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Prostate cancer ablation with a 4D robotic system using thermal ultrasonic waves under MRI guidance.

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PROSTASONIC
Prostate solutions with focused ultrasound

Ευρωπαϊκή Ένωση
Ευρωπαϊκά Διαρθρωτικά
και Επενδυτικά Ταμεία

Κυπριακή Δημοκρατία

Διαρθρωτικά Ταμεία
της Ευρωπαϊκής Ένωσης στην Κύπρο

Submitted at the: 7th International Symposium on Focused Ultrasound 2020. 9th-13th November 2020, Virtual Event

Submitted Abstract:

MRI guided positioning device using focused ultrasound for treatment of prostate cancer.

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Abstract

A magnetic resonance imaging (MRI)-positioning device with 2 computer-controlled axes (one linear and one angular) was developed. The positioning device holds a single element focused ultrasound (FUS) endorectal transducer. Four manually driven axes were also developed in order to properly place the transducer close to the rectum. The purpose of this positioning device is to ablate prostate cancer in humans in the future.
The positioning device includes MRI compatible piezoelectric motors, and optical encoders and ABS plastic. All the parts of the positioning device were developed using an industrial 3D printer.
The MRI safety of the device was successfully evaluated in a GE 1.5 T MRI scanner. The positioning device has the ability to accurately move the transducer. The ability of the transducer to cause high temperatures was tested successfully in a water-agar phantom. A reliable, simple, cost effective, portable positioning device has been developed which can be used in virtually any MRI scanner since it can be placed on the scanner's table. The proposed positioning device can be used in the future for clinical trials for prostate cancer treatment using FUS provided that it is evaluated extensively in animal models.

Acknowledgements

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Submitted Poster:

MRI POSITIONING DEVICE USING FOCUSED ULTRASOUND FOR TREATMENT OF PROSTATE CANCER

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INTRODUCTION

- A magnetic resonance imaging (MRI) robotic device with 2 computer-controlled axes was developed
- The device carries a single element focused ultrasound (FUS) endorectal transducer
- It is equipped with 3 manually driven axes for placement of the transducer to the rectum
- The device can fit on the table of any commercial MRI scanner up to 7 T
- The device has been developed for future ablation of prostate cancer in humans

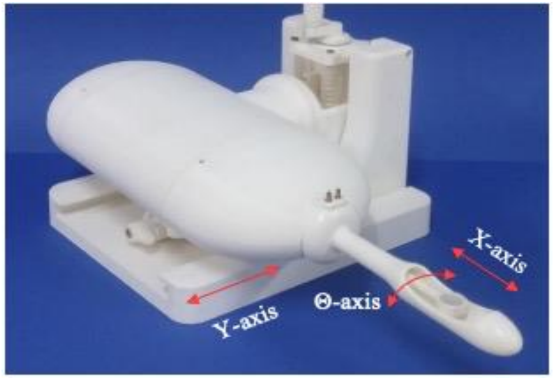

Figure 1: Photo of the robotic device (front view).

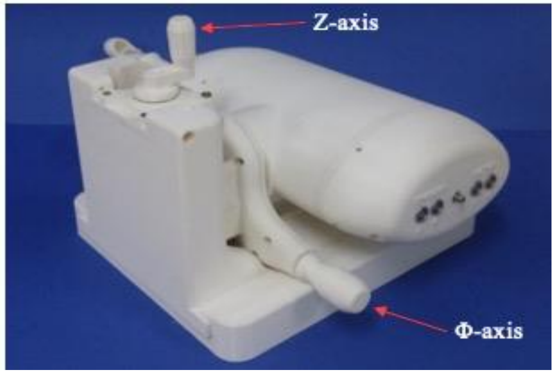

Figure 2: Photo of the robotic device (rear view).

