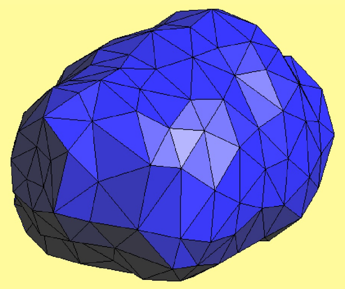

3D Needle-Tissue Interaction Simulation for Prostate Brachytherapy

Orcun Goksel, S.E. Salcudean, Robert Rohling

Robotics and Control Laboratory
University of British Columbia
Vancouver, BC, Canada

Introduction

- The *Prostate* is a stiff egg-sized gland surrounded by relatively softer tissue (see Fig. 1).
- *Prostate cancer* is the most common cancer among men in Canada, with 20,100 new cases and more than 4,200 deaths estimated in 2004.
- *Brachytherapy* is often the treatment of choice for early stage locally confined prostate cancer. It is the permanent implantation of radioactive pellets (seeds). See Fig. 2.

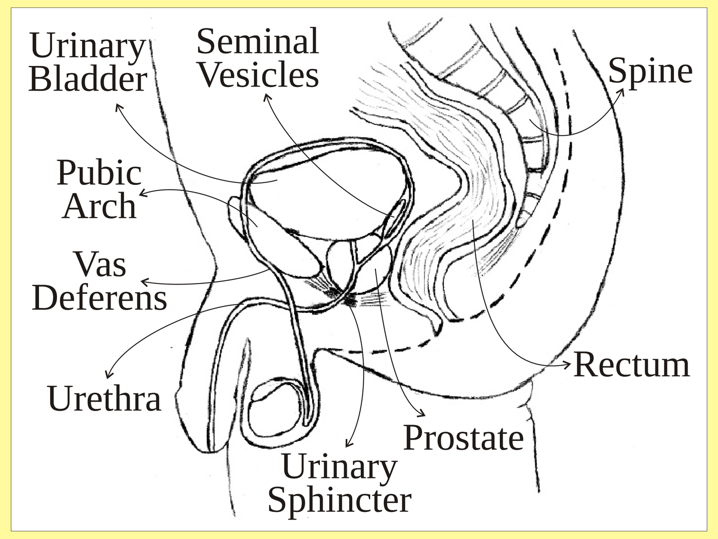

Fig.1: Prostate anatomy

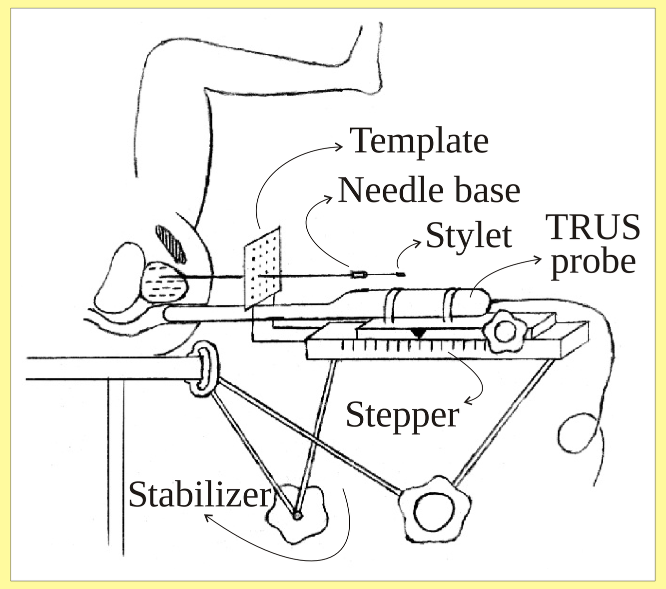

Fig.2: Brachytherapy procedure

Procedure

- 80 to 150 seeds are implanted using 20 to 25 needles according to a preplan.
- Needles are 20 cm long and quite flexible with a bevelled tip.
- A template grid is used as an insertion guide.
- Transrectal ultrasound (TRUS) and fluoroscopy give visual needle position feedback.

