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MRI-Guided Robotic Prostate Biopsy and Brachytherapy: Update from the EU-funded CoBra Project



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Purpose/Objective

The Interreg 2 Seas (EU)-funded CoBra research initiative is a five year project to develop a novel device for MR-guided robotic biopsy and brachytherapy for prostate cancer. We report on research achievements at two years into the work. We present details from several of the work packages: 1) MRI-safe I-125 seed delivery module, based on Piezoelectric motors, and evaluation of MR seed artefact in the closed loop control of the MR-guided robot; 2) MRI-safe pneumatic biopsy system; 3) novel steerable needles developed to improve access to all parts of the prostate; 4) prototype trajectory planning for ideal needle paths from an optimal number of insertion points; and 5) phantoms designed to test MR image quality in the presence of needles and seeds.

Method

For the work streams detailed in this report the lead developers are 1) the University of Lille, 2) Demcon, 3) TUDelft, 4) University of Portsmouth, and 5) Portsmouth Hospital University Trust. Project milestones and progress are reviewed bi-weekly via web conference and every six months at a steering meeting, led by the University of Lille.

Results



CoBra Robot

The CoBra robot is actuated with MR compatible motors. It's placed at the entrance to the bore, targeting the prostate at isocentre. The seed delivery module placed next to the robot uses Iodine-125 seeds.

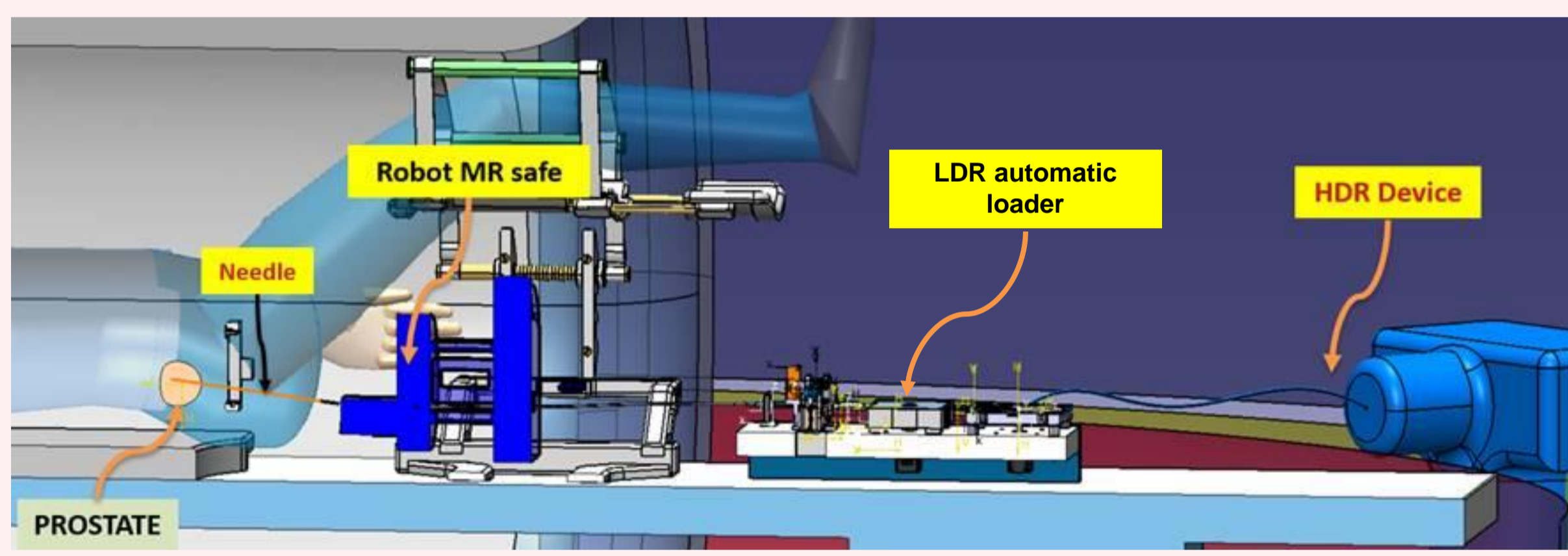


Figure 1. Section view of CoBra concept with MRI

- MRI seed distortion tests showed no change in artifact size with (1) no motors active (2) a single motor active (3) both motors active.
- Seeds showed 11 – 12 mm length in imaging (actual length 4.5 mm) & 3.1 to 4.3 mm diameter (actual diameter 0.8 mm)
- The artefacts were significant (with or without the motors present), demonstrating the need to develop an algorithm that can detect seed positions accurately for clinical use (< 1 mm vector displacement from combination of uncertainty in 3D between planned and delivered position).