ROBOTIC DEVICE

- The device offers motion in 2 computer-controlled axes for maneuvering the transducer:
  - 1 linear X axis for motion along the rectum
  - 1 angular Θ axis for rotation within rectum
- 3 manual axes were also added for enabling the appropriate placement of the transrectal probe:
  - 1 linear Z axis for adjusting robot up and down for varying rectum height
  - 1 linear Y axis for adjusting the robot left and right
  - 1 angular Φ axis for setting the entry angle to the rectum

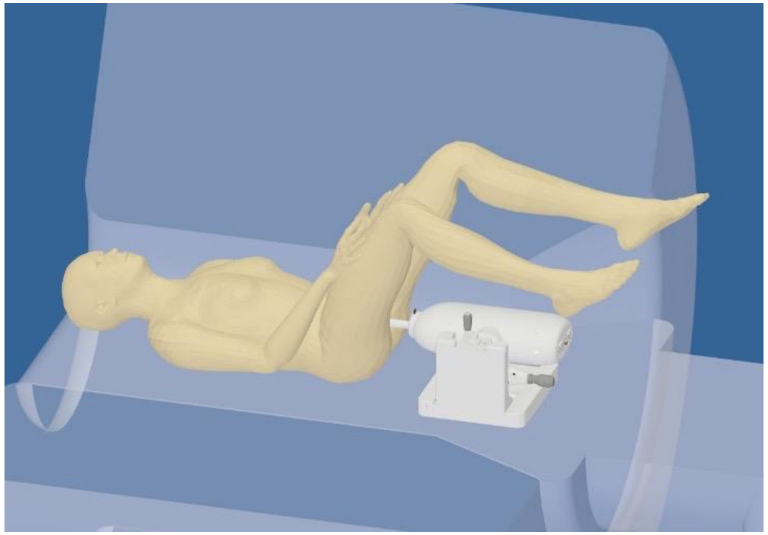

Figure 3: Configuration of the device during treatment.

- Motion of the computer-controlled axes was achieved through MRI compatible piezoelectric motors (USR60-S3N, Shinsei, Tokyo, Japan)
- Motion of the computer-controlled axes is controlled through a software
- The device was 3D printed (FDM 400, Stratasys, Minnesota, USA) with Acrylonitrile Butadiene Styrene (ABS)
- The device can be placed on the table of high-field MRI scanners
- Patient in supine position with legs elevated

FUS TRANSDUCER

- The device is equipped with a single element focused ultrasound transducer
- Non-magnetic materials were used for development, allowing operation inside MRI
- Manufactured with piezoceramic material in ABS holder
- Diameter of transducer ranges from 17-25 mm
- Frequency ranges from 3.2-4.4 MHz

Figure 4: Photo of the manufactured transducer inside the probe.

MRI SAFETY

- According to ASTM standards the device is classified as MRI conditional due to the use of electricity
- The compatibility of the transducer and the robotic device in an MRI environment was assessed
- 1.5 T MRI system (Signa, General Electric, Fairfield, CT, USA) with a GPFLEX coil (USA instruments, Cleveland, OH, USA) was used
- Compatibility of transducer and robotic device was assessed using FSPGR, T2-W FRFSE and EPI sequences
- For assessing the transducer, an agar-phantom (6 % w/v agar, 30 % v/v evaporated milk) was used
- An MR quality phantom was used for evaluating the robotic device
- The Signal to noise ratio (SNR) was measured in the phantoms for different sequences and activation configurations

Transducer

- The SNR was measured under various conditions (no hardware, motor activation or not, transducre activation or not)
- SNR drop upon activation proves compatibility
- FSPGR resulted in biggest SNR drop

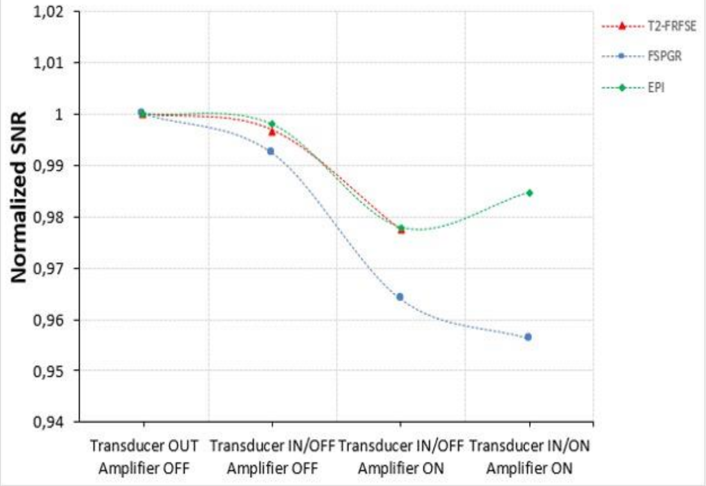

Figure 5: SNR for the three MR imaging protocols for different activation conditions of the transducer.

