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● *Technical Note*

THE FEASIBILITY OF THERMAL IMAGING AS A FUTURE PORTAL IMAGING DEVICE FOR THERAPEUTIC ULTRASOUND

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Abstract—This technical note describes a prototype thermally based portal imaging device that allows mapping of energy deposition on the surface of a tissue mimicking material in a focused ultrasound surgery (FUS) beam by using an infrared camera to measure the temperature change on that surface. The aim of the work is to explore the feasibility of designing and building a system suitable for rapid quality assurance (QA) for use with both ultrasound- and magnetic resonance (MR) imaging–guided clinical therapy ultrasound systems. The prototype was tested using an MR-guided Sonalleve FUS system (with the treatment couch outside the magnet bore). The system's effective thermal noise was 0.02°C, and temperature changes as low as 0.1°C were easily quantifiable. The advantages and drawbacks of thermal imaging for QA are presented through analysis of the results of an experimental session. (E-mail: piero.miloro@npl.co.uk)

Key Words: **High intensity focused ultrasound dosimetry, Quality assurance, Thermal mapping, Acoustic field evaluation, Magnetic resonance–guided focused ultrasound surgery, Infrared camera.**

INTRODUCTION

The increasing number of devices and applications of focused ultrasound surgery (FUS), also known as high intensity focused ultrasound (HIFU), poses a significant challenge in terms of standardization of measuring and reporting ultrasound dosimetry, and there is a growing need for fast, reliable and accurate quality assurance (QA) strategies (Civale et al. 2015). HIFU transducers are often inextricably embedded in the clinical device and most conventional strategies for pressure mapping and power measurement of acoustic fields are difficult to apply in routine clinical practice (ter Haar et al. 2015). The use of multi-element transducer arrays generates a vast range of configurations that could need to be tested.

In radiotherapy, photographic film has been used since the 1950s to map the spatial distribution of energy incident on a specific plane (Granke et al. 1954). More recently, electronic portal imaging devices (EPIDs) have been developed (Heijmen et al. 1995) that record the energy distribution digitally (*e.g.,* using amorphous silicon detectors) instead of on films. EPIDs offer advantages both as relative mapping and dosimetric measurement devices (van Elmpt et al. 2008).

The use of thermal imaging acquired by infrared (IR) cameras has recently been proposed as a potential strategy for fast quantitative measurement of both diagnostic (Yamazaki 2008) and high power acoustic fields (Shaw and Nunn 2010). Advantages of thermal imaging are the speed of 2-D data acquisition, good spatial resolution and wide dynamic range. However, IR radiation (wavelengths approximately 10 μm) is strongly absorbed by water, so an air path is required between the camera and target, which results in a highly ultrasonically reflective interface at the plane of measurement. Recent advances include recording the temperature of the interface between air and tissue mimicking materials (TMMs) (Myers and Giridhar 2011) or strongly absorbing thin layers (Shaw et al. 2011). Khokhlova et al. (2013) have shown that the temperature distribution near the reflecting air interface closely follows the distribution of the temporal average intensity in the incident beam.

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The aims of this study were to test whether the IR camera can be used close to a magnetic resonance (MR) imaging scanner without significant thermal image artefacts and map the in-plane temperature distributions in the same configuration used for therapy. Future work will compare the results with other measurement systems such as hydrophone mapping and acoustic holography (Kreider et al. 2013).

In this work, the device has been tested on a Philips Sonalleve MR-guided FUS system (Royal Philips, Amsterdam, the Netherlands) installed at ICR/Royal Marsden Hospital in Sutton, UK.

