

# Chapter 31

## Needle Insertion Force Modeling using Genetic Programming Polynomial Higher Order Neural Network

**Mehdi Fallahnezhad**

*Norwegian University of Science and Technology (NTNU), Norway*

**Hashem Yousefi**

*Amirkabir University of Technology (Tehran Polytechnic), Iran*

### ABSTRACT

*Precise insertion of a medical needle as an end-effector of a robotic or computer-aided system into biological tissue is an important issue and should be considered in different operations, such as brain biopsy, prostate brachytherapy, and percutaneous therapies. Proper understanding of the whole procedure leads to a better performance by an operator or system. In this chapter, the authors use a 0.98 mm diameter needle with a real-time recording of force, displacement, and velocity of needle through biological tissue during in-vitro insertions. Using constant velocity experiments from 5 mm/min up to 300 mm/min, the data set for the force-displacement graph of insertion was gathered. Tissue deformation with a small puncture and a constant velocity penetration are the two first phases in the needle insertion process. Direct effects of different parameters and their correlations during the process is being modeled using a polynomial neural network. The authors develop different networks in 2nd and 3rd order to model the two first phases of insertion separately. Modeling accuracies were 98% and 86% in phase 1 and 2, respectively.*

### INTRODUCTION

Most of minimal invasive devices, computer-assisted or robotic surgery systems incorporate a needle insertion process (e.g. stereotactic brain biopsy, laparoscopy, radioactive seed-implanta-

tion, etc.). In such operations, accurate needle insertion process provides efficient access to the target area through biological tissues. In needle steering procedures, needle usually faces a soft and non-homogenous tissue, which causes more complexity of the process (Abolhassani, et al., 2007). In most applications, having a highly accurate process in both accessing the target and an

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efficient insertion is essential. Some applications of percutaneous needle insertion can be observed in different works of prostate brachytherapy (Wei, 2004; Zivanovic & Davies, 2000), 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 also studied (Lagerburg, et al., 2006; Mahvash & Dupont, 2010).

Some phenomenological models were generated based on common needle insertion experiments, to describe the force-displacement graph of insertion as efficient set of terms including friction, inertia, viscous, deformation, and plasticity (Okamura, et al., 2004; Dimaio & Salcudean, 2003; TouficAzar & Hayward, 2008). In-vitro experimental data could be achieved by performing standard compression tests. Although many complexities and difficulties in modeling arise due to deformation and non-homogeneity in tissue structure, process parameters and model can be exploited from experimental data of such in-vitro experiments. 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 needle tip position, interactive medical imaging is useful in robotic surgery simulation (Dimaio, et al., 2005; Alterovitz, et al., 2005; Mahvash & Dupont, 2010). In addition to the real-time imaging, Schwartz (2005) provides an accurate pre-operation modeling of soft biological tissues to simulate surgery process. Nonetheless, in these procedures some complications have arisen because of misplacement of surgical

tools. While, less misplacement of end-effector during target finding would lead to more accurate needle insertion (Nath, 2000). Analysis of deep penetration of the tissue was performed in friction force identification (Dimaio & Salcudean, 2003). Under specified condition, harmonic velocity experiments were conducted for a definite tissue thickness to determine the amount of friction force (Okamura, et al., 2004).

In other applications such as drug delivery, imprecise placement of surgical tools may lead to false dosage distribution or may damage delicate structures. The authors discuss about four phases for the process of needle insertion (Abolhassani, et al., 2007; Barbe, et al., 2007; TouficAzar & Hayward, 2008; and Mahvash & Dupont, 2010). It includes deformation, steady state penetration, tissue relaxation, and needle extraction phases. There are 4 different types of needle insertion:

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

It must be mentioned that Mahvash and Dupont (2009) used to describe the phenomena of fast needle insertion, in which their gauge for pain was variation in force-displacement diagram.

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.



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