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Survey on Needle Tip Estimation Methods

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Abstract

A method for estimating the needle tip has previously been developed combining a modified Hough transform, image filters, and machine learning. This paper improves that method by introducing a dynamic selection of the region of interest in the US images and filtering the tracking results using either a Kalman filter or a particle filter. Automating the insertion of a needle by using a robot could increase the accuracy and decrease the execution time of the procedure.

Keywords: *Kalman filter, Needle, US images*

I. INTRODUCTION

Automating the insertion of a needle by using a robot could increase the accuracy and decrease the execution time of the procedure. Moreover, in cryoablation treatments, robot-aided insertion will reduce the number of CT scans the patient has to undergo. The needle is the end-effector of the robot and its tip should be positioned inside the human body to hit a target from a specific insertion point. Then, estimating the needle tip position from the US images is of paramount importance for verifying that the needle is not approaching any forbidden regions (e.g., major vessels, ribs, and nerves) and for eventually updating the planned trajectory. There are several reasons for tracking the needle tip during the insertion. The estimated needle tip may be used directly by the controller of the robot inserting the needle as a feedback variable. In addition, when a robot is inserting the ablation probe, the insertion trajectory is

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planned using preoperative images and errors in the registration or movement during the intervention may cause deviations from the precalculated plan. In manual insertion, it is hard even for expert radiologists to position the device accurately: an autonomous tracking system for the needle could be very helpful to increase the precision. Robotic approaches to needle insertion are shown, but none of these use US image feedback during the insertion. Use a preoperative 3-D US model and a magnetic tracker. A real-time algorithm for finding straight biopsy needles is presented based on a modified version of the Hough transform. However, a detailed accuracy analysis of the needle tip detection is not provided. Two real-time algorithms for finding curved needles in 2-D US images are presented, one based of the Hough transform and one approximating the cured needle as an arc of constant radius. The algorithms find points on the needle, but do not provide a reliable estimation of the needle tip position. Those algorithms are compared with a novel method to find biopsy needles on transrectal US images, where both of the above algorithms are found to give biased results. The algorithm in defines an objective function from three needle tip metrics, and selects the needle tip based on this function. The results are very accurate, but all the images of the biopsy procedure need to be available before the execution of the algorithm. Therefore, the method is not suitable for real-time applications. A Gabor filter is used for localizing the needle, and is improved by introducing an entropy-based parameter tuning scheme. Kalman filtering of the result is introduced to reduce estimation noise.

Segmentation of 3-D US images is done for brachytherapy needles and for biopsy needles. Another method for localization and tracking of biopsy needles is presented. This method uses the random sample consensus algorithm and Kalman filtering, and adapts the region of interest (ROI) to decrease the execution time. These methods have a much higher computational cost than the 2-D segmentation methods and can only be used in real-time applications using dedicated graphics processing unit. Some recent attempts have been proposed by moving the US probe to track the needle. The image plane is perpendicular to the needle and the US probe is moved by a robot to continually see the tip. The main drawback of this approach is that neither the target itself nor the needle axis is visible in the US image. It present a method to localize and track a needle by combining the random sample consensus

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algorithm with Kalman filtering on the images from a 3-D US probe. It also presents a visual servoing algorithm for keeping the needle within the field of view.

Rather than segmenting the needle to find the tip from gray-scaled US images, it is possible to use stylet vibration and power Doppler. Even though this method guarantees a very high accuracy, it requires a mechanical device to induce the vibration of the needle increasing the overall complexity and cost. In this paper, we present a new real-time needle tip estimation method for rigid needles based on 2-D US images. The method presented here improves the one proposed in the following aspects.

1) Online adaptation of the ROI for estimating the needle axis in a more robust and reliable way.

2) Implementation of Statistical Filtering: Kalman filter (KF) and particle filter (PF) have been used to improve the accuracy and precision of the tip tracking, to filter out the noise, and to cope with outliers.

3) The algorithm can also rely on velocity measurements to improve the tracking accuracy when the insertion is performed by a robotic system.

The performance of the algorithm in manual and robotic insertions is deeply investigated and compared, and the differences between using a KF and a PF for this specific application are evaluated. The main objective of this paper is to design an accurate and robust observer for a robotic system inserting a needle, while a secondary objective is to provide a method that may assist physicians inserting a needle manually.

