THREE-DIMENSIONAL FLEXIBLE NEEDLE STREERING USING TWO-DIMENSIONAL ULTRASOUND IMAGES

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ABSTRACT

One of the most commonly performed minimally invasive surgical procedures is needle insertion. Such needle insertions are often performed either for diagnosis (e.g., biopsies) or therapy (e.g., brachytherapy), both of which require accurate needle placement. These procedures are frequently performed under ultrasound image-guidance which provides visual feedback. Clinicians usually use rigid bevel-tipped needles that easily cut and penetrate the soft tissue. The use of rigid bevel-tipped needles offer limited steering capabilities. Steering allows for the compensation of target motion, and the initial misalignment between needle and target. Flexible bevel-tipped needles offer steering capabilities to compensate for target motion and initial misalignment. Further, flexible needles can be steered to avoid sensitive organs and obstacles. In order to provide accurate steering capabilities, the needle needs to be accurately controlled at its base. Steering a flexible needle in three-dimensional (3D) space is a demanding task, and requires needle visualization throughout the entire insertion.

In this study, 3D needle tip pose is obtained by a novel technique which uses a two-dimensional (2D) ultrasound transducer [1]. The 2D transducer is placed perpendicular to the needle insertion direction (Fig. 1). Position measurement of the needle tip in the out-of-plane direction of the transducer cannot be obtained directly. Therefore, the transducer needs to be positioned at the needle tip during insertion, which is done by a positioning device. Relocation of the transducer is performed using a Kalman observer and compensator. The observer is used to minimize the influence of noise, and to estimate the needle tip position and velocity. The compensator uses the needle insertion velocity corrected by tip velocities to determine the required out-of-plane motion. Locating the transducer at the needle tip during needle insertion allows for the computation of the needle tip pose. Maximum mean errors in needle tip positions are 0.64 mm, 0.25 mm and 0.27 mm along the x-, y- and z-axes, respectively, while the tip orientation errors are 2.68º and 2.83º about y- and z-axes, respectively. The tip pose is used to steer the flexible needle towards a target while avoiding obstacles.

Steering of a flexible needle at its base such that it moves towards a target avoiding obstacles requires extensive training and experience. This study uses a customized Rapidly-exploring Random Trees (RRTs)-based path planner, to determine feasible trajectories [2]. These trajectories are computed online and consider the constant radius of curvature introduced by the asymmetric distributed forces acting on the bevel tip. The optimal trajectory is determined by optimizing clinically motivated criteria such as minimizing the insertion length to minimize tissue damage, or maximizing the minimum clearance to obstacles to maximize safety. Control of the needle along such a trajectory is done by duty cycled spinning of the needle during insertion. Duty cycling relaxes the constraint on the constant-curvature of the needle trajectory, and allows any needle curvature between straight and the constant radius of curvature. Improved needle steering is achieved by combining visualization with path planning and duty cycling, which offers the clinician better targeting accuracy in minimally invasive procedures.

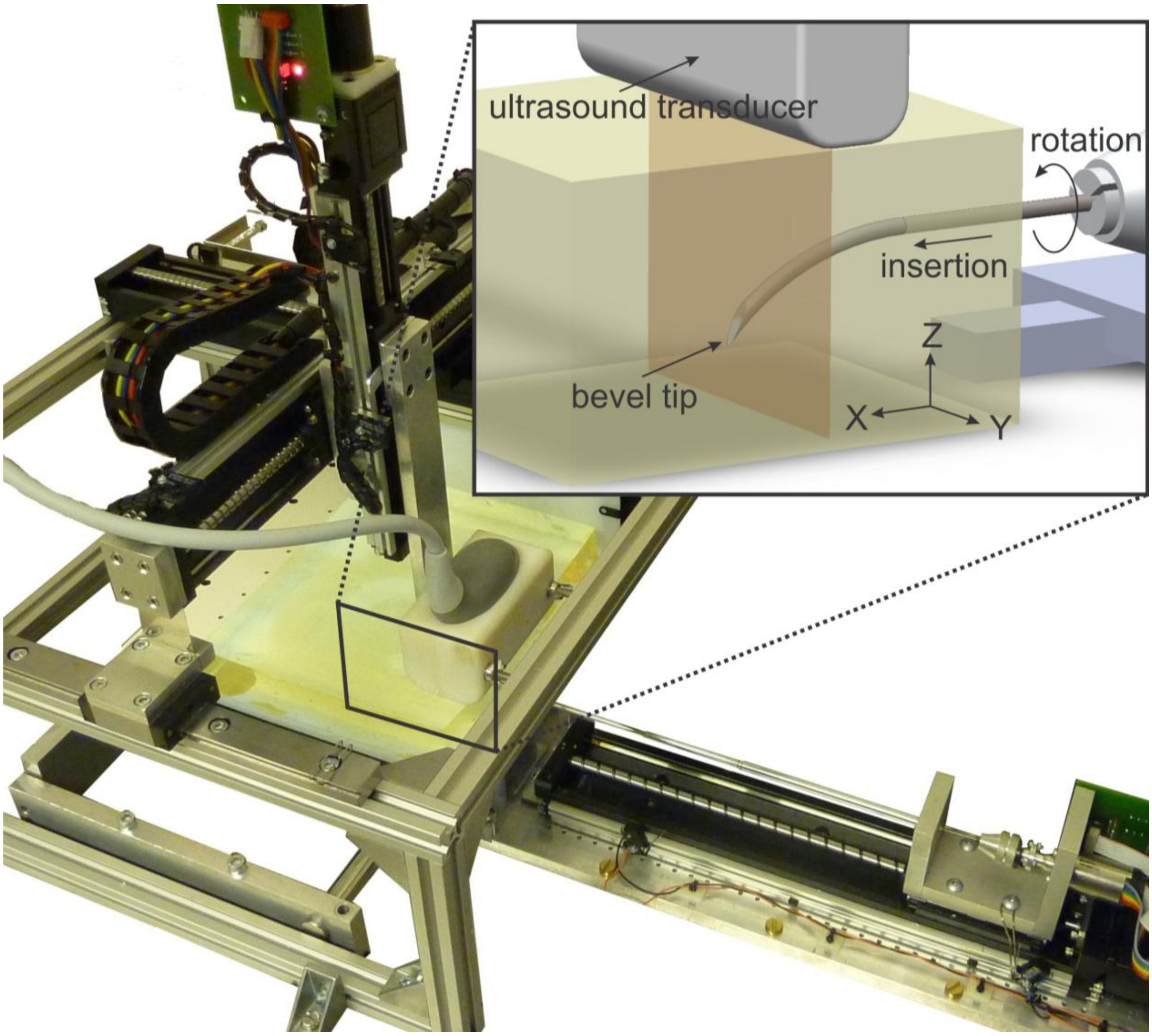

Fig. 1 An overview of the needle tip tracking and steering. A flexible bevel-tipped needle is inserted in the soft-tissue simulant. The soft-tissue simulant is based on a gelatin mixture (by-weight 14.9% gelatin powder, 84.1% water and 1.0% silica) simulating the elasticity property of breast-tissue (35 kPa). During insertion the needle deflects along a curved trajectory in three-dimensional space depending on the orientation of the bevel tip. The needle is tracked by a two-dimensional ultrasound transducer, which is placed perpendicular to the needle insertion direction, as shown in the inset. The transducer provides ultrasound images showing a radial cross-sectional view of the needle. The transducer is robotically repositioned during the insertion in order to provide the needle tip pose. The needle tip pose is used in path planning to steer the needle towards a target while avoiding obstacles (not shown).

REFERENCES

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