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Toward a New Approach of Tracking of Medical Deformable Needles

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Abstract

Needles used in medical percutaneous procedures are brought to deform because of its interactions with inhomogeneous and anisotropic tissues. In this paper, the premises of the development of a new generation of tools for assistance in the realization of gestures taking into account these deformations are presented. We provide a new approach for determining, in real time and in 3D, the shape of an instrumented needle inserted into a complex tissue by using strain gauges. The knowledge of the real time local deformation from these strain gauges would improve the current navigation systems by considering not only the rigid needles but also the flexible needles. Our aim is to reconstruct in real time the instrumented needle shape in order to track and to steer it during a medical intervention.

Purpose

Many medical procedures are based on the insertion of needles to perform a diagnostic or therapeutic act. The access for the clinician to a new needle navigation system, allowing maximizing the benefit / risk ratio of the act, could further optimize the procedures accuracy. This system should allow pushing back the limits due to insufficiently powerful tools. Many techniques were developed to assist in the realization of gestures. They are specific of each method of imagery used (CT scan, magnetic resonance imaging, ultrasound) for real-time or only preoperative imaging and are largely carried out in a daily way. While the medical imaging is constantly improving with ever finer spacial resolutions, the tools available to the radiologist to guide and locate themselves in real time in the images remain rather little developed. They may involve the use of robotic, optical or electromagnetic devices. Such strategies suffer from major limitations in their application to the interventional radiology, among which the assumption of the non-deformability and the difficulty of steering the used tool. Regardless of the strategy used, taking into account the needle deflection and then tracking the needle shape will allow to make the medical procedure safer, less invasive and more efficient. We present here the model associated with the reconstruction of the needle starting from the information given by strain gauges with the first associated 2D/3D results.

Methods

Strain gauges

Works in progress raise the problems to incorporate strain gauges on the needle. These gauges inform on the local deformations of the needle as shown in equation 1. They are integrated on the needle by the way of the micro fabrication coming from the process of microelectronics. The first achievements of micro fabrication allowed verifying experimentally the feasibility to incorporate strain gauges on the needle as shown in figure 1.a.

$$\frac{\Delta R}{R} = k \frac{\Delta l}{l} = k \varepsilon$$

Where R is the electrical resistance, ε is the relative variation of length and k the sensitivity of the gauge.

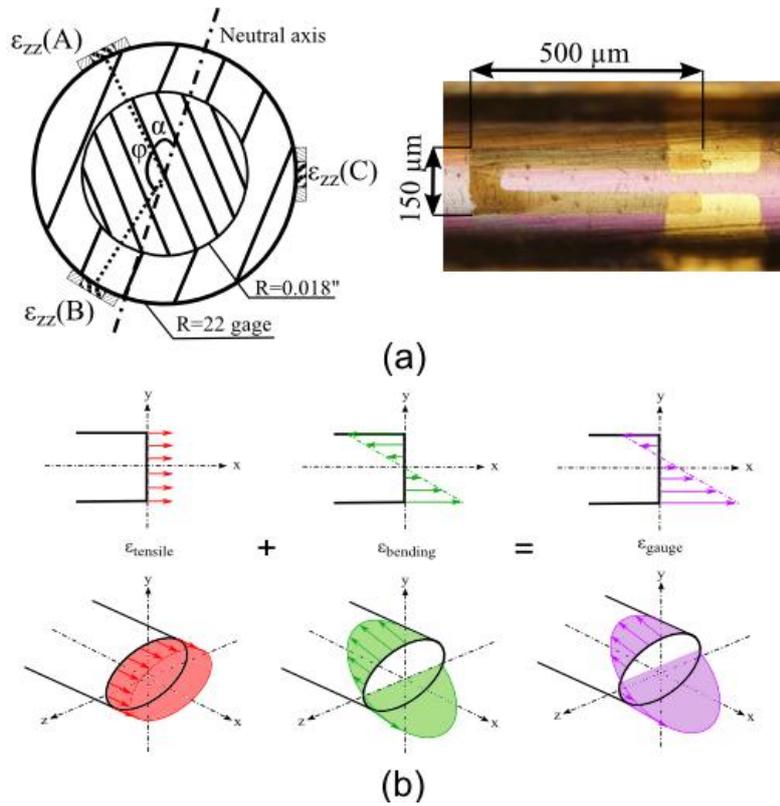


Figure 1 Strain gauges and superposition principle

Strain gauges information

Needles can be considered as beam element as the length of the neutral axis is large compared to the dimensions of the cross-sections. Based on Beam theory, the bending moment-curvature beam equation can be associated to the gauges information:

$$\gamma \approx \frac{d^2y}{dx^2} = \frac{M_f}{EI} = \frac{\epsilon}{r}$$

Where γ is the curvature, y is the displaced position, x is the coordinate along the beam, M_f is the bending moment, E is the Young's modulus of the material, I is the second moment of area and r is the distance between the gauges and the neutral axis.

Furthermore, it is possible to determine the curvature of a needle in 3D using strain gauges as shown in figure 1.a and figure 1.b. The tensile deformation can be determined and then it can be removed to only have the bending deformation, which can be used to determine the curvature of the needle (γ) and the neutral axis (α):

$$\tan \alpha = -\sqrt{3} \frac{\epsilon_{zz}(B) + \epsilon_{zz}(C)}{\epsilon_{zz}(B) - \epsilon_{zz}(C)}$$

$$\gamma \approx \frac{M_f}{EI} = \frac{2}{\sqrt{3}R} \sqrt{\epsilon_{zz}(B)^2 + \epsilon_{zz}(C)^2 + \epsilon_{zz}(B)\epsilon_{zz}(C)}$$

Needle model

From the information carried by the strain gauges, it is possible to model the needles. Needle deflections are approximated as a uniform cubic B-spline S , i.e. as a linear combination of basis cubic B-splines:

$$\forall t \in [t_0 t_n], S(t) = \sum_{i=-3}^{n-1} P_i N_{i,k}(t)$$

Where $k=3$ is the degree of the B-spline, P_i are the control points for the needle deflection and $N_{i,k}$ are the B-splines basis.

The P_i coefficients are totally defined by minimizing the following problem:

$$u_0(S(0) - y_0)^2 + u_1(S'(0) - dy_0)^2 + \sum_{k=1}^m w_k(S''(x_k) - y''_k)^2 + \tau \int_0^L S^{(3)}(t)^2 dt$$

Where $(', ', ^{(3)})$ represent the first three derivatives. (x_k, y''_k) , $k=1\dots m$ are the gauges information with m the number of gauges, y_0 and dy_0 are the information on the position and the orientation of the proximal extremity, u_0 , u_1 , w_k and τ are the weights chosen to acquire a good compromise between the smoothness of the result and the interpolated cubic B-spline.

Results

The incorporation of strain gauges highlights the limits of the possible number of gauges positions accepted to not interfere with connections (minimum two). The gauges enable us to obtain information in 3D. Our first approach was to reconstruct the needles in 2D in the two principal planes. A work on the parameters of the model must also be carried out to find the best compromise of reconstruction on a set of representative needles. An example of reconstruction with 2 positions of strain gauges of a real clinical needle is shown in figure 2. The tip errors and the maximum errors along the needle are 0.3mm and 1.2mm in figure 2.a and 0.9mm and 0.9mm in figure 2.b, respectively.

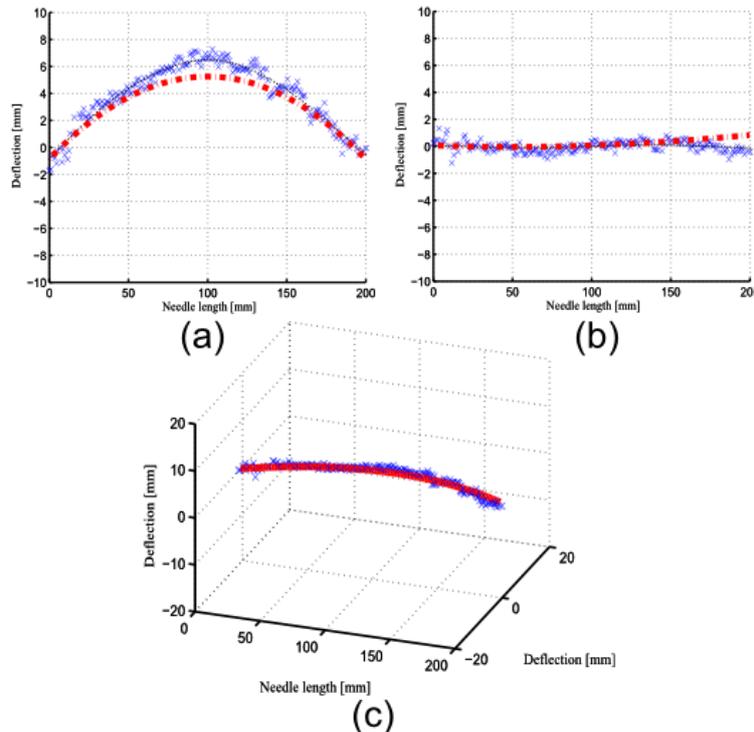


Figure 2 3D reconstruction of a medical needle from two local strain measurements.

Conclusion

We presented the feasibility of reconstructing, with an instrumented needle, the 3D deflection of this one starting from the information given by the strain gauges. During percutaneous procedures, such as biopsies and localized treatments, it is useful to track in real time any tool deviation from the planned trajectory to minimize positioning error and post-operative complications.