Quality Assurance Phantom



- Phantom was used to confirm geometric accuracy to which needle tips and seeds can be located in MR images.
- Relaxation time has been measured for a potential PTMM (prostate tissue mimicking material) consisting of Agar, Carrageenan, GdCl₃ and water.
- Phantom construction:
 - PMMA 3D grid (3 x 3 x 3, 15 mm cubes) filled with PTMM, with 3D printed needle guide for precise placement of needle tip.
 - 8 x 5 mm deep PTMM discs (60 mm diameter) with preconfigured loose seeds on each layer in clinically relevant arrangements.
 - Grid and seed stack contained in Perspex cylinder filled with oil.

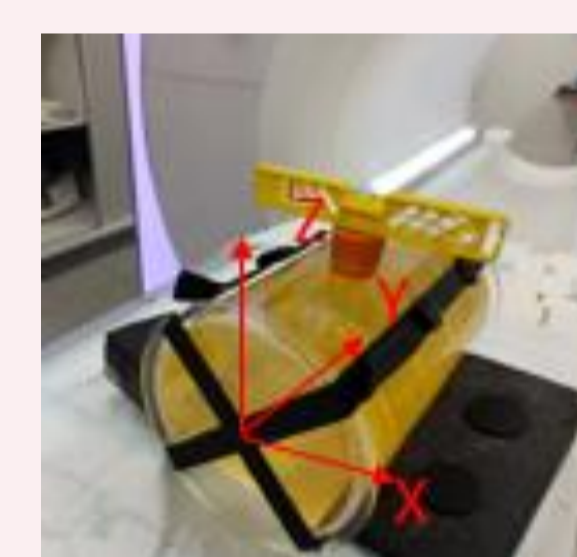


Figure 2. QA phantom filled with oil in MR scanner



Figure 3. QA internal grid with needle guide (50x50x50mm).



Figure 4. Seed configurations

- Metal artefact corrected MRI sequence gives best agreement in seed position detected in MRI compared to known position
- Up to 3 mm discrepancy, in the x-y plane was seen between measured and actual locations when seeds are clustered.
- Seeds at boundary of prostate/surrounding tissue are difficult to detect



Trajectory Planning Software

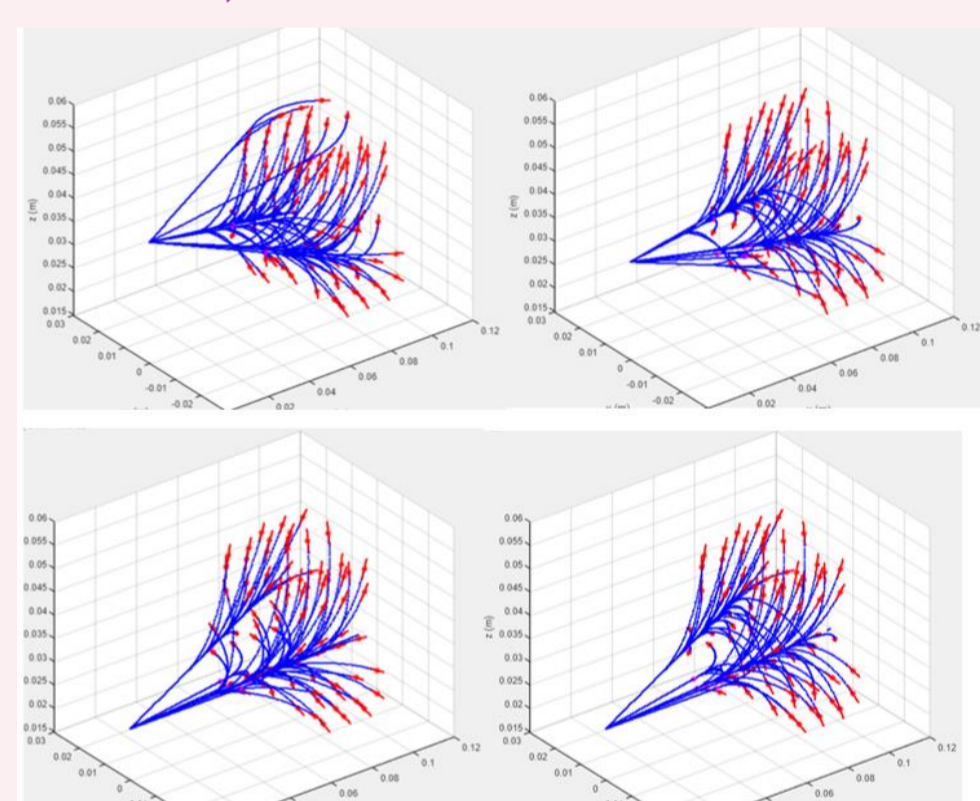


Figure 5. Example image of trajectory outcomes from CoBra software (seeds in red, needle paths in blue).