MATERIALS AND METHODS

Hardware

A compact (46 mm × 56 mm × 90 mm), USB-powered PI-200 IR camera (Optris Infrared Thermometers, Berlin, Germany) with 120 × 160 pixel resolution and a maximum frame rate of 128 Hz was used. The claimed noise-equivalent temperature is 80 mK, and temperature data can be displayed and exported by the camera software with a resolution of 0.1°C. However, by directly processing raw data files, it has been possible to improve the resolution to 0.02°C. The camera is mounted within a 3-D printed waterproof holder (Fig. 1) composed of two flanges sealed with O-rings. A 100-mm-diameter, 6-μm-thick Mylar membrane was the measurement surface. The camera was fixed to the base, and its distance from the membrane can be varied between approximately 30–130 mm, in order to provide spatial resolution between 0.07 and 0.3 mm per pixel, and a field of view of 12 mm × 9 mm to 52 mm × 39 mm, respectively. A 10-m USB cable with built-in amplification chipset (BlueRigger Active Extension, Redmond, WA, USA) was connected to the IR camera passed through the holder base *via* a waterproof seal.

For the configuration shown in Figure 1, a 65-mm-high cylinder of TMM was used as the absorbing target, pushed against the front membrane using an additional flange. The target size allowed measurement of both the pre- and post-focal fields of the Philips Sonalleve system. The TMM is an agar-based gel whose formulation is given in IEC60601-2-37 (IEC 2008). The main acoustic properties of the TMM are: an amplitude attenuation coefficient that is almost linear with frequency (0.49 dB/cm/MHz ± 0.05 dB/cm/MHz), a speed of sound of 1540 m/s ± 1%, density of 1070 kg/m^3 ± 30 kg/m^3 and specific heat capacity of 3770 J/kg/K ± 3% (Brewin et al. 2008).

The tests were performed using a Philips Sonalleve MR-guided FUS system at a distance of approximately 1 m from the edge of the magnet bore of a 3.0 T Philips Achieva MR imaging scanner (*i.e.,* the Sonalleve patient bed was in its “pulled-out” position). The 256-element array transducer, with a 140-mm geometric focal length and 140-mm diameter can be operated at 1.2 or 1.45 MHz. It is mounted within the patient bed in an oil-filled chamber on a 5 degree of freedom positioning system.

Experimental procedure and data processing

The assembly was acoustically coupled to the Sonalleve transducer using degassed water between the coupling membrane of the HIFU system and the TMM. The axial distance between the transducer and the coupling membrane of the HIFU system was varied over a range of 50 mm around the transducer’s homing position. Sixteen measurements were carried out at different axial positions and input powers (see Table 1). For each experiment, the transducer was driven in

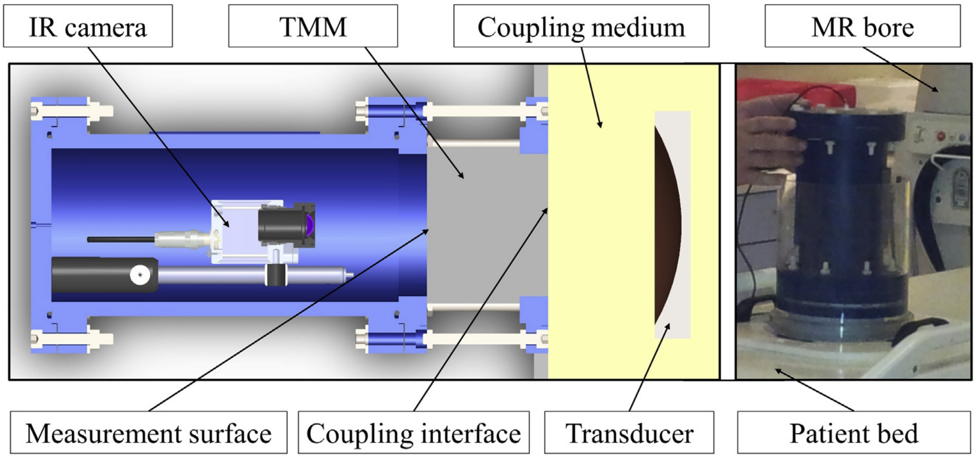

Fig. 1. Experimental setup. Left: sketch of a cross-section through the measurement device, TMM, coupling medium and ultrasound transducer. Right: the device positioned on the MR bed of the Sonalleve system. IR = infrared; MR = magnetic resonance; TMM = tissue mimicking material.