Challenges:

- limited visual feedback
- limited time to minimize side-effects,
- Tissue deforms (see Fig. 3) during needle insertion and this has to be accounted for,
- On-the-fly preplan modifications may increase the effectiveness of the treatment,
- Needles need to be steered.

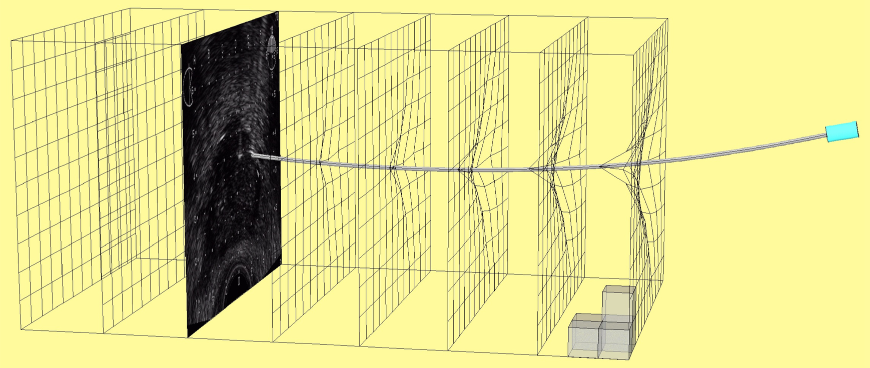

Fig.3: Illustration of the tissue deformation with a needle inserted.

A prostate brachytherapy simulator is proposed to facilitate training of residents. It is based on an earlier 2D needle insertion simulation using the finite element method (FEM) [1].

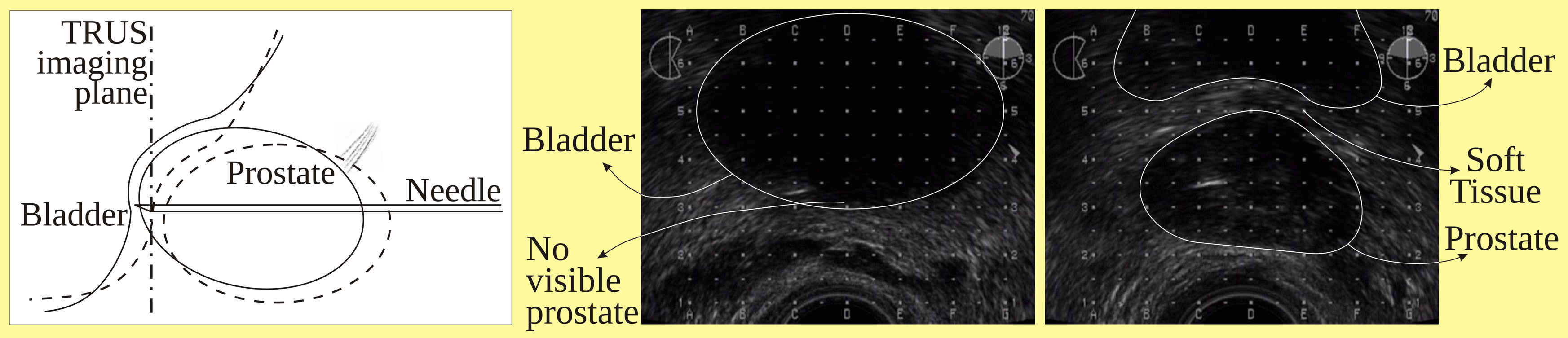

Fig.4: Prostate torquing due to its bond to the pubic arch [left] and the TRUS images of the same depth before [center] and after [right] the needle insertion.

Goal: To develop a simulator that correctly predicts the needle trajectory using a physical model while displaying realistically synthesized TRUS images to the user and rendering needle base force feedback on the user's hand at > 200 Hz..

Methods

- A 3D tissue mesh with high-quality elements and few number of nodes is required by the FEM.
- This mesh is coupled with a flexible needle model.
- The coupled system runs fast enough for realistic kinesthetic feedback while preserving the mesh integrity.
- TRUS images are synthesized to mimic visual feedback.