II. LITERATURE SURVEY

Comparison of a Computer-Assisted Navigation System and the AcuBot Robotic System

Fenster A et.al proposed a method for percutaneous access to the kidney is required for the execution of a multitude of urological tasks ranging from nephrostomy tube placement to needle ablative procedures[1].Currently, these procedures are performed free-hand via image-guided assistance. This approach is associated with a steep learning curve and remains time consuming, difficult, and, in some circumstances, inaccurate. This is

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particularly important during percutaneous image-guided ablation of renal tumors, where accurate probe placement is of paramount importance in determining treatment success. Two emerging technologies that have the potential for increasing the accuracy and efficiency of renal targeting are computer-assisted navigation systems and purpose-built robots. The computer-assisted navigation system allows the surgeon to know the alignment of the puncture needle in real time corresponding to a three-dimensional model acquired from preoperative computed tomography (CT) images. After the preoperative imaging is obtained and reconstructed, markers are placed both on the patient's body and the surgical tool to spatially localize the needle in relation to the desired target. This allows the surgeon to execute the needle trajectory based on real-time imaging feedback that displays needle orientation relative to that of the target.3 AcuBot is a robotic system built in our URobotics laboratory at the Johns Hopkins Medical Institutions, and it can be mounted on a CT scanner. Images acquired are processed by the AcuBot system, which then automatically orients and drives the needle tip to the desired target location.

Temporal-based needle segmentation algorithm for transrectal ultrasound prostate biopsy procedures

Cool DW1, Gardi L et.al Automatic identification of the biopsy-core tissue location during a prostate biopsy procedure would provide verification that targets were adequately sampled and would allow for appropriate intraprocedure biopsy target modification. Localization of the biopsy core requires accurate segmentation of the biopsy needle and needle tip from transrectal ultrasound (TRUS) biopsy images. A temporal-based TRUS needle segmentation algorithm was developed specifically for the prostate biopsy procedure to automatically identify the TRUS image containing the biopsy needle from a collection of 2D TRUS images and to segment the biopsy-core location from the 2D TRUS image.

Needle path planning and steering in a 3D non-static environment using 2D US images

Gustaaf J et.al Needle insertion is commonly performed in minimally invasive medical procedures such as biopsy and radiation cancer treatment [2].

During such procedures, accurate needle tip placement is critical for correct diagnosis or successful treatment.

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Accurate placement of the needle tip inside tissue is challenging, especially when the target moves and anatomical obstacles must be avoided. Develop a needle steering system capable of autonomously and accurately guiding a steerable needle using two-dimensional (2D) ultrasound images. The needle is steered to a moving target while avoiding moving obstacles in a three-dimensional (3D) non-static environment. Using a 2D ultrasound imaging device, system accurately tracks the needle tip motion in 3D space in order to estimate the tip pose.

The needle tip pose is used by a rapidly exploring random tree-based motion planner to compute a feasible needle path to the target. The motion planner is sufficiently fast such that replanning can be performed repeatedly in a closed-loop manner. This enables the system to correct for perturbations in needle motion, and movement in obstacle and target locations.

Optical Flow-Based Tracking of Needles and Needle-Tip Localization Using Circular Hough Transform in US Images

Kamali S,H et al Rasul Enayatifar et al Image-guided interventions have become the standard of care for needle-based procedures[3]. The success of the image-guided procedures depends on the ability to precisely locate and track the needle. This work is primarily focused on 2D ultrasound-based tracking of a hollow needle (cannula) that is composed of straight segments connected by shape memory alloy actuators. An in-plane tracking algorithm based on optical flow was proposed to track the cannula configuration in real-time. Optical flow is a robust tracking algorithm that can easily run on a CPU.

However, the algorithm does not perform well when it is applied to the ultrasound images directly due to the intensity variation in the images. The method presented in this work enables using the optical flow algorithm on ultrasound images to track features of the needle. By taking advantage of the bevel tip, Circular Hough transform was used to accurately locate the needle tip when the imaging is out-of-plane.

Through experiments inside tissue phantom and ex-vivo experiments in bovine kidney, the success of the proposed tracking methods were demonstrated. Using the methods presented in this work, quantitative information about the needle configuration is obtained in real-time which is crucial for generating control

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inputs for the needle and automating the needle insertion.

Biopsy Needle Detection in Transrectal Ultrasound

Alper Ayvaci et al proposed a method using the fusion of pre operative MRI and real time intra-procedural transrectal ultrasound (TRUS)[4].To guide prostate biopsy has been shown as a very promising approach to yield better clinical outcome than the routinely performed TRUS only guided biopsy. In several situations of the MRI/TRUS fusion guided biopsy, it is important to know the exact location of the deployed biopsy needle, which is imaged in the TRUS video.

