Chapter 8
Brachytherapy Needle Steering Guidance Using Image Overlay

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**ABSTRACT**

This chapter presents a physical simulator for needle steering in brachytherapy. As the user inserts the needle in a phantom tissue, images of the needle and prostate shape reconstructed from 2D transverse ultrasound images are displayed online in a semi-transparent mirror. During insertion, the user sees the images as if they were floating inside the phantom accounting for scale and orientation. The ultrasound images of the needle are combined with a needle-tissue interaction model that predicts the needle deflection further along the insertion process. The necessary manoeuvres that bring the needle towards its intended target location are displayed to the user along with the actual needle location. This platform allows the user to test different manual and robotic-assisted needle steering techniques. Reported experimental results confirm the accuracy of the system in reconstructing and overlaying images onto the phantom.

**1. MOTIVATION**

Percutaneous needle insertion is a widespread minimally invasive surgical intervention. Applications of needle insertion include brachytherapy cancer treatment, tissue biopsy sampling, neurosurgery, radio-frequency ablation, and drug delivery. In brachytherapy, for instance, needles loaded with tiny radioactive seeds are inserted in the patient’s prostate. Once the needles are fully inserted, the needles are pulled back to permanently leave the seeds in their desired destinations. As a consequence, controlling the radiation dose that will destroy cancer cells without affecting adjacent healthy tissues critically depends on the accurate guidance of the needle towards a body target.

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Due to the lack of sufficient feedback during insertion and the limited steerability of needles, needle placement during brachytherapy is usually planned with needles assumed to follow a straight-line trajectory. In practice, this assumption does not hold true as the needle deviates from this path. For a comprehensive survey on issues related to needle steering, see Rossa (2017). In turn, inserting and retracting needles in tissue causes the tissue to move and deform, posing a strong risk of inadvertent target misses. To deal with these challenges, ultrasound images of the needle within the tissue are typically used to guide the needle towards the target. Ultrasound images often contain artifacts that are hard to identity and distinguish from targets and needles. In addition, to view the ultrasound images, the surgeon must look away from the patient and towards a monitor while manoeuvring the needle, introducing an additional challenge in interpreting the images.

In order to improve the visualization of needles and targets during clinical interventions, augmented reality (AR) has been the focus of significant research. Image processing combined with augmented reality has the ability to project onto real world images, reconstructed images of the inner body acquired from any medical imaging modality Weiss (2011). An augmented reality display adds an extra layer of virtual information on top of the perception of the real world in real time, making many surgical tasks simpler and safer for the surgeon. The simplest AR system consists of a semitransparent mirror through which the viewer looks directly at the patient Nikou (2000). An image is projected onto the mirror by a standard monitor so that the viewer simultaneously sees a reflection of the computer display that appears with correct orientation and scale and the real world image Blackwell (2000). In brachytherapy, this can be used as a training environment to help user develop needle steering skills based on the ability to visualize needles and anatomical structures within the tissue in an intuitive way.

Related applications of AR for needle insertion guidance include arthrography Fichtinger (2005), Westwood (2006), ultrasound guided needle placement training Magee (2007), Zhu (2006), surgical laparoscopy Wacker (2005), magnetic resonance image guided biopsy Wacker (2006), liver puncture Nicolau (2005) and ablation Nicolau (2009), Teber (2009), and computed tomography Stetten (2001), Stetten (2001b), Sauer (2002). In Fischer (2007), the AR system identifies the optimal needle insertion path such that the surgeon can follow a desired needle insertion trajectory under the assumption that the needle will remain unbent during insertion. This chapter introduces the first implementation of an AR system for skills development for brachytherapy needle steering. The system displays reconstructed images of the actual shape of a needle in the tissue, as well as the location of the prostate phantom and the target locations in real time. In addition to measuring the actual needle deflection, ultrasound image processing is combined with a needle-tissue physical model Rossa (2016) that predicts the needle deflection further along the insertion process. The necessary manoeuvres that bring the needle towards its intended target location are then displayed to the user online.

This chapter is structured as follows. After we get acquainted with the proposed physical system in Section II, we will see how several transverse ultrasound images are combined to reconstruct the actual 3D shape of a prostate phantom embedded in a synthetic tissue. Next, the needle-tissue model presented in Rossa (2016) is used to predict needle deflection during the insertion process. Once we have reconstructed the prostate geometry and the needle trajectory, we will proceed with image registration to ensure the prostate and needle will appear to the user with correct orientation and scale floating inside the patient. Finally, in Section IV, experimental results confirm the ability of the proposed system in overlaying the reconstructed images.