CoBra robot for localized cancer treatment and diagnosis under real-time MRI guidance

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Introduction

We present the CoBra (Cooperative Brachytherapy) project 2018 - 2022. The CoBra purposes an integrated concept to perform localized cancer treatment and biopsy of soft-tissues under real-time (RT) MRI guidance [1]. The robot executes needle insertion within the MRI-scanner, performing adaptive prostate brachytherapy under RT-imaging. An active steerable-needle under closed-loop control is used to achieve precise positioning of the seeds with the increased reach of the needle to pubic arch and organs-at-risk occluded areas. Dose calculation under RT-MRI is achieved by the generation of synthetic-CT datasets based on a Machine-learning algorithm. Needle trajectory planning based on a steerable needle with minimal entry points is optimized by an algorithm depending upon the target, seed plan, and prostate contours attained from MRI. A bio-inspired active phantom (BIP) is designed for concept validation. The CoBra project is funded by the EU Interreg 2 Seas programme, led by the University of Lille partnering with multiple institutions and industrial observers.

Materials and Methods

The MR-conditional robot has been developed to perform in-bore prostate adaptive-BT and biopsy (BX) with the aid of a steerable needle targeting the lesion sites under RT-MRI. The steerable needle is able to reach pubic arch obstructed zones and a new target position when pre-defined target shifts during needle insertion, prostate motion, tissue deformation, or inflammation. Targets are planned based upon an initial dosimetry plan under RT-MRI, then tracked and updated in parallel using rapid creation of accurate synthetic-CT (sCT) datasets from the live MR images and are used to update the needle trajectory planning software NPS to deliver the seed with more accuracy using active steerable needle. Thus, the dosimetry plan integrated to NPS and robot helps to deliver dose to the new target position.
In order to attain an RT dosimetry plan using sCT datasets, the team use an augmented cycle Generative Adversarial Network (AugCGAN) algorithm [2]. AugCGAN is more robust with the erraticism of MR-images as compared to the standard cycleGAN. This study incorporated T2w MR and CT pelvic images of 38 patients from 5 centers. The AugCGAN was trained on 2D transverse slices of 19 patients from 3 different sites. The network was then used to generate sCT images of 19 patients coming from two other sites. Mean Absolute Errors (MAE) for each patient were evaluated between real and sCT.
The novel steerable needle has been manufactured and omnidirectional steering at the distal tip can be achieved by a jointless integrated pull-push mechanism. The degree and direction of needle steering are controlled by four piezoelectric motors at the proximal end of the robotic BT module as shown in Figure 1 (a). The inner needle and outer catheter with a 1.4 mm and 2.0 mm diameter, respectively. After needle placement, the inner needle can be retracted leaving behind a channel for seed delivery. Artifact formation of the needle and piezoelectric motors is evaluated in 3 T MRI.
CoBra's needle path planning algorithm is designed for steerable needles based on the seed plan and prostate contours received from MRI. It clusters the seeds and creates candidate path plans to reach all seed positions, using a single insertion point. Acceptable results are those that allow all seed positions to be reached, while keeping a minimum, pre-set distance between the needle and the urethra. From all candidates, the one that causes the least amount of tissue damage is chosen. For CoBra robot testing, the team developed a bio-inspired prostate phantom, depicting the motion, deformation, and inflammation of the prostate seen clinically during needle insertion. The active BIP is connected to SOFA (Simulation open framework architecture) to estimate the changes in the prostate, thus enabling tracking of target position interactively (Figure1 (b)).

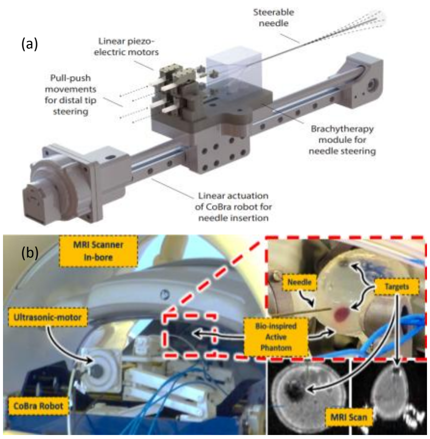

Figure 1: (a) Steerable needle module; (b) CoBra robot and active prostate phantom

