Haptic Device for MR-guided Transrectal Prostate Biopsy

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Introduction: Prostate cancer is the most common form of cancer in men and is second only to lung cancer in terms of mortality rates in the UK. Prostate biopsy would be recommended if the results of either the Prostate Specific Antigen test (PSA) or the Digital Rectal Examination (DRE) are positive in order to confirm whether the suspicious tissue is cancerous and what the current stage is. However, the limited image resolution of ultrasound results in diagnostic inaccuracies and a number of biopsies have to be repeated on the patient in different areas of the prostate in order that cancerous tissue, if any, is more likely to be hit. Compared with ultrasound scanning, MRI scans present a superior image quality with no radiation exposure on patient bodies and no contrast agents required. A compact mechatronic manipulator for transrectal prostate biopsy in MRI is presented, with procedure similar to traditional TRUS biopsy (patient in left lateral decubitis position) shown in Figure 1(a), in which a clinician controls the system with the touch screen, showing the real-time prostate image. The system includes force feedback (haptics) in a needle insertion axis and real-time 3D fiducial tracking to adjust the orientation and position of the needle tip.

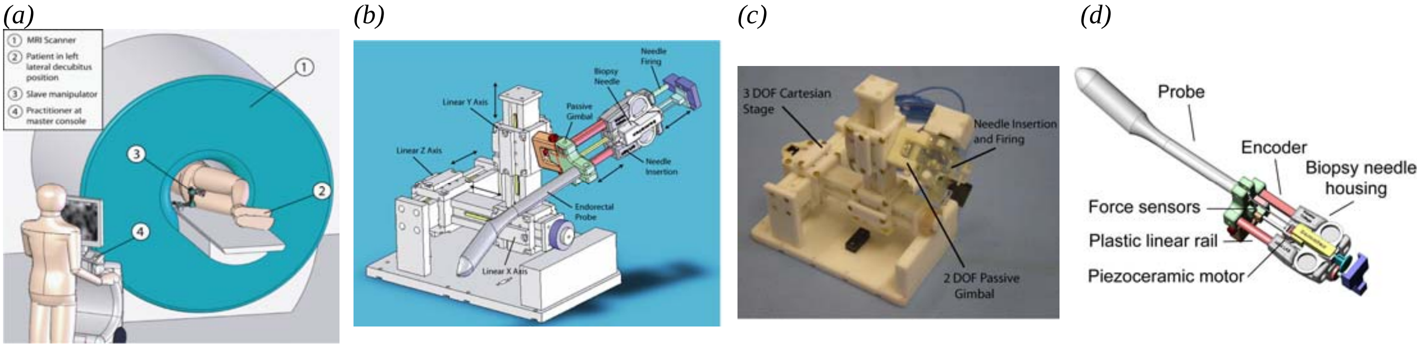

Fig. 1: (a) A MR guided transrectal biopsy is preformed with the system controlled by a touch screen (b) CAD rendering of the full mechatronic system (c) the system with the endorectal probe removed (d) CAD rendering of the needle insertion and firing mechanism.

Table 1: Specifications of the system

	Needle Axis	X,Y & Z Axes
- Range	90 mm	100mm
- System Resolution	85 μm	85 μm
- Max. Holding Force	7.3 N	17N

Fiducial Tracking

-Accuracy	0.2 mm
-Update Time	2.4 s
-Time for Needle Alignment to the Target Tissue	Less then 2 min

