Development of a Modular MR-Compatible Robot System

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Introduction: Since the original pioneering studies of Lufkin (1) and Schnall (2), there has been interest in the possibilities of image guided biopsy. The space available in a typical modern imager means that it is very difficult for a clinician to gain access to a patient in the manner that is needed, and a robot-based solution has seemed attractive (3). Even then, the space that is left in which to perform a procedure such as prostate biopsy is very restricted. We describe here the development of a modular approach to the problems of MR-compatible robots, comprised of actuated individual axes, that can be interconnected to produce multi-axis devices. Prime requirements are that the units be small, and that they shall be capable of operating in the imager main field without degrading system performance to a significant degree. The original target of the device described here was prostate biopsy, and most of the constraints surrounding the design of the system were developed from that requirement.

Module Development: The form of an individual single axis module is shown in figures 1 and 2, and comprises two piezo-electric motors and an optical encoder for position feedback and closed loop control. The base unit which contains the motors moves the slider unit producing linear translation at the highest speed of 2.7mm/s, a maximum force of approximately 17N and a positional accuracy of better than 0.2mm. The structure is made of ABS (although other MR compatible materials can be used), and all the electronics and motion control hardware are placed inside a Faraday cage just outside the scanner bore. With filtering of all electrical lines to the servo equipment from its control box, it was demonstrated both to be MR-compatible as far as the B_0 field is concerned but also to introduce no more than a 19% reduction in SNR if the servo is operated during image acquisition.

Module Assembly: For prostate biopsy it is sufficient to use three axes of control, and the modules can be stacked as is shown in figure 3 and 4, to form a three axis Cartesian structure. The robot positions an endorectal probe and biopsy needle into a target in the prostate. A needle positioning and firing mechanism is attached to the probe for performance of the biopsy. The needle is fired via a small cylinder-piston assembly which is manually actuated by the practitioner through a hydraulic transmission.

System Implementation: Initial trials of the system were performed on a 1.5T Siemens Vision. Figure 5 shows a photograph of the three-axis system in the bore of the machine. The positional data from the robot can be fed back to the machine operator to allow slice orientation and position to be adjusted, and the clinician can be presented with an overlaid image showing the path of the needle as currently measured. Imaging is via an internal coil (of a type described previously (4)), which is inserted into the anus of the patient at the start of the procedure, and which includes a needle guide in its structure. It also includes three fiducial markers to help with aligning images and needle.

Results: Preliminary tests have shown the compatibility of the robot system and the MRI scanner. Thus far only phantom studies have been performed (with the target being a grapefruit). In Figure 6 an MR image is shown with the biopsy needle reaching a target pip in the grapefruit. System accuracy in vivo has not been established, but phantom studies have indicated that a small target can be easily reached quite swiftly.

Figure 1

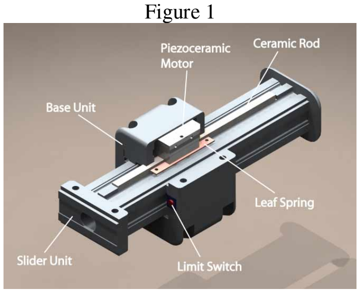


Figure 2

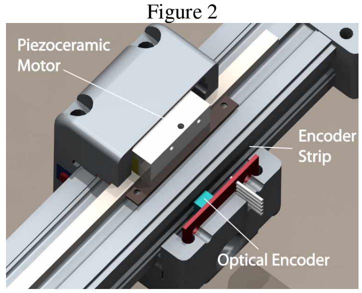


Figure 3

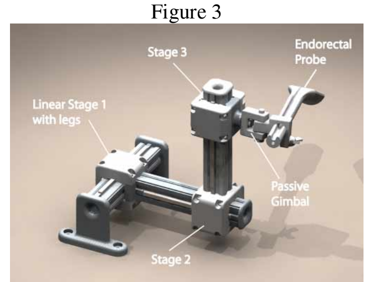


Figure 4

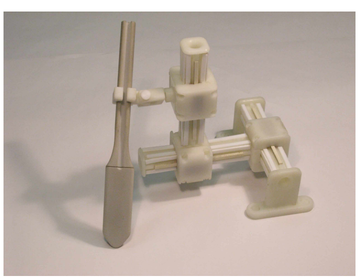


Figure 5

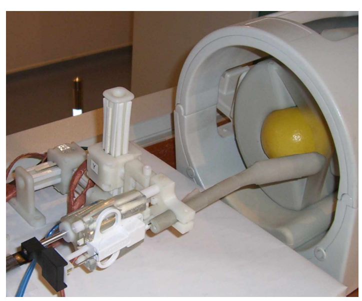
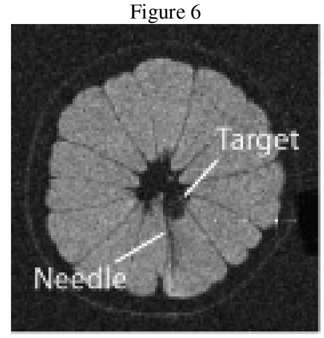


Figure 6



Discussion: The system is now being readied for clinical studies, which it hoped will begin in the next very short period of time. The robot system can readily be re-configured for a variety of other robot-based activities in an MRI scanner.

References:

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5.

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