An MR Compatible Tactile Sensor Array for Palpation-Based Diagnosis and Noise Analysis in MR environment

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Introduction: The separation between surgeons and imaged tissue during scanning imposed by the spatial constraints of the MR scanner means that the practitioner loses a large amount of information, particularly visual and tactile which are both vitally essential for surgery. While the images coming from the scanner substitute direct vision of the target area and give information about tool location inside the body, force feedback is also desirable. Palpation provides important information for surgeons to characterize a tissue and determine if a suspected tissue is a benign or malignant tumour. An MR compatible tactile sensor array has been developed with the use of piezoelectric materials to assist surgeons to achieve a quantitative stiffness of a target tissue. Due to the very tiny amount of voltage signal generated by the materials, the fast switching RF pulses, magnetic gradients and strong main field have imposed challenges on signal acquisition and noise filtering. Hence noise analysis has been performed in the MR environment. A proposed data transmission scheme for noise elimination is proven to be effective for blocking inference to/ from the scanner and minimize SNR reduction in the sensing signal.

Piezoelectric sensor array and data transmission scheme for noise elimination: An MR compatible sensor array is presented in Fig. 1(a) with the use of piezoelectric materials. Charges and potential difference are generated momentarily on the electrodes of the material when it is squeezed. The high sensitivity of the piezoelectric material with its minimal size makes it ideal for force sensing in MR environment with virtually no generated artifact outside its body as shown in Fig. 1(b). By applying a low-frequency vibration with a piezoceramic shaker, stable charges can be generated and detected on the electrodes for force measurement. Telepalpation can then be performed with the sensor array to achieve the tactile information and stiffness distribution in a target tissue. The MR compatibility of the piezoceramic shaker has been proven in [1]. As piezoelectric materials have intrinsically very high impedance but weak output signal, a charge amplifier system coupled with a filtering circuit has been designed specially for signal processing. Our pervious experiment has shown that if the sensor array is directly connected from the device placed in the scanner room to the control system, the MR image quality and sensing signal from the sensor array would be adversely affected with poor SNR. Therefore, a scheme for data transmission and noise elimination shown in Fig. 1(c) is proposed. As long cables connected from the control room to the scanner room is a potential antenna inducing and amplifying noise, optic fibre is used for data transmission and all electrical pulses are encoded to be optical pulses by optical converters. The sensor array is connected to the charge amplifier system and through to the data acquisition device via twisted cables with proper shielding well connected to the ground of the scanner. All electronics in the scanner room are put inside a faraday cage.

Noise analysis and Palpation on kidney tissue with a phantom tumour: Experiments were conducted to understand the nature of the noise in the sensing signal provided by the scanner when gradient echo and turbo spin echo sequences were applied respectively with results showing in Fig. 1(d), (e) and (f). The proposed scheme successfully minimized and controlled the noise within 4mV in both sequences. Fast Fourier Transform was performed on the sensing signal and it is observed that the dominant noise came from the mechanical vibration of the scanners at around 10Hz and also the RF pulses at around 100 Hz in both sequences. A proper band pass filter was then selected in our programme for noise filtering. Another experiment was performed in the scanner to apply palpation by the sensor array on a lamb kidney with a phantom tissue implanted as shown in Fig. 1(g), and it demonstrated the capability of the sensor array to detect the force distribution corresponding to the location of the tumour as indicated in Fig. 1(h)

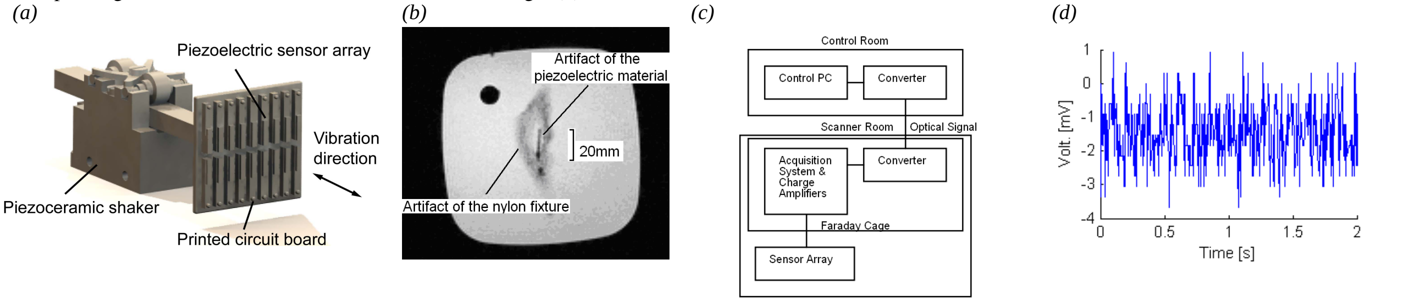
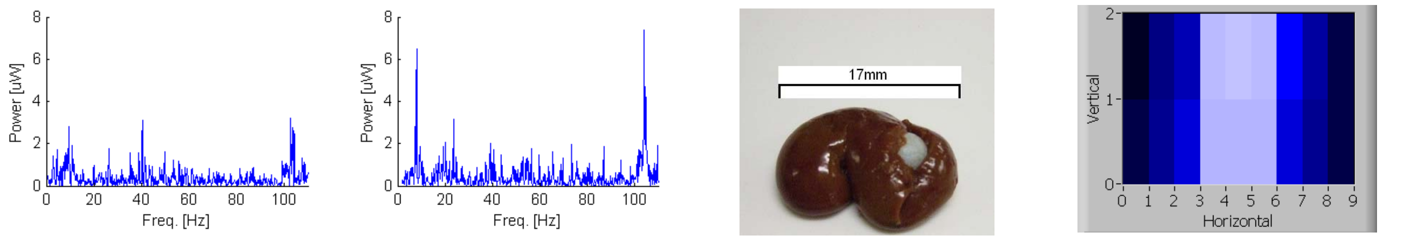


Fig. 1: (a) CAD rendering of the tactile sensor array mounted on an MR compatible piezoceramic shaker. (b) MR image of the slice containing the maximum size artifact for the piezoelectric material in gradient echo and turbo spin echo sequences. The artifact produced was virtually identical to the size of the body itself. (c) A proposed data transmission scheme for noise elimination (d) noise captured during scanning with gradient echo sequence.



FFT of the sensing signal during scanning with (e) gradient echo and (f) turbo spin echo sequences. (g) Measurement setup of a phantom tumour implanted in a normal lamb kidney and (h) its force distribution.

Conclusion: An MR compatible sensor array has been presented providing the functionality for practitioners to characterise a target tissue. Tactile information provides extra information besides visual information from MRI images for verification of the movement of surgical tools and is believed to be capable of enhancing the quality of the surgery. Analysis of the results concludes that the sensor noise is almost entirely due to sensitivity of mechanical vibrations of the scanner and not the background noise of the scanner room. This has been seen to occur at low levels and at clearly definable frequencies, such that a clear signal can be retrieved by use of digital filtering within the control software.

Reference: 1. H. Elhawary et al., "A modular approach to MRI compatible Robotics: Interconnectable one DOF stages," *IEEE Engineering and Medicine in biology magazine* 2007, accepted for publication.