Mesh Generation

First, nonessential nodes (too close to their neighbours) are removed from the clinical segmentation and then a *conforming* prostate mesh is generated using advancing fronts (see Fig. 5). The entire mesh consists of 570 nodes and 2801 tetrahedra.

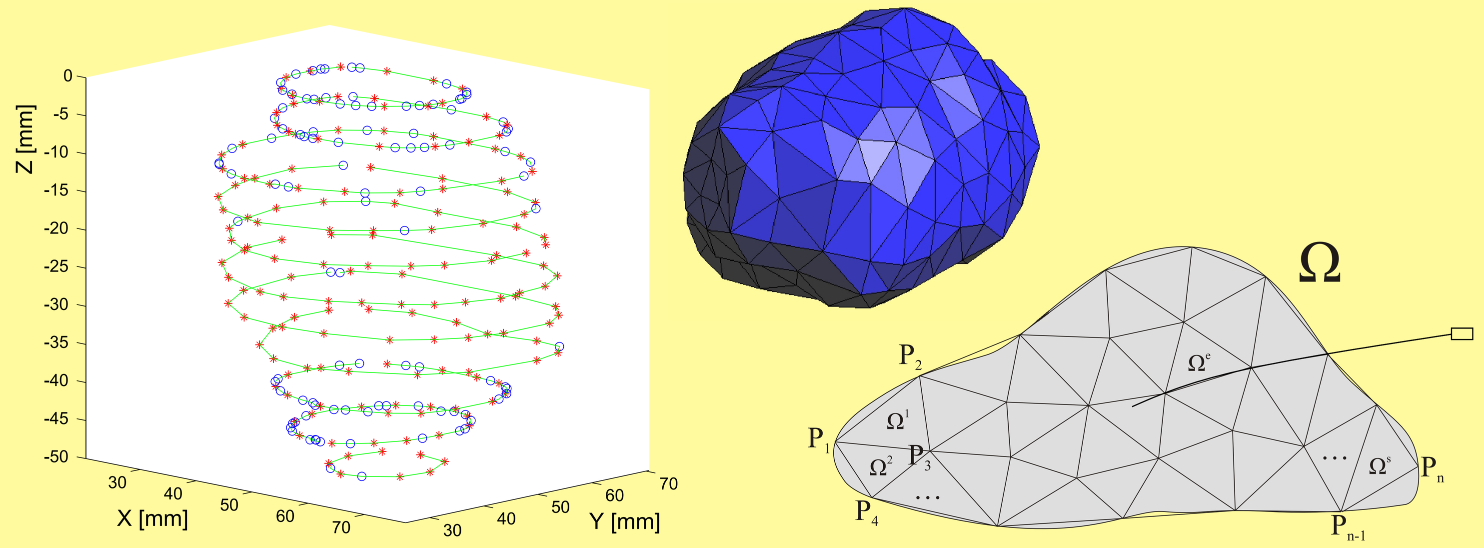

Fig.5: Prostate segmentation (blue marks the nodes removed) [left]; the surface of the generated prostate mesh [top]; and a 2D sketch of the needle-tissue coupling [right].

Needle-Tissue Coupling

A quadratic needle model is coupled with a linear quasi-static tissue FEM model at the *contact nodes* as in Fig. 5(right). The methods in [1] are extended to 3D with a flexible needle. Tissue remeshing (see Fig. 6) is needed when the tip penetrates a new element. This is also a computationally demanding step. Two possible remeshing approaches are shown in Fig. 7(c &d).