- The trajectory planning algorithm receives the seed distribution plan as input
- The algorithm generates a number of trajectory candidates
- The trajectory that causes the least tissue damage is chosen
- Tissue damage is quantified as the total volume of the holes made by the needle
- Future variations could take into account the angle of contact between the needle and the prostate capsule, to improve accuracy

Active Steerable Needle Design



Active steering during the procedure (3 DOF's) possible by pull/push mechanism (4 x piezo-electric motors).

- Steer around critical organs and anatomical obstructions.
- Correct for positioning errors caused by deflection.
- Needle curvature follows orientation of the tip
- Steerable inner needle (tungsten)
- Compliant outer catheter (polyamide)
- Lateral needle steering: 0 – 10 mm over 100 mm length
- Outer diameter: ± 1.7 mm
- Suitable for both stranded and loose seeds

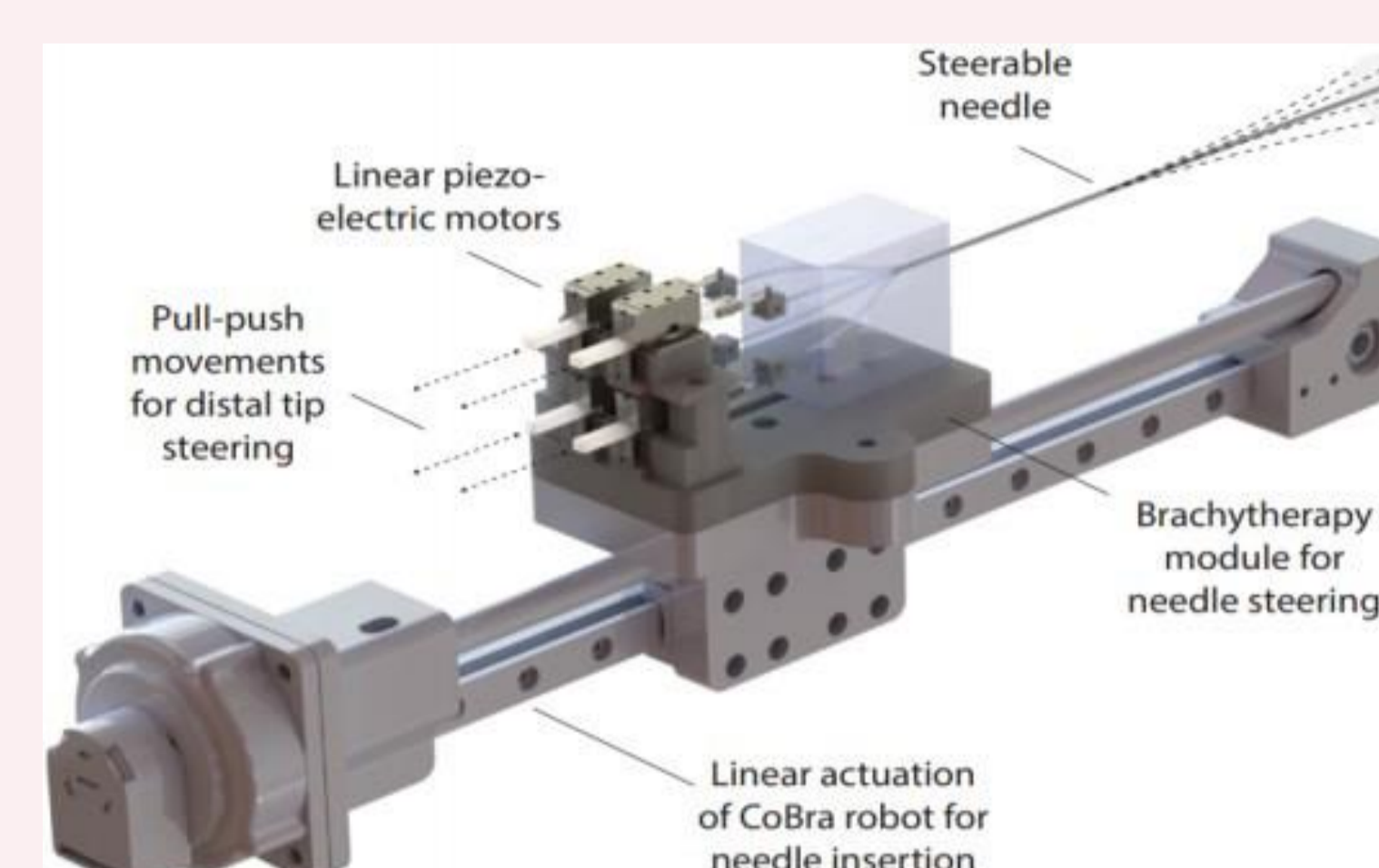


Figure 6. Steerable needle module.



Robotic Biopsy Module

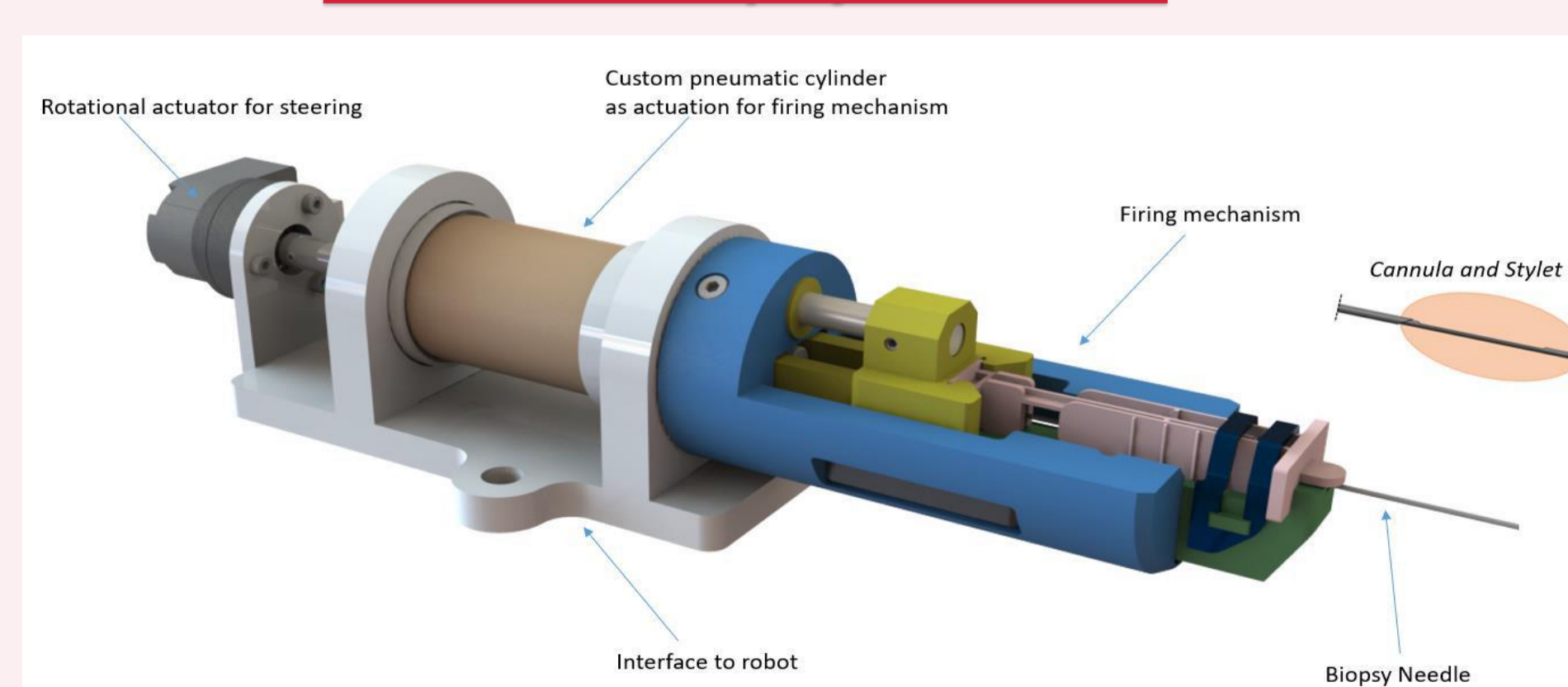


Figure 7. Image of robotic biopsy module design.

A novel technique has been developed for the robotic biopsy module, alongside a unique methodology to automatically remove prostate core from the needle.

Conclusions

At this three year point in the programme, we present key outcomes and deliverables, on the MRI-guided robotic brachytherapy and biopsy system, prototype parts and software that have been developed and initial test results. The CoBra project is generating new knowledge of benefit to brachytherapy and biopsy, with broader applications in the medical field.