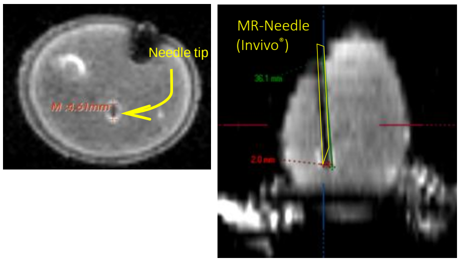

Figure 3: Needle insertion to bio-inspired active prostate phantom

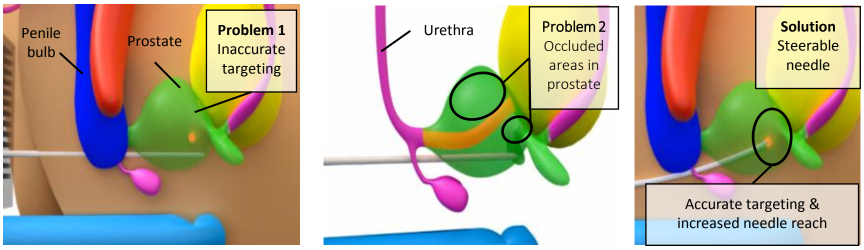

Figure 4 *:* Conventional straight needle vs. steerable needle concept for 1) accurate targeting & 2) increased needle reach

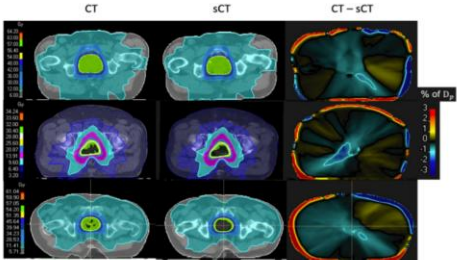

Figure 5: From left to right, Dose distribution from the same radiotherapy external plan computed on the CT, sCT and the dose difference related to the prescribed dose.

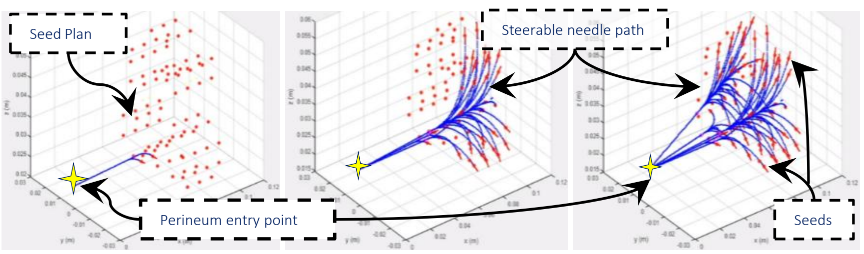

Figure 6: Seed plan using single perineum entry point using steerable needle.

Results

The CoBra robot was tested under a 3 T Philips MRI scanner at Lille Hospital.

- The absolute encoder and USM actuators resulted in normal functioning under 3 T field without influencing the MR-images during the scan.
- Developed software for needle path planning with single entry point, Figure 6.
- Robotized needle insertion in BIP under RT-MRI resulting features with good fidelity and the needle tip identified under T1w, T2w, and DYN-B FEE sequences, Fig 3.
- sCT datasets showed a mean MAE of 59.8 HU and 65.8 HU for first and second test sites, taking on average 8.5 s to generate a complete sCT (90 slices) on our GPU (Nvidia Quadro P6000), Fig 5.

Conclusion

This poster presents the recent progress attained from the CoBra project, as it reaches the phantom testing stage.

- BIP developed to mimic the actual condition of prostate intervention, with sensory feedback dynamic in nature, and resulting rotation and twist motion.
- The CoBra concept contributes towards adaptive treatment and diagnosis, which consists of adapting the control of the robot for precise deposition of seed with a minimal perineum entry points and reducing the tissue damage.
- The steerable needle concept helps further to reach the targets which are inaccessible to conventional prostate brachytherapy treatment with straight needles in a grid.
- The CoBra concept, a multi-system model, integrates the robotic sub-systems using MRI-guidance in closed-loop feedback to implement an adaptive MR-robot control, for the treatment of localized cancers.

References

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