Integration of Acoustic Emission and Ultrasound for Needle Guidance in Interventional Procedures

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ABSTRACT

Challenges like interrupted visualization and artifacts are common during interventional surgery while guiding medical interventional devices (MIDs) such as needles, catheters, etc. This proclaims the need of efficient accessories for improving simultaneous targeting and visualization of MIDs during interventional surgeries. Diagnostic devices are often used, but only visual perception is not enough due to image-related shortcomings. This article proposes a novel approach that reads audio signals via microphone attached to the proximal end of a biopsy needle to support verification and tracking during a surgery. A needle tracking algorithm was also integrated for visual support of intervention. The algorithm acquires the audio signal due to tissue-needle interaction and simultaneously detects the needle in the ultrasound frames using progressive regional properties. The proposed combination has ability to solve problems related to MID localization during interventional procedures, where it is crucial to maintain information flow for verification and target location.

KEYWORDS

Image Processing, Integration, Medical Interventional Devices, Multithreading, Needle Acoustics, Needle Detection, Minimal Invasive Surgeries (MIS), Real-Time Diagnosis, Signal Processing, Ultrasound

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INTRODUCTION

The significance of verification in MIS has led to the development of various imaging and mechanical innovations for enhancing the workflow during interventional surgeries. Among all the imaging devices, ultrasound is used extensively for MIS due to low cost, easy mobility, radiation-free, and real-time nature. Biopsy, regional anesthesia, and central venous catheterization are few popular procedures where ultrasound and MIDs work hand to hand (National Research Council, 1996; Griffin & Nicholls, 2010). Albeit, ultrasound is a practical choice for intervention guidance its limited resolution quality and inadequate training to handle ultrasound make needle tracking a challenging task (Chapman, Johnson, & Bodenham, 2006). Artifacts commonly observed while using ultrasound in MIS are either acoustic or anatomic which results in a low-quality image which can easily result in errors like mallocation of biopsy needles (Henderson & Dolan, 2016).

Ultrasound’s ability to obtain real-time images in an intraoperative surgery is a major reason for the development of several image processing solutions for enhancing needle or needle tip location. 2D Ultrasound is preferred over 3D ultrasound for real-time tracking because of its high acquisition rate, high update rate, and less computational cost (Mathiassen, Dall’Alba, Muradore et al., 2013). Several algorithms have been proposed to enhance needle detection in US images whose foundation has been laid over Hough Transform, a special case of the Radon transform, that extracts the needle long axis (Ayvali & Desai, 2015; Mathiassen, Dall’Alba, Muradore et al., 2013). Hough transform, demonstrated in (Ding & Fenster, 2003) is not underlining accurate needle estimation and in (Mathiassen, Dall’Alba, Muradore et al., 2013) a novel set of features are used to find needle tip location in real time, state high accuracy, but are computationally expensive and designed for robotic systems, therefore not considering error introduced by the human-held probe.

Several other solutions have also been proposed in the literature to address the above problems by having a mechanical add-on to biopsy needle, for example, Klein et al. designed a new piezoelectric needle that provides distal tip visualization using colour flow Doppler. Shen et al. presented a MEMs design with a mini actuator fixed near the needle, causing interference between radiated and diagnostic ultrasound that can determine the fixed position of needle tip even in inconsistent ultrasonic view (Klein, Fronheiser, Reach et al., 2007; Shen, Zhou, Miao, & Fong Vu, 2015). The introduction of the echogenic needle has been in vogue for quite some time, but it does not have any significant improvement over needle tip visibility over standard needle due to limited scanning area of an ultrasound probe. Moreover, all the solution described above are more focused on enhancing the visibility of needle in low-quality ultrasound images but do not provide any information about needle-tissue interaction which is also very crucial during MIS.

The author proposes a novel technological solution that supports simultaneous verification and visualization of the biopsy needle in MIS by processing acoustic signals from the distal end of the needle using a stethoscope and detecting needle
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