An adaptive MR-compatible lens

J. Maclaren[1], F. Schneider[2], M. Herbst[1], M. Aksoy[3], D. Kopeinigg[3], J. Hennig[1], R. Bammer[3], M. Zaitsev[1], and U. Wallrabe[2]
[1]Medical Physics, Dept. of Radiology, University Medical Center Freiburg, Freiburg, Germany, [2]Dept. of Microsystems Engineering - IMTEK, University of Freiburg, Freiburg, Germany, [3]Dept. of Radiology, Stanford University, Stanford, United States

Introduction

We present an MR-compatible adaptive membrane lens, which is integrated into a wide-angle objective to form part of an optical tracking system. This work is motivated by the need for optical head tracking devices for use in prospective motion correction [1], but an alternative application could be high-resolution eye tracking for fMRI. The challenge for in-bore cameras is the limited focal depth and small field of view, which this approach addresses. We have previously described the fabrication process of the lens [2] and elements of its design and characterization [3, 4]. The aim of this work was to construct an MR-compatible objective incorporating the lens, and to verify the performance and compatibility of the adaptive lens during MR imaging.

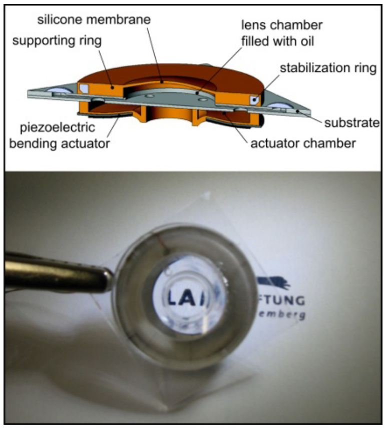

Fig. 1: Schematic diagram (top) and photo (bottom) showing the adaptive lens.

Methods

Lens The adaptive lens (Fig. 1) consists of two oil-filled chambers: the lens chamber, and the actuator chamber. The lens chamber is surrounded by a silicone supporting ring and covered with a silicone membrane. The actuator chamber is bounded by a piezoelectric bending actuator embedded in silicone. The two chambers are separated by a silicon-glass plate, which contains several channels through which oil (refractive index, $n = 1.33$) can flow. When a voltage is applied to the actuator, it forces oil out of the actuator chamber and into the lens chamber. The membrane then bulges outwards, reducing the focal length of the lens. The lens membrane diameter is 10 mm and the aperture, as defined by the inner supporting ring diameter of the actuator chamber, is 5 mm.

Objective To allow testing of the lens in an MR environment, we incorporated it into an objective, which we designed for tracking a head-mounted target. The design constraints were a maximum target size of 60 × 45 mm, the image size at the camera chip, and an adjustable working distance of 90 ± 20 mm (defined by the expected variation of head size, expected head motion, and the objective position). Due to the limited space between the top of the head coil and the magnet bore, the objective incorporates a mirror at 45 degrees, allowing it to lie parallel to the z-axis of the magnet (Fig. 2). Light reflected by the mirror is collected using a plane-concave lens. This is followed by an iris aperture (diameter 4.5 mm), which is placed in front of the adaptive lens. Two achromatic lenses are then used for projection onto the camera CCD. By varying the focal length of the adaptive lens from -3.5 to +10.2 m, the working distance of the objective can be varied from 70 to 110 mm.

Lighting To illuminate the tracking target we use a ring of surface-mount white LEDs (Nichia Corp., Japan) arranged around the entrance of the objective (Fig. 2). The ring provides homogeneous illumination over an area 200 mm in diameter (current: 40 mA, power: 600 mW).

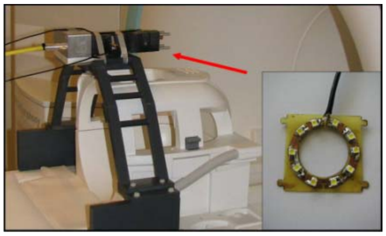

Fig. 2: The objective mounted on a frame attached to the patient table. Inset: the LED lighting arrangement.

Compatibility testing MR imaging and compatibility testing were performed using a clinical MRI system (1.5 T Symphony, Siemens, Germany). Field maps of a water phantom were generated using the vendor-supplied field mapping sequence, with and without the adaptive lens attached to the head coil (5.5 cm above the surface of the bottle). RF noise testing was performed with the lens and lighting system off, and then with both switched on and with the lens constantly refocusing. Finally, the function of the lens was verified during MR imaging. For this step, the objective was combined with an analog camera (CCD-3820, Sharp Corp.), which was shielded with an aluminum box to prevent interference with the MR system. A tracking target was attached to a phantom and placed in the MR isocentre. The lens was then repeatedly focused and defocused during MR imaging of the phantom with both a gradient echo and an EPI sequence.

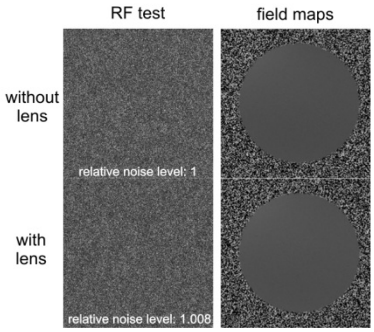

Fig. 3: Results of MR-compatibility tests show no significant increase in RF noise or field distortions caused by the lens.

Results and Discussion

Figure 3 (right column) shows the field mapping results. The lens causes no noticeable field distortions. Figure 3 (left column) shows identically scaled noise images from the RF test, which indicate that the lens and lighting do not generate any significant RF noise. The operation of the lens was unaffected by simultaneous MR imaging (Fig. 4). However, occasional video frames contained artifacts from the MR scan, which was caused by imperfect camera shielding and RF coupling to the video cable. Better camera compatibility is an area for future work.

In conclusion, an adaptive lens has been developed and built into an objective to form an adaptive wide-angle objective. Compatibility tests indicate that the full function of the autofocus lens is preserved in the MR environment and that no MR imaging artifacts result from its use.

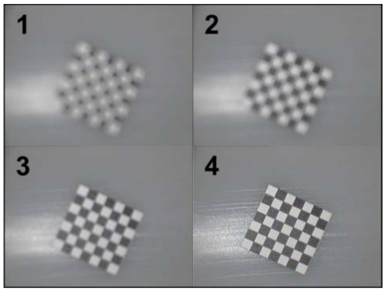

Fig. 4: Frames from a video sequence showing focusing of the lens on a checkerboard target during MR imaging.

References

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