Robotic device

- SNR measured for different activation conditions (phantom only, robotic device in bore with no cables, connected robot/deactivated electronics, connected robot/activated electronics
- SNR drop in all sequences upon robot connection
- T2-W FRFSE resulted in greatest SNR drop

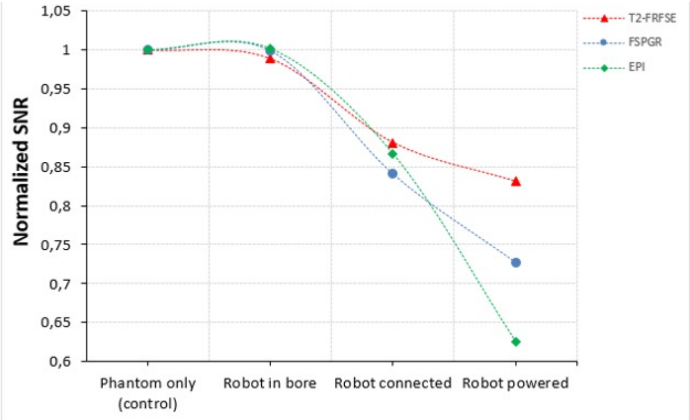

Figure 6: SNR for the three MR imaging protocols with the robotic system in different configurations.

ACCURACY OF THE ROBOTIC DEVICE

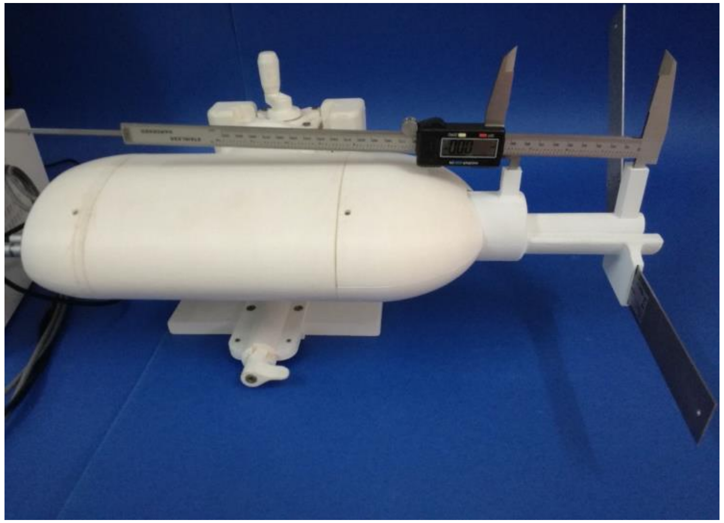

Figure 7: Experimental set-up used for accuracy measurements.

- Optical encoders were used to ensure linear X and angular Θ motion accuracy
- The motion accuracy of the robotic device was experimentally assessed using an ABS printed set-up and a digital caliper
- The set up was designed to offer caliper stability on the transducer holder
- Accuracy was measured as percentage error between the distance as set by the software and the distance measured by the caliper

- The error in forward and reverse motion in X was evaluated at different distance steps
- The error in the Θ axis was calculated in both clockwise (CW) and counter-clockwise directions (CCW)
- Speed of motion in each direction and axis was also measured
- Speed in reverse X direction was slightly larger that forward direction
- Larger errors were noted in larger distance steps in X plane
- Smaller errors were noted in larger angle increments in CW direction
- Speed of motion was approximately the same between CW and CCW direction in the angular axis