In this paper, we present a method to automatically detect and segment the biopsy needle in TRUS. To achieve this goal, propose to combine information from multiple resources, including ultrasound probe stability, TRUS video background model, andthe prior knowledge of needle orientation and position. The proposed algorithm was tested on TRUS video sequences which have in total more than 25,000 frames. The needle deployments were successfully detected and segmented in the sequences with high accuracy and low false-positive detection rate.

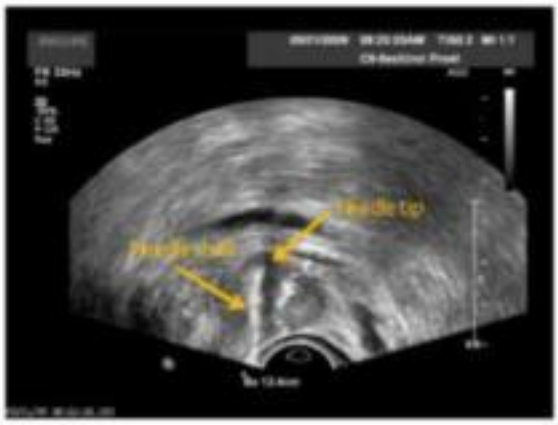


Figure 1: TRUS image with needle

Sliding Mode Control of Steerable Needles

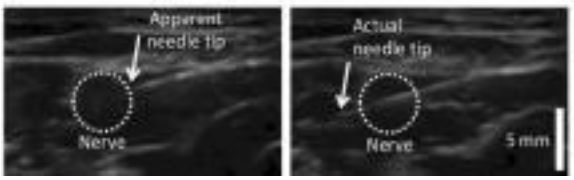
Tariq Shah et al propose a criterion Steerable needles can potentially increase the accuracy of needle-based diagnosis and therapy delivery, provided they can be adequately controlled based on medical image information[5].In this paper propose a novel sliding mode control law that can be used to deliver the tip of a flexible asymmetric-tipped needle to a desired point, or to track a desired trajectory within tissue. The proposed control strategy requires no a priori knowledge of model parameters, has bounded input speeds, and requires little computational resources. We show that if the standard non holonomic model for tip-steered needles holds, then the control law will converge to desired targets in a reachable workspace, within a tolerance that can be defined by the control parameters. Experimental results validate the control

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law for target points and trajectory following in phantom tissue and ex vivo liver.

Needle-tip localization using an optical fibre hydrophone

Ibrahim S I Abuhaiba et.al proposed an ultrasound imaging is frequently used for guiding needles during minimally invasive procedures, but accurate identification of the needle tips can be challenging, even for experienced practitioners [6]. In this study, a novel method for tracking needles inside the human body was developed. This method, called ultrasonic device tracking (UDT), involved the detection of ultrasound pulses from the external imaging probe with an optical fibre hydrophone integrated into the needle cannula. Two methods for estimating the needle tip position that were based on the maximum and the centroid of the optical fibre hydrophone signal were tested.



A Tutorial on Particle Filters for Online Nonlinear/Non-Gaussian Bayesian Tracking

Qiudong Sun et.al proposed this paper, review both optimal and suboptimal Bayesian algorithms for nonlinear/non-Gaussian tracking problems, with a focus on particle filters[7]. Particle filters are sequential Monte Carlo methods based on point mass representations of probability densities, which can be applied to any state-space model and which generalize the traditional Kalman filtering methods. Several variants of the particle filter such as SIR, ASIR, and RPF are introduced within a generic framework of the sequential importance sampling (SIS) algorithm.

CONCLUSION

This paper proposed and compared different algorithms that allow to improve the needle tip tracking precision in the US images with respect to other solutions in the literature. The precision in the estimation of the needle insertion angle has been increased significantly. The improvement comes from:1) the introduction of a dynamical adaptation of the ROI to find the needle axis and 2) filtering the insertion angle using statistical estimators. The method with overall best performance was the b algorithm based on a KF with feedback and velocity measurements (i.e. robotic-aided insertion), where the 95th percentile of the position error was reduced by 87.4 percentage and the standard deviation by

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more than 87.8 percentage compared with the previous methods. In addition, the standard deviation of the tip position error along the needle was significantly smaller than all other evaluated methods.

Future Work: In future work, plan to improve the algorithms in order to track steering needles and to design a control architecture to optimal positioning the US probe in robotic needle insertion.

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