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IRBM

IRBM 36 (2015) 52–60

Original article

A new phantom to assess and correct geometrical distortions for Magnetic Resonance Imaging: Design and preliminary experiments

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Received 21 July 2014; received in revised form 23 December 2014; accepted 23 December 2014

Available online 7 January 2015

Abstract

Purpose: Nowadays, many focal therapies use Magnetic Resonance (MR) imaging for treatment planning purpose. In this context, geometric distortions should be as low as possible. In this paper, we present a new device to assess image distortions in MRI.

Methods: The phantom consists of a stack of plates made of Polymethyl Methacrylate (PMMA). The detection elements are balls forming MRI capsules and delimiting an internal volume filled with paraffin oil. When imaged, this system enables having a regular pattern with the same distance in the three space directions between each capsule center of mass.

Correction of the distortions is done using a registration of the detected balls pattern with the theoretical pattern. Iterative Closest Points (ICP) algorithm is used for thus purpose.

Results: Preliminary evaluations on different MR sequences have been conducted, the combination of device and ICP-based correction method shows the feasibility of the approach.

Conclusion: From the promising preliminary results obtained, future developments will include an upgrade of the phantom and the implementation of more sophisticated correction algorithms.

1. Introduction

Focal therapy refers to a variety of minimally invasive techniques such as High Intensity Focused Ultrasound (HIFU), LASER, cryotherapy, radiosurgery or hypo-fractionated radiotherapy for destroying tumors while sparing normal surrounding tissue. This technique is generally performed under image guidance, and necessitates going through a preliminary treatment planning stage to obtain an accurate delineation of tumor volume and adjacent structures at risk. Among the possible imaging modalities, Magnetic Resonance Imaging (MRI) offers a good soft tissue contrast but may suffer in counterpart from geometric distortions that mainly come from gradient field nonlinearity and magnet field inhomogeneity. These distortions appear under the form of pixel shift and intensity variation in the image volume.

In MRI, several issues may induce these distortions [1–3]. These sources of distortions can be analyzed from intrinsic and extrinsic points of view. The main cause of intrinsic distortions is the heterogeneity of the main field B_0. Distortions due to this phenomenon are proportional to B_0 [4] leading to MRI spatial encoding distortions increasing with higher magnetic field strength [5], almost near the external limits of the field of view (FOV). Nonlinear gradient is also an intrinsic source of distortions. Nonlinear gradient distortions affect precision and accuracy and are typical of the latest generation of MR scanner [6]. The build of new MRI scanner with higher magnetic fields, shorter bores, higher gradients and shorter gradient rise times mainly causes these nonlinear gradient distortions. “Barrel-shaped” distortions on morphometric images

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http://dx.doi.org/10.1016/j.irbm.2014.12.002
1959-0318/

are specific of such nonlinear gradients [7–10]. Extrinsic distortions are mainly due to the patient himself (difference of magnetic susceptibility, prosthesis, implants, surgical clips . . .), hardware set-up on the patient (e.g. stereotactic frame) and chemical shift.

Distortion correction has been the subject of a certain number of works. They can be classified into two families: online and offline techniques. The first one is applied during the image reconstruction process and is based on the magnetic field maps while the second one makes use of designed phantoms to estimate these distortions and then apply a correction technique on the image volume. Our work has focused on the latter one.

In this paper, preliminary results obtained from a new device and from application of basics correction processing [9] are described in the following sections.

2. Related works

2.1. Correction methods

2.1.1. Correction from magnetic fields map

Magnetic field maps describe the spatial magnetic field heterogeneity on images. A map can be estimated from the phase of a complex image. Measuring the phase variations (i.e. the magnetic field) from multiple echoes, spaced in time inside a given MRI sequence, enables to create a voxel shifts map. This map is thereafter used to correct the distortions.

This approach was used in many studies [11–17]. They were mainly focused on Echo Planar Imaging (EPI) technique and applied for functional MRI (fMRI).

2.1.2. Correction from phantom acquisitions

Correction of geometric distortions can also be applied offline from the space domain. Images acquired from phantom are post-processed in order to build up distortion maps according to control points detected on the phantom images. This approach offers the advantage of correcting most of the field heterogeneities and gradient non-linearities [6,7,9,18–23].

2.2. Measurement and characterization of the MