Chapter 74
Multi-Objective Higher Order Polynomial Networks to Model Insertion Force of Bevel-Tip Needles

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ABSTRACT

Needle insertion has been a very popular minimal invasive surgery method in cancer detection, soft tissue properties recognition and many other surgical operations. Its applications were observed in brain biopsy, prostate brachytherapy and many percutaneous therapies. In this study the authors would like to provide a model of needle force in soft tissue insertion. This model has been developed using higher order polynomial networks. In order to provide a predictive model one-dimensional force sensed on enacting end of bevel-tip needles. The speeds of penetration for quasi-static processes have chosen to be in the range of between 5 mm/min and 300 mm/min. Second and third orders of polynomials employed in the network which contains displacement and speed as their main affecting parameters in the simplified model. Results of fitting functions showed a reliable accuracy in force-displacement graph.

1. INTRODUCTION

Most of the minimal invasive surgery methods, computer-assisted and robotic surgery systems incorporate a needle insertion process (e.g. stereotactic brain biopsy, laparoscopy, radioactive seed-implantation, etc). In such operations, precise penetrations always provide efficient access to target locations. In needle steering procedures, facing a non-homogenous soft tissue causes more complexity in the phenomenon and necessitates the employment of adaptive control (Abolhassani et al, 2007; Sadjadi et al, 2014). In most applications, having a highly accurate process in both accessing the target and an efficient inser-

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tion is essential. Some applications of percutaneous needle insertion was observed in different works of prostate brachytherapy (Asadian et al, 2014; Sadjadi et al, 2014; Wei, 2004), biopsy (Bishoff, 1998; Schwartz, 2005), and neurosurgery (Masamune et al, 1995; Rizun, 2004). Some other applications such as deep needle insertion have been employed in the failure mechanism of ventricular tissue (Gasser et al, 2009). In order to study tissue behavior, some researchers have used quasi-static needle insertion methods. In addition some other types of needle insertion such as rotational needle insertion, needle tapping, and fast needle insertions were studied (Lagerburg et al, 2006; Mahvash and Dupont, 2010).

Some phenomenological models were generated based on quasi-static one, two or three dimensional compression test of needle penetration experiments, to describe the force graph of insertion as efficient set of terms including friction, inertia, viscous, deformation and plasticity (Vrooijink et al, 2014; Roesthuis et al, 2014; TouficAzar & Hayward, 2008; Okamura et al, 2004; Dimaio & Salcudean, 2003). In-vitro experimental data were achieved by performing standard compression tests. Deformation and non-homogeneity in tissue structure may lead to many potential sources of forces applied to surgical tools, which leads to an imperfect prediction of force (Okamura, et al, 2004). To have better prediction of both force and beveled-tip position, interactive medical imaging is useful in robotic surgery simulation (Vrooijink et al, 2014; Mahvash & Dupont, 2010; Dimaio et al, 2005; Alterovitz et al., 2005). In other applications such as drug delivery, imprecise placement of surgical tools may lead to false dosage distribution or may damage delicate structures. Therefore, there are 4 different types of needle insertion:

- Quasi-static insertion (Dimaio & Salcudean, 2003; TouficAzar & Hayward, 2008);
- Fast needle insertion (Mahvash & Dupont, 2009);
- Rotational insertion (Alterovitz, et al, 2005; Yousefi, et al, 2010);
- Needle insertion with tapping (Lagerburg, et al, 2006).

Overall, numerical simulation for better modeling of forces has been extensively studied by different researchers in recent years, which can be used in surgical simulations and robot-assisted surgeries. Furthermore, accurate modeling could be used in determination of tissue deformation during contact with surgical tools.

1.1. Literature Review on Needle Insertion Force Modeling

Okamura (2004), Barbe (2007), Misra (2009) and Maurel (1999) employed numerical methods to simulate the process of needle penetration in soft tissue. Barbe (2007) used a RLS-CR algorithm (recursive least square with Covariance Resetting) to determine the coefficients of a non-linear viscoelastic Kelvin-Voigt model. Okamura (2004) describes soft tissue behavior based on nonlinear models by damper-spring with various functions. Crouch (2007) reported a gradually reduction in force during the insertion process.

Okamura (2004) determined a model for friction force in needle insertion process. They performed a sinusoidal stimulation of the tissue during needle insertion. This leaded to a hysteresis effect on force distribution.

Both Okamura (2004) and Barbe (2007) achieved their numerical results using in-vivo experiments in force modeling. In some other works, using phantom soft tissues, complex non-linear models dependent on tissue deformation were studied (Dimaio & Salcudean, 2003). Other non-linear elastic models were employed to investigate the effect of velocity variation and deformation-velocity correlation on