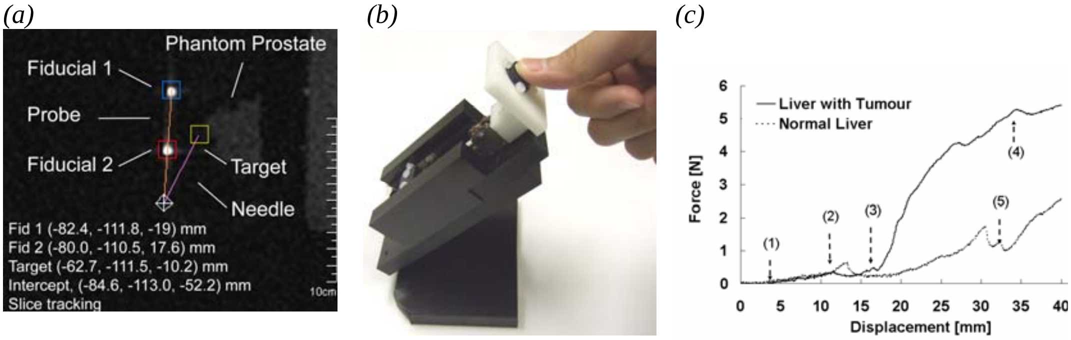

Fig. 2: (a) MR image of two passive fiducial markers with image processing algorithm for real-time tracking (b) haptic master interface for needle insertion (c) Stiffness measurement of a lamb liver with a phantom tumour versus a normal liver. Stage (1) needle in contact with the surface of the liver, (2) liver is punctured, (3) tumour is hit, (4) needle piercing through tumour, and (5) puncture of the internal structure of the liver.

A 5-DOF mechatronic system coupled with a haptic needle axis: Figures 1(b) and (c) show a MR compatible Cartesian robot with three active linear modules in X, Y and Z axes, coupled with a haptic needle insertion axis (Figure 1(d)) via a two DOF passive gimbal. Each linear module consists of two piezoceramic motors and an optical encoder for actuation and position control [1]. The haptic needle axis as shown in Figure 1(d) contains (i) an endorectal probe with an imaging coil and two passive fiducial markers for 3D tracking (tracking image is shown in Figure 2(a)) [2]; (ii) a pair of piezoresisitive force sensors for bi-directional force measurement; (iii) piezoceramic motor and optical sensor for position control. The MR compatibility of the components used and the fiducial tracking algorithm has been previously published in [1,2]. A fiducial tracking algorithm has been integrated into the system and programmed in the scanner software for real-time tracking of the biopsy needle, probe and slice orientation with accuracy of 0.2mm [2]. This information can be verified by the position data from the encoders in the system. Sense of touch is reconstructed in the master interface shown in Figure 2(b) which allows real-time telepalpation during biopsy. The force profile, when the needle punctures a rectum and a targeted tissue in the prostate, can be captured, providing extra information to verify if the needle hits the target and to characterize the tumour with its stiffness.

Detection of a tumour in soft tissue: A phantom tumour (made of plasticine) with a stiffness 10 times greater than a lamb liver tissue was implanted inside. Force profiles were generated, where a 17-gauge biopsy needle was driven by the system to penetrate the liver, with the sense of touch reconstructed in the master system. A force vs. displacement graph is shown in Fig. 2(c) and compared with that for a control experiment of liver needle insertion without the phantom tumour. The graph shows that for the case of the tumour present, puncture of the liver starts at a displacement of 12 mm while the target is hit at around 17 mm, as can be observed by the increase in stiffness. For the normal liver, fluctuation was detected in the force profile from 30 mm to 36 mm where internal structures of a hepatic artery and a portal vein were pierced.

Conclusion: The MR-guided mechatronic system has been described coupled with fiducial tracking, touchscreen control, and haptic control interface for transrectal prostate biopsy. The haptic functionality has been demonstrated in the experiment to detect the force profile of piercing a phantom tumour, compared with that of a healthy lamb liver tissue. Haptic feedback provides extra information besides visual information from MRI images for verification of the movement of the biopsy needle and characterization of the suspected tissue. Full clinical trials will be carried out in the coming year.

References:

1. H. Elhawary et al., "A modular approach to MRI compatible Robotics: Using Robotic Modules with Interconnectable 1- DOF stages," *IEEE Engineering and Medicine in biology magazine,* 27(3), 2008.
2. M. Rea et al., "A system for 3D real-time tracking of MRI-compatible devices by image processing," *ASME/IEEE Transactions on Mechatronics,* 13(3), 2008, *in press*.