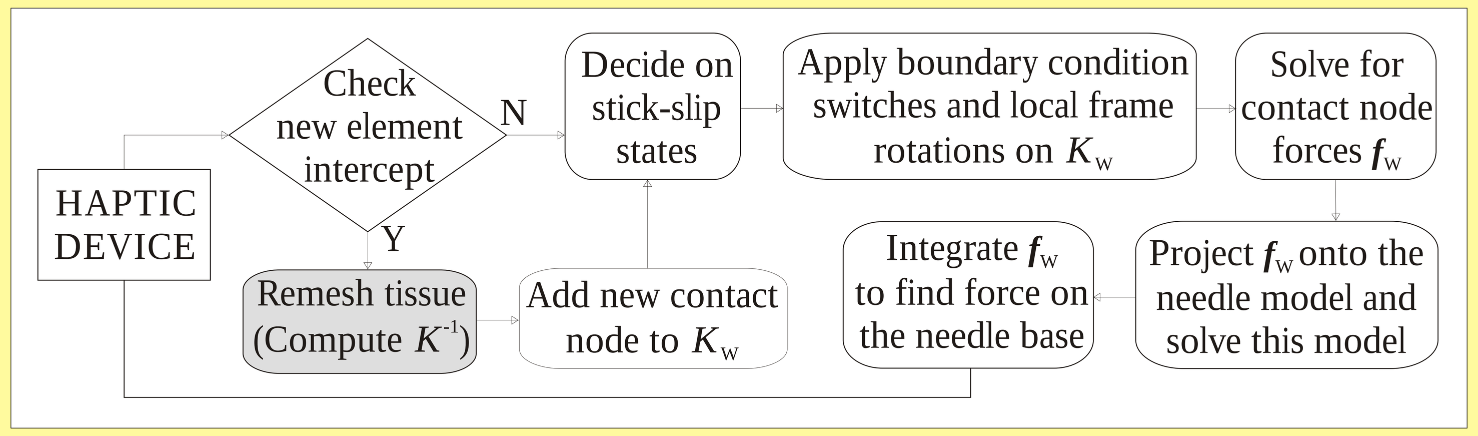

Fig.6: Flowchart of an iteration of the needle-tissue interaction simulation.

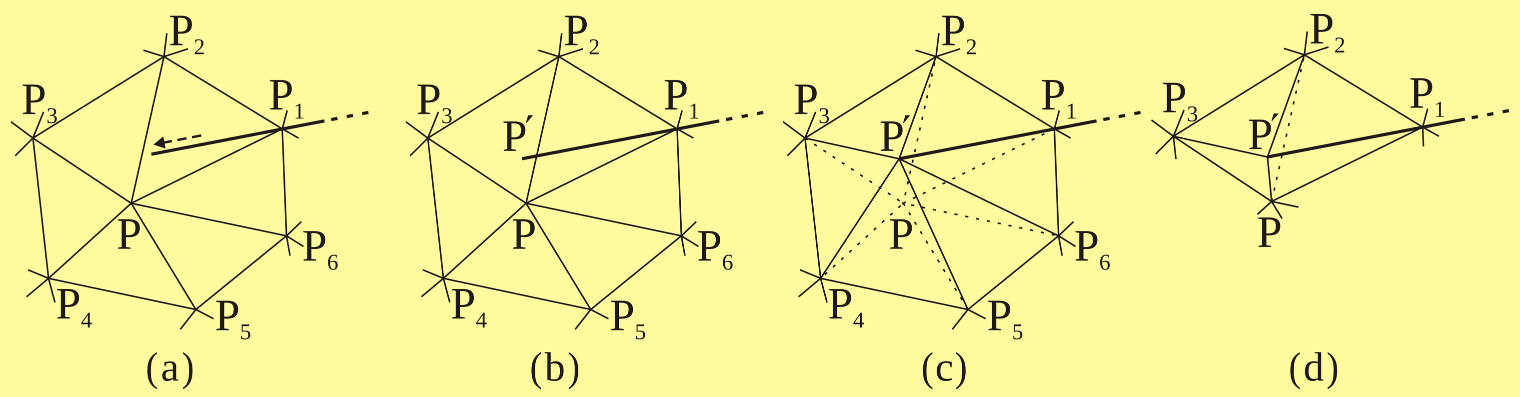

Fig.7: The simulation step (a) before and (b) after a new element penetration; and (c) node repositioning and (d) addition for preserving mesh conformity.

Results

- ✓ Slices from the running simulation are shown in Fig. 8.
- ✓ All haptic iterations, including remeshing cycles, are finished in < 1 ms.
- ✓ The force feedback on the needle base is computed as in Fig. 9.
- ✓ Ultrasound slices (see Fig. 10) are interpolated in the deformed volume using FEM basis functions and initial data from a TRUS volume study.