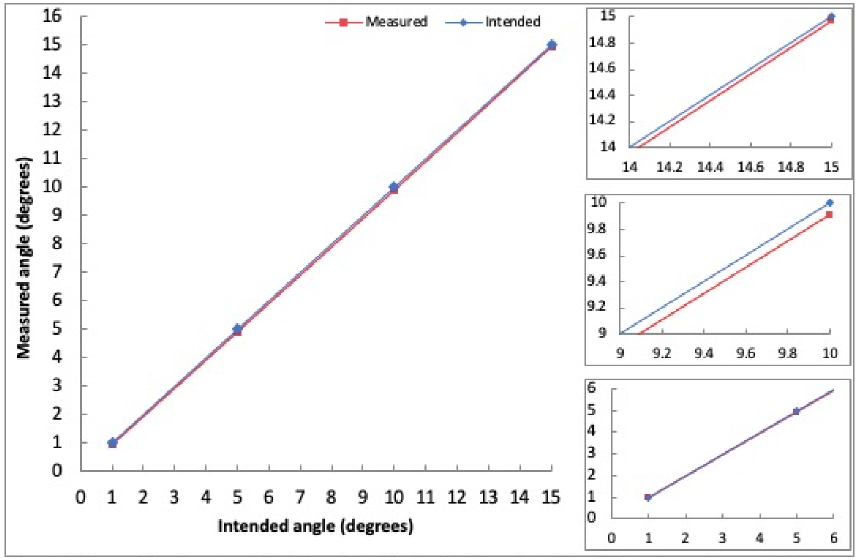

Figure 8: Measured angle versus intended angle for the Θ axis in CW direction (left) and zoomed areas of the graph (right).

THERMAL HEATING OF TRANSDUCER

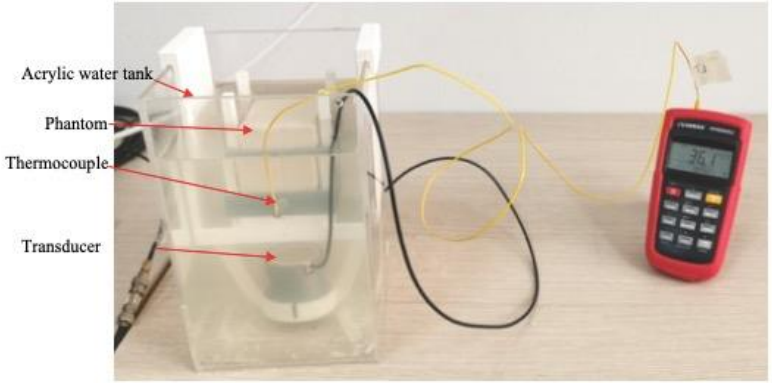

Figure 9: Experimental set-up used in laboratory setting.

- The ability of the transducer to cause high temperature increases was evaluated in laboratory and MRI setting
- An agar-based phantom with 6 % w/v agar and 30 % v/v evaporated milk was used
- The phantom was placed in a specially designed ABS holder and immersed in a water tank
- In the laboratory setting, a thermocouple was inserted within the phantom at the focal point to measure temperature increase

- Acoustical power of 10 W and 15 W were used for a sonication time of 10 s
- The acoustical power of 15 W caused a temperature change of 45.6 °C

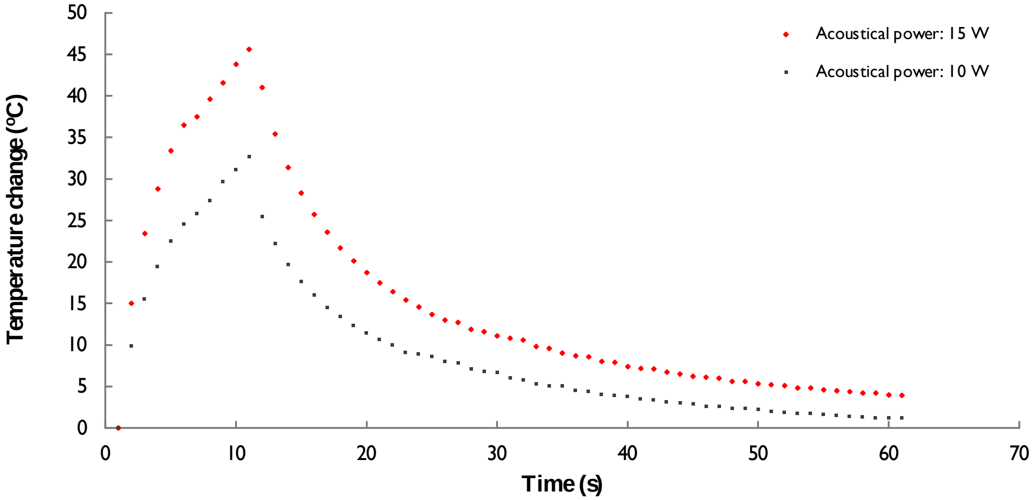

Figure 10: Temperature change at the focal point versus time for different acoustical powers and sonication time of 10 s.

