MRI at 2.15 MHz in a large-bore Halbach Array

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Introduction: Halbach arrays can be used to generate very homogenous magnetic fields if the length-to-diameter ratio is high [1]. However, this presents challenges for their application to human imaging in which the ratio is typically 2:1 or less. In this work we present a new approach for improving the homogeneity of a Halbach array by varying the diameter of the array over its length and use this approach for designing a Halbach-array-based MRI scanner for paediatric neuroimaging.

Methods: The Halbach array is constructed from 23 layers of 12 mm cuboid N42 neodymium magnets, each layer consisting of 2 rings of magnets (see figure 1a) with a total magnet length of 50.6 cm. The radius of the rings in each layer was varied to optimise the homogeneity over a 20 cm diameter sphere using a genetic algorithm. B_0 maps were acquired using a Hall-probe attached to a measurement robot [2]. Shimming was performed using 3 mm cuboid magnets placed inside the bore using the acquired B0 map as input. Gradient coils were constructed using 1.5 mm diameter copper wire wound on cylindrical formers. A 15 cm diameter, 15 cm long solenoid was used as an RF transceive coil. A 1 kW RF amplifier was designed using MOSFET technology.

Results & discussion: The constructed magnet had a field strength of 50.4 mT and a homogeneity of 13000 ppm over a 20 cm diameter sphere. The homogeneity was improved to 2500 ppm after a single shimming iteration. Images were acquired from a 9×6×3.5 cm 3D printed Shepp-Logan-based phantom filled with aqueous gel. Data were acquired using a 2D spin-echo sequence without slice selection and an in-plane resolution of 1.2×1.2 mm with 8 signal averages and an acquisition time of 16 minutes.Figure 3b shows a reconstructed image of this phantom.

Conclusion: The homogeneity of a Halbach array based magnet can be improved by varying the ring diameter along its length. Initial 2D images have been acquired using this shimmed magnet design. Using custom-built open source hardware it should be feasible to produce a MR system for less than 30000 euros for paediatric neuroimaging in low-resource settings.

References: [1] Turek, J. Magn. Reson. (2014). [2] Han, Sci. Rep. (2017).

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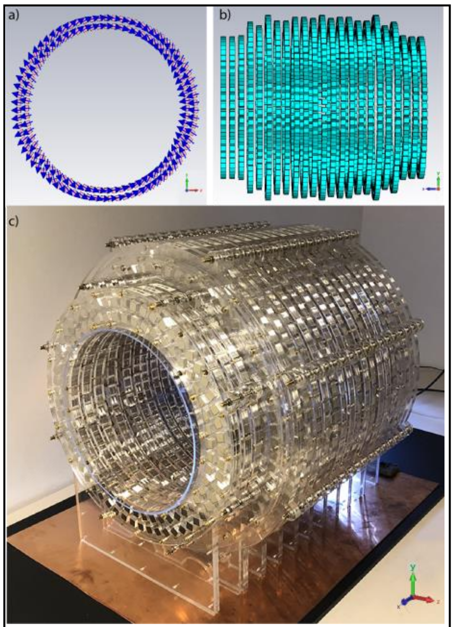

Figure 1. a) Double-ring Halbach configuration used to increase B_0 strength. b) Side-view of the Halbach array optimised for homogeneity. c) The constructed Halbach array with a bore diameter of 27 cm, wide enough to be used for paediatric neuroimaging. The cost of the magnet was 4000 euros.

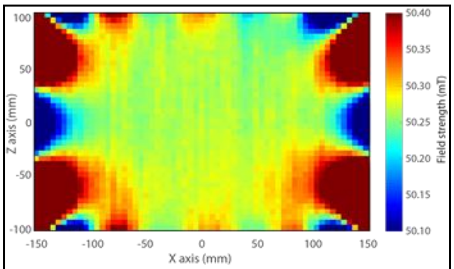

Figure 2. A B_0 map of the constructed magnet after shimming. Homogeneity over a 20 cm diameter spherical volume was 2500 ppm.

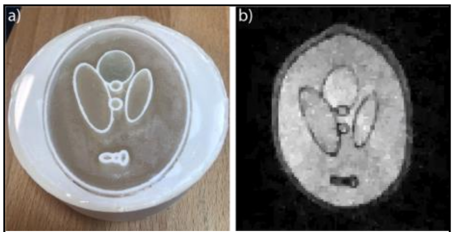

Figure 3. a) A 3D printed Shepp-Logan based phantom, the lines separating the compartments are 1 mm thick. b) Images acquired using a spin echo sequence and reconstructed using a standard Fourier transform.