THREE-DIMENSIONAL FLEXIBLE NEEDLE STEERING USING AN AUTOMATED BREAST VOLUME ULTRASOUND SCANNER

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ABSTRACT

Needle insertion into soft tissue is a minimally invasive procedure used for diagnostic and therapeutic purposes such as biopsy and brachytherapy, respectively. In the current study, we integrate 3D tracking, path planning and control algorithms to steer a bevel-tipped flexible needle to reach a target in 3D space while avoiding an obstacle. We introduce a system that uses a clinical ultrasound transducer (Automated Breast Volume Scanner (ABVS)) for 3D online needle tracking. The algorithms used in the system are validated by conducting insertion experiments into a soft-tissue phantom while avoiding virtual obstacles. The contributions of this work include the following: (a) to the best of our knowledge this is the first study to use ABVS technique for target localization and needle tip tracking in a 3D ultrasound-guided steering system; (b) experimental evaluation of needle steering towards a target while avoiding an obstacle.

The experimental setup is divided into two parts. First, the insertion device allows the needle to be inserted and rotated about its axis. The details of the needle insertion device are presented in previous work [1]. Second, the ABVS transducer that permits the ultrasound transducer to scan the phantom with a constant velocity. The 15 MHz transducer is connected to a Siemens Acuson S2000 ultrasound machine (Siemens AG, Erlangen, Germany). The needle is inserted into a soft-tissue phantom made of a gelatin mixture [2]. The flexible needle is made of a super-elastic Nitinol alloy (nickel and titanium). The Nitinol needle has a diameter of 0.5 mm with a bevel angle (at the tip) of 30°.

Different experimental scenarios are conducted to evaluate the performance of the proposed needle tracking, path planning and control algorithms. The needle curvature in the phantom is determined empirically [1]. A safety margin is added to the needle curvature value to compensate for variations or disturbances that may take place during insertion. The ultrasound scan velocity is 1.5-1.7 mm/s. Each experimental case is performed five times. The phantom is scanned pre-operatively to localize the physical target in the soft-tissue phantom. The obtained target and obstacle locations are exported to the path planning algorithm. The control algorithm steers the needle along the generated path to avoid the obstacle and reach the target using milestones. The path is updated every second to avoid the obstacle and to correct for needle tip deviation during insertion. The targeting error is the absolute distance between the target position that is pre-defined and needle tip position obtained from the needle tracking algorithm. The results show that the needle did not collide with the obstacles in any experimental trials. The mean targeting error ranges between 0.64±0.24 mm and 0.94±0.37 mm. The achieved submillimeter accuracy suggests that our approach is sufficient to target the smallest lesions (2mm diameter) that can be detected using state-of-the-art ultrasound imaging systems.

REFERENCES

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