The Johns Hopkins University

Whiting School of Engineering

Department of Electrical and Computer Engineering

Integrated Active Ultrasound Systems for Medical Interventions

Dissertation Defense by

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Abstract

Ultrasound is becoming an increasingly preferable tracking and imaging modality in the interventional surgeries due to its low cost, safety, mobility and ease-of-use. Besides the merits, there are also challenges to use ultrasound in many applications. To address these challenges, I have developed a collection of novel technologies, and validated them with prototype systems under ex vivo or in vivo conditions.

In this dissertation thesis, I introduce multiple technologies to improve the performance of ultrasound systems in the interventional procedures, break the limitations of the ultrasound guidance capability, and integrate ultrasound into more interventional areas. These technologies can be categorized into three themes: (1) accurate and effective interventional tool tracking and imaging using ultrasound systems, (2) accurate and automatic calibration between ultrasound and other systems, and (3) improving the interventional tool imaging and tracking capability by combining ultrasound with optical systems.

My main contribution to the first theme is inventing the active ultrasound pattern injection system (AUSPIS) for interventional tool tracking and imaging applications. AUSPIS is the first system that establishes a bi-directional ultrasound communication between the catheter and probe. This enables multiple methods to perform highly accurate tool guidance with near-mid-plane configurations. I also studied the working and fail conditions of the AUSPIS with lab bench experiments, integrated it with multiple interventional tools, and validated the clinical environment performance by multiple ex vivo and in vivo experiments.

With respect to the second theme, I invented the first active phantom ultrasound calibration system, which is capable to localize the ultrasound mid-plane with a higher accuracy, thus improve the calibration accuracy. More importantly, it enabled the automatic-segmentation method, thus made the entire calibration process user-independent and image-quality independent, and the fully automatic calibration becomes possible. Based on this system, I also developed the solutions to tracking a tool far away from the ultrasound image plane. All these methods are demonstrated with a series of lab bench experiments.

In the third theme, my main contribution is designing and building the photoacoustic experimental platform, integrating the system with multiple interventional devices, developing the all-optical AUSPIS system, and investigating the several signal acquisition methods to improve the photoacoustic system performance.

Monday, December 15, 2014

8a.m.

Barton 117

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