

Where y is the needle reconstruction using Beam theory (referential) and S is the needle reconstruction using strain microgauges. y_{tip} and S_{tip} represent the values of these two reconstructions at the needle tip. The placement errors in the needle tip location are typically of the most concern. Nevertheless, to use the Beam theory, the interaction forces between needle and tissue during a percutaneous procedure are to be known.

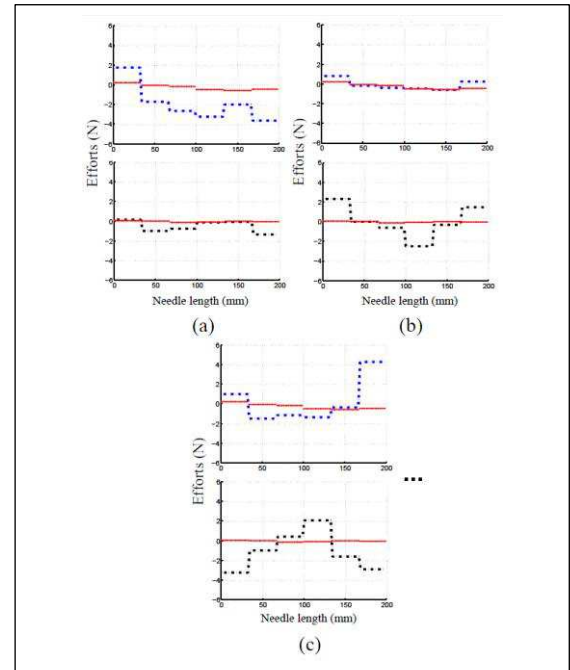


Figure 1 The first three loading modes. The efforts corresponding to these modes are represented.

To study the needle-tissue interactions, a generic 3D loading basis was determined [Robert, 2013b]. This loading basis was built from experiments on a fresh pig shoulder and validated on needles inserted during real clinical procedures. A 22-gauge needle with a length of 200mm and the Young's modulus estimated at 200GPa was used. All needle deflections were modeled by using B-splines. Then, by associating the B-spline and beam theories, the bending moment and shear forces along each needle were computed.

Finally, a statistical approach (Principal Component Analysis (PCA)) [Cootes, 2000] was employed to extract the relevant information from the set of deflections and to build the loading basis as shown in figure 1.

An algorithm is used to determine the optimal position of the microgauges. It attempts to find a constrained minimum of a scalar function (equation 1) of several variables starting at an initial estimate. Due to the manufacturing process, the number of microgauges is settled at two. The variables are then the two positions G1 and G2 of the microgauge 1 and 2, respectively.

3. Results and Discussion

The results of the optimal position are shown in figure 2. The values of the optimization function are shown in gray depending of the two positions G1 and G2 of the strain microgauges. The position G1 is considered under the position G2. The results give a position G1 and G2 at 37mm and 133mm for a needle with a length of 200mm.

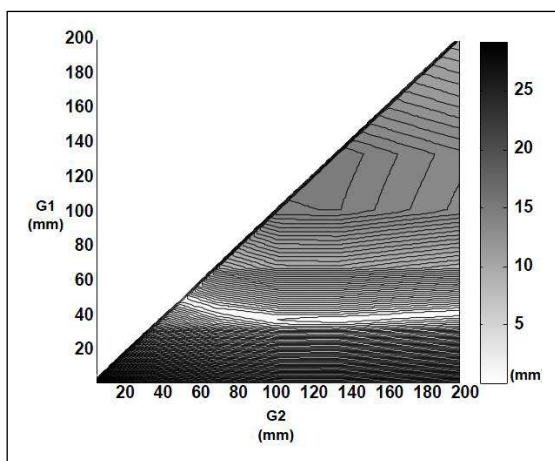


Figure 2 Reconstruction errors with all possible strain microgauges locations. The brighter region gives the lower errors.

The use of a 3D loading basis that acts on the needle during a medical procedure allows to determine an optimal position for the strain microgauges placed on the needle in order to track it.

This loading basis is generic enough to take into account most of the loading applied on needles

during real clinical interventions. Thereby, the placement of strain microgauges takes accounts most of the possible deflection of the needles.

4. Conclusions

After the construction and the validation of the loading basis, this basis was used to determine an optimal position for the strain microgauges placed on a needle.

The knowledge of the interaction forces between needle and tissues may be useful to enrich techniques enabling to track in real time the motion of the needle with the aim of achieving a safer, less invasive and more efficient medical procedure.

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