Automatic Search for Photoacoustic Marker Using Transrectal Ultrasound Actuator

Hamid Moradi, Hyunwoo Song, Zijian Wu, Keshuai Xu, Emad Boctor, Septimiu Salcudean
University of British Columbia, Vancouver, Canada, Johns Hopkins University, Baltimore, USA

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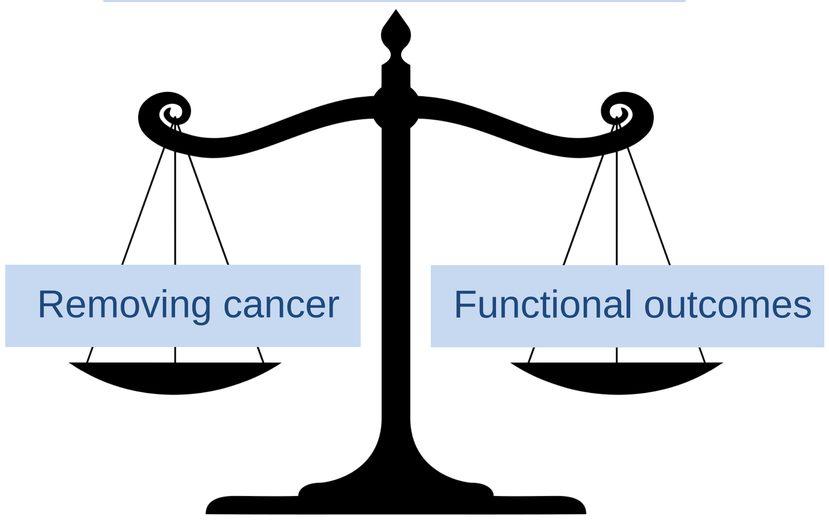
INTRODUCTION

Intra-operative Prostate Imaging



- Current Magnetic Resonance Imaging cannot be used intra-operatively and Ultrasound (US) imaging is not sensitive enough to detect prostate cancers [1].

Robotic Prostate Imaging

- Imaging using robotic transrectal US (TRUS) manipulator
- TRUS transducer follows the da Vinci tool tip [2]
- da Vinci tool tip is kept within the imaging plane of the transducer
- The real-time ultrasound image of where surgeon works on is provided.

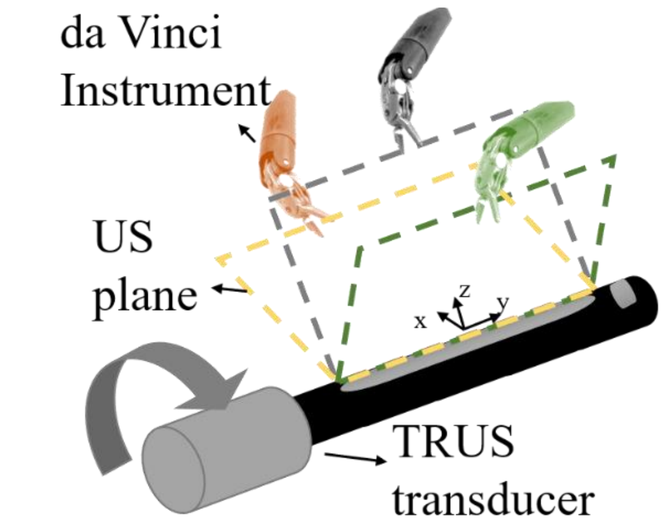


Figure 1. TRUS transducer follows the da Vinci tool tip providing intra-operative imaging

- The da Vinci and TRUS coordinate systems are registered by touching the tissue with the instrument tip [2] or photoacoustic (PA) markers [3] at three or more different locations.
- **While accurate, this registration is time-consuming (as much as 7 min), because the TRUS is manually rotated to align its imaging plane to the laser spots.**

Automatic Search

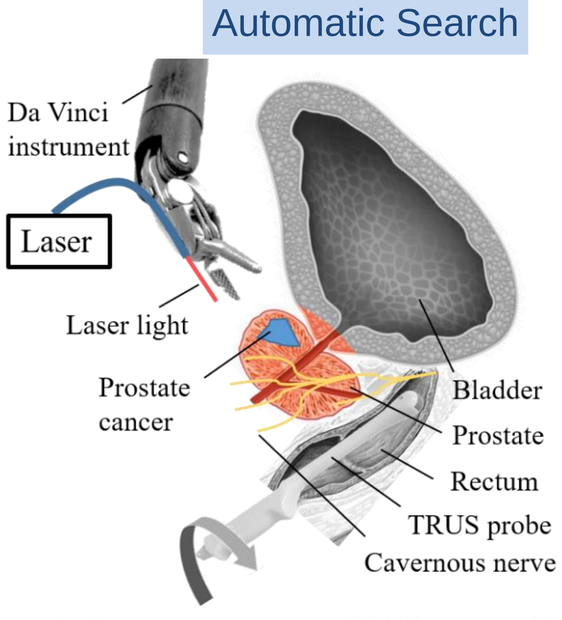


Figure 2. Arrangement of the TRUS and da Vinci robot with respect to the prostate.