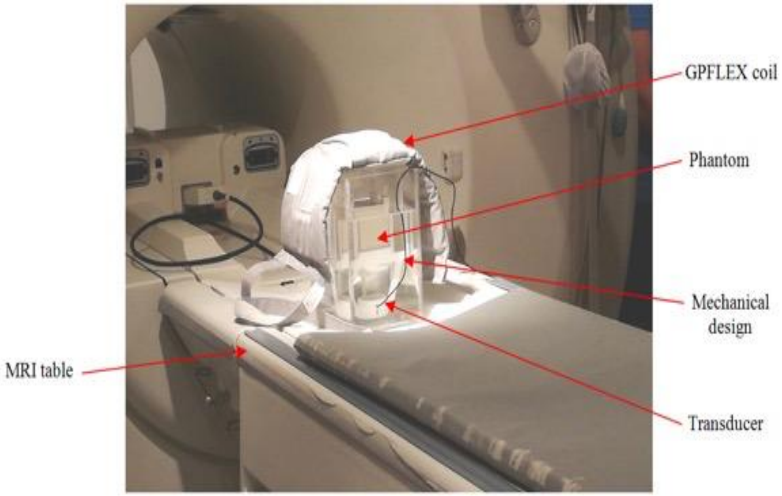

Figure 11: Experimental set-up in MRI environment.

- The set up was also placed in a 1.5 T MR system (Signa, GE,USA)
- MR thermometry maps were taken using the proton resonance frequency method
- FSPGR was used to produce the thermal maps

- An acoustical power of 14 W was used for a sonication time of 36 s
- Temperature change of 38 ^{o}C was recorded

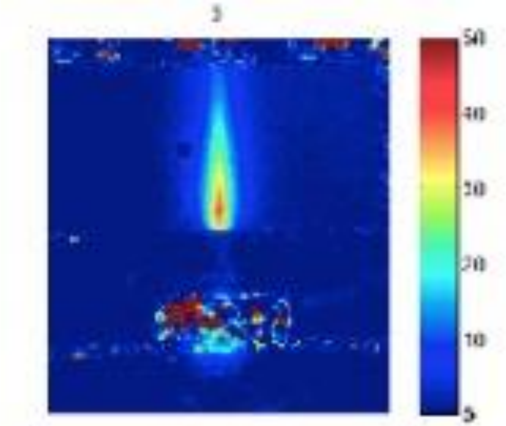

Figure 12: Thermal map recorded on axial plane.

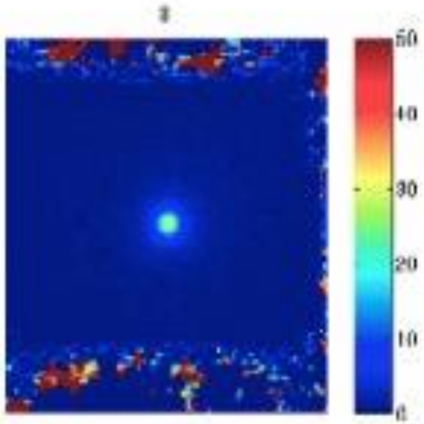

Figure 13: Thermal map recorded on coronal plane.

SUMMARY

- The positioning device is accurate and MR compatible
- Transducer is capable of producing high temperature increase at the focal point
- It can be used in any MRI up to 7 T
- Its simple design makes it portable and cost-effective
- It uses an endorectal approach to treatment
- After extensive use on animal models it can be used in clinical trials for prostate cancer treatment

ACKNOWLEDGEMENTS

The project has been funded by the Research Promotion Foundation of Cyprus under the name PROSTASONIC(ENTERPRISES/0918/0012)

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