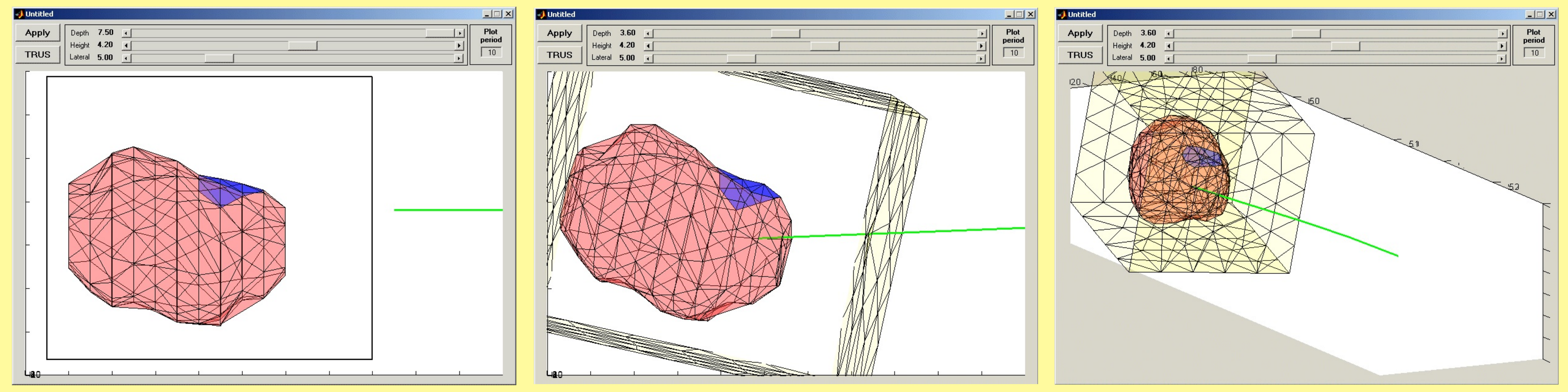

Fig.8: Three screen-shots of the simulation

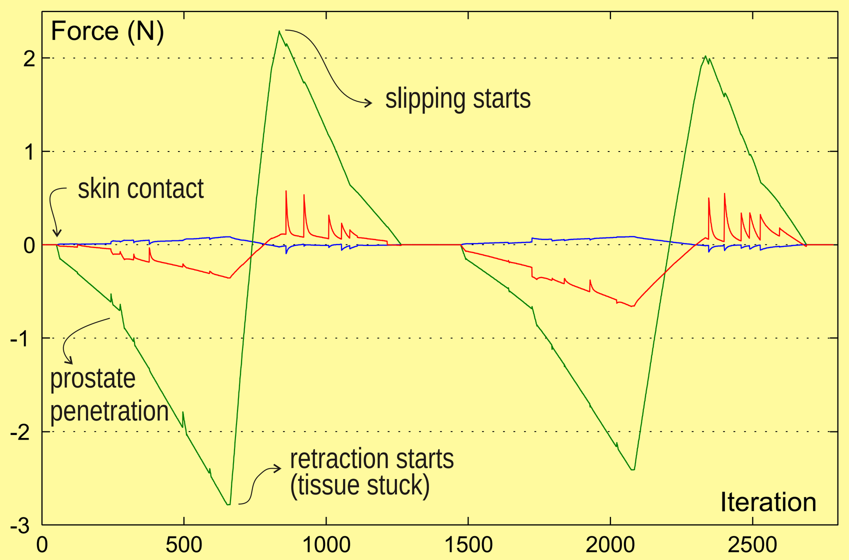

Fig.9: Force feedback on the needle base during two insertion-retractions. green, red, and blue denote axial, sagittal, and lateral axes, respectively.