- In this paper, an automatic image-based search for the PA marker is proposed and is validated in simulation and experiments.

METHODS

- The laser illuminates a small spot as shown in Fig 3. The motorized TRUS rotates from -35 to 35 degrees in increments of 5 at θ_is.
- The goal is to find θ_p in the TRUS coordinate system.

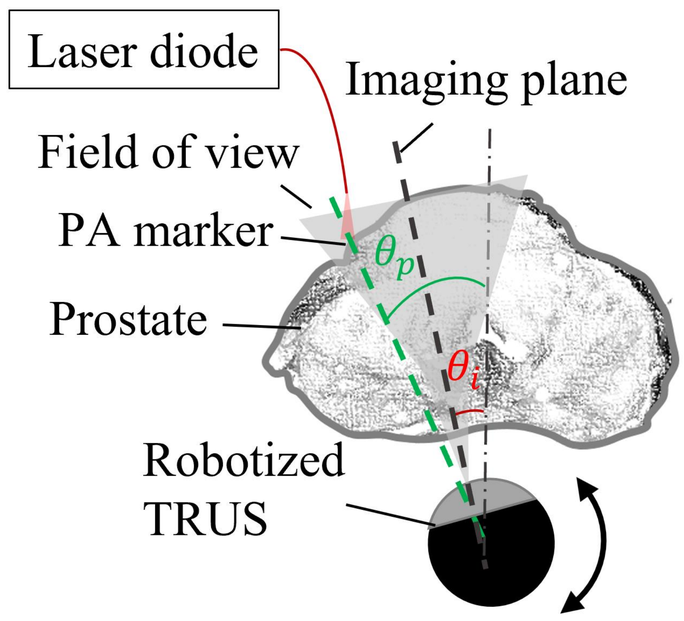


Figure 3. Automatic search. The laser illuminates a small spot θ_p and PA data are recorded at θ_is

- The TRUS also receives out of plane signals.
- The maximum PA signal, $S(\theta_i)$, is recorded for each θ_i (see Fig 4).
- The directivity pattern of the TRUS transducer with respect to the incoming waves is symmetric.
- A simple weighted average can be used to localize the PA marker, θ_p:

$$\theta_p = \sum \theta_i S(\theta_i) / \sum S(\theta_i)$$

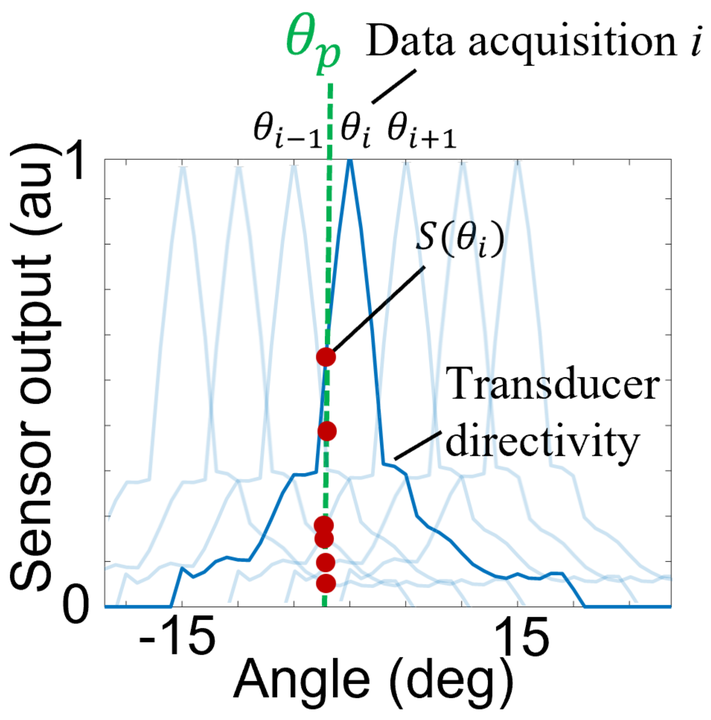


Figure 4. The directivity pattern of TRUS transducer for θ_i is shown in dark blue. Red dot shows the intensity recorded for different θ_is

Simulation and Experiment Validation

- For the simulation, the experimental directivity pattern and PA model developed in [4] was used. The PA markers were located at 1000 random locations.
- For the experiment, a pulse laser diode (QSP-785-4) illuminates three random locations.
- At each location, PA signals are collected at 15 angles using the motorized TRUS transducer and the SonixDAQ (see Fig 5).
- Then, a manual search was performed to find the reference location of the laser source.
- The same threshold line was used for all the experiments to reject noise level signals.

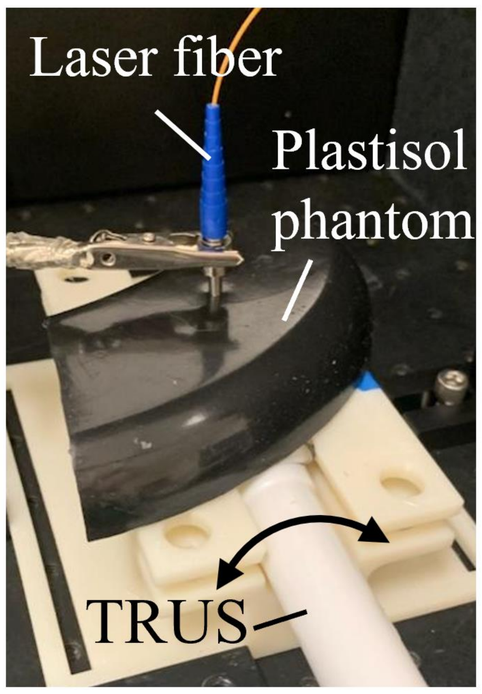


Figure 5. Experiment set-up. Random locations on plastisol phantom are illuminated and PA signals are collected at equal intervals using TRUS transducer.

RESULTS

- Simulation and experimental results and the reference angle of the PA markers are shown in Fig 6 and 7, respectively.
- The average localization error for the simulation study was 0.38±0.2 degrees.
- The error for experiments 1, 2, and 3 were 0.05, 0.43, and 0.31 degrees, respectively.

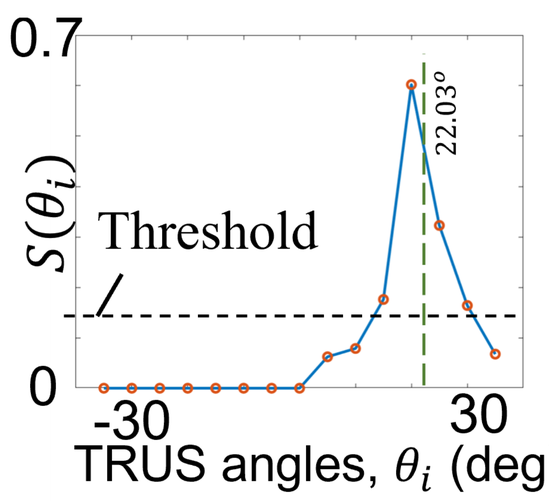


Figure 6. Simulation results. The recorded intensity with respect to the TRUS angles are shown.

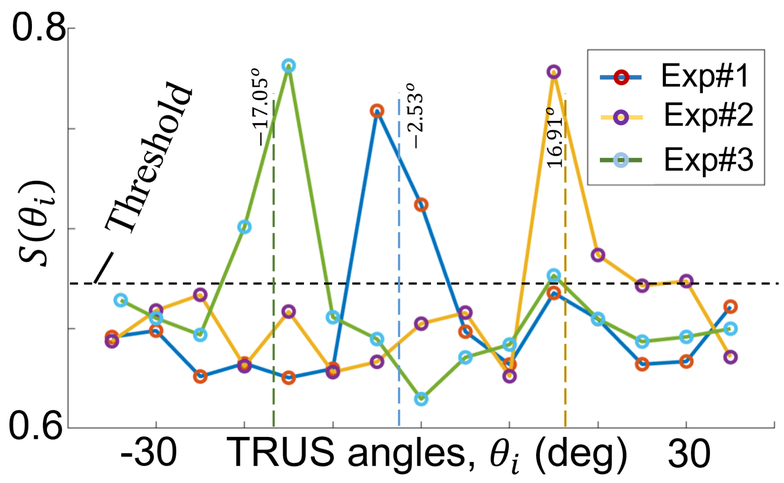


Figure 7. Experiment results. The recorded intensity with respect to the TRUS angles are shown.

CONCLUSIONS

This study focused on the feasibility of automatic search for photoacoustic marker using transrectal ultrasound actuator.

- Although data collection was at 5 degrees intervals, the localization error of the proposed method was less than 0.5 degrees.
- This allows to significantly reduce the time needed for registration process.
- More sophisticated search algorithm are being investigated.

REFERENCES

1. S. Tang, et al., 2016.
2. Mohareri, et al., 2015.
3. Song, et al., 2022.
4. H. Moradi, et al., 2017.