Ultrasound Image-guided Robotic Brachytherapy Systems for Prostate Seed Implant

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In image-guided brachytherapy (IGBT), accurate percutaneous intervention of needle and precise placement radiation sources are challenge tasks. In traditional prostate brachytherapy, needles are introduced through fixed, parallel holes of a template where the maneuverability of the needle is extremely limited. The accuracy and consistency of needle placement and seed delivery is subject to variation with procedure-specific and patient-specific factors as well as clinician techniques.

Here, we present two robotic platforms for IGBT: (1) a fully automated single robotic system (Fig. 1), and (2) a semi-automated multichannel robotic system (Fig. 2) designed and fabricated for performing prostate brachytherapy with radioactive seeds. Both the IGBT systems consist of two main modules: (a) a 9 DOF positioning module, and (b) a 7 DOF (5 DOF needling and 2 DOF TRUS) surgery module. The positioning module has a 3 DOF cart and a 6 DOF platform. All motions of the surgery module and the vertical lift of the platform are motorized. The needle progression and see delivery are monitored through continuous ultrasound imaging. The single channel robotic system uses one needle as opposed to multiple needles in multichannel system. Seeds are delivered into the prostate through a single channel in both the systems.

These two systems incorporated numerous important data and methods garnered from *in-vivo* measurements during actual brachytherapy procedures. Various techniques to enhance precision of needle insertion and seed delivery have been implemented into the system, after extensive verification via phantom experiments. Three force-torque sensors were incorporated for tracking the forces on the needle to detect pubic arch interference and to improve robot control. Rigidity and factor of safety of the mechanical structures have been analyzed using finite element method. The system has provisions for the feedback of various states (position, velocity and force), which will be useful to improve needle insertion and seed delivery accuracy, consistency and efficiency. The integrated interactive software is capable of dosimetric planning, 3D visualization, needle tracking and seed detection for dynamic planning. Preliminary seed implant experiments using tissue mimicking soft material phantoms prepared from polyvinylchloride have been performed.

Assessment of the deposited seeds for single channel system revealed that the accuracy of seed placement is quite high, for instance, the 3D (Euclidean) rms error is about 0.23mm, which is small as compared to clinically acceptable limit. Thus, it appears that this robotic system can potentially improve seed placement accuracy while will be assisting clinicians.
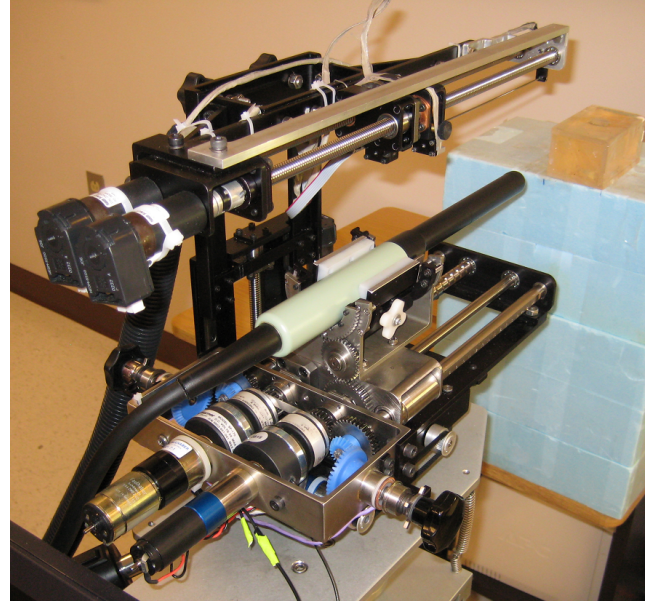
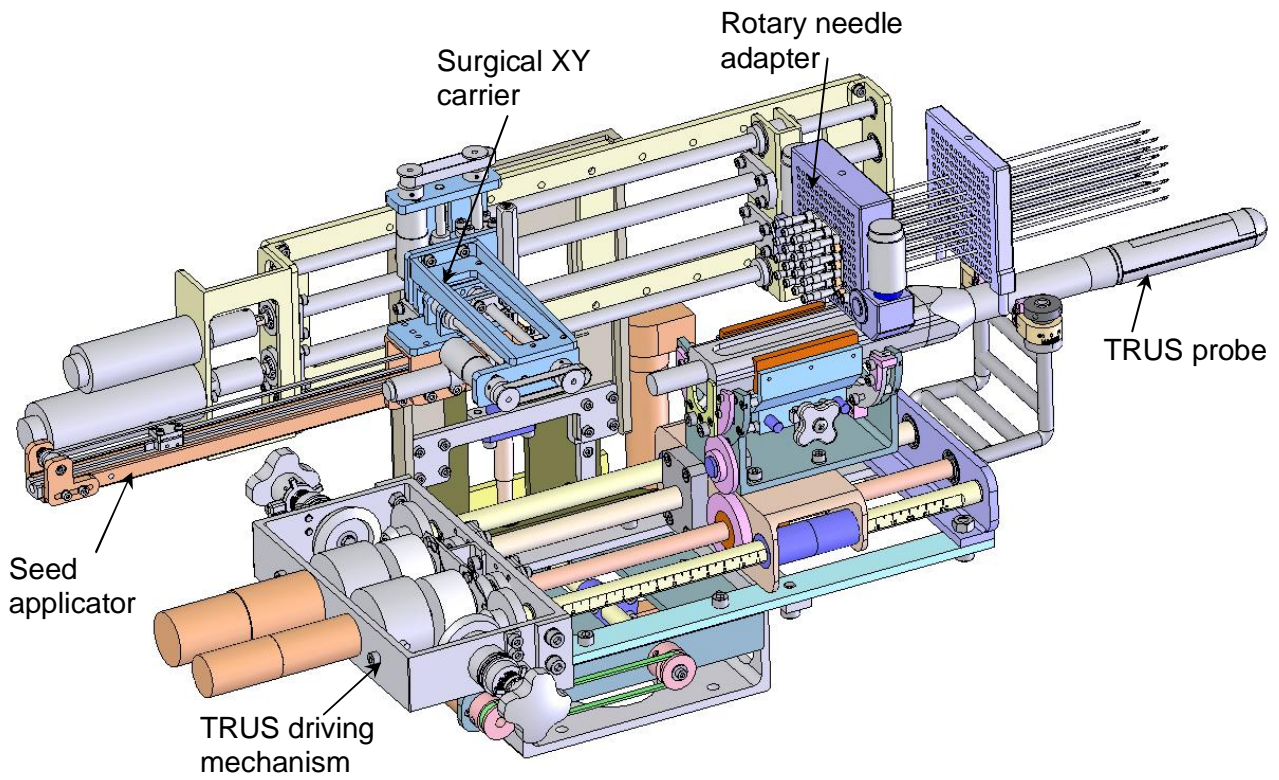Fig. 1. Single channel image-guided robotic brachytherapy system.

Fig. 2. Multi-channel image-guided robotic brachytherapy system.