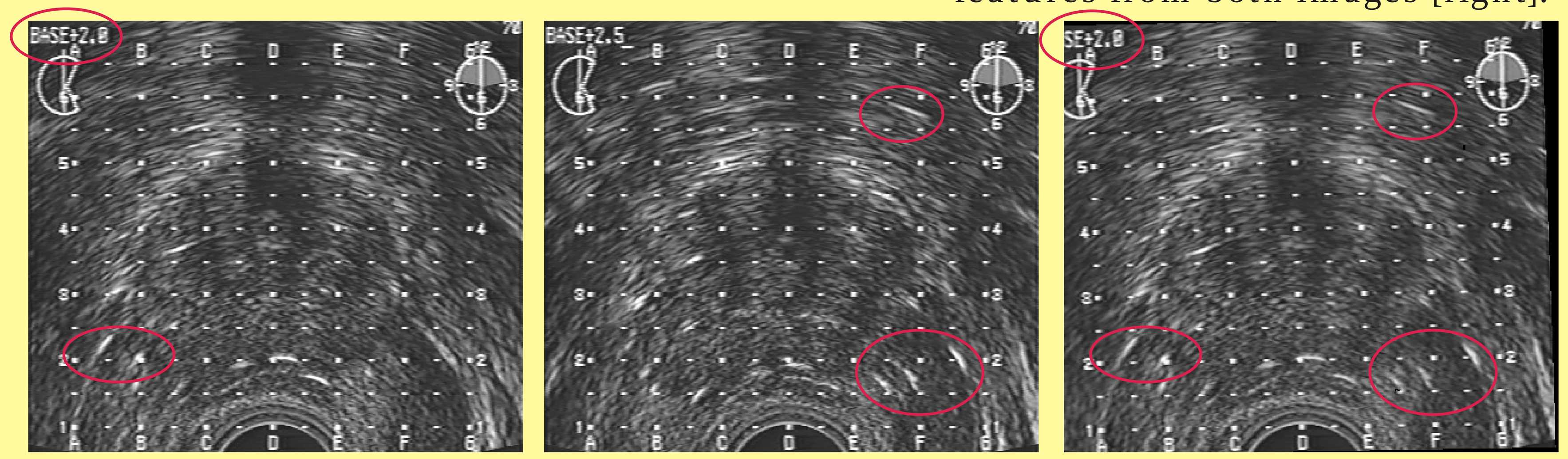

Fig.10: Two consecutive TRUS slices [left and center]. A synthesized reslice between these two slices after deformation shows features from both images [right].

Conclusions

We present the first physically-based 3D interaction model for flexible needle insertion into a soft deformable body. This is the first physically-based 3D simulation of prostate brachytherapy procedure. The TRUS synthesis is also the first medical image generation from a deformed volume based on FEM.

Future Work

- Incorporate pubic arch and bladder into the mesh and perform validation.
- Achieve real-time (12Hz) TRUS synthesis.
- Implement the complete haptic simulator design shown in Fig. 11.
- An online brachytherapy planner can be developed based on the simulation presented with tissue parameters acquired in-vivo using elastography.

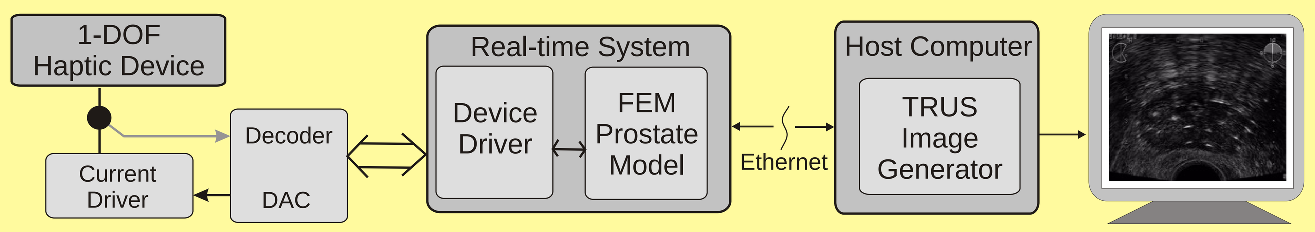

Fig.11: Design of the haptic brachytherapy training simulator to be developed.

References

[1] S.P. DiMaio and S.E. Salcudean, "Needle Insertion Modelling and Simulation," *IEEE Trans. Robot. Automat.*, vol 19, pp 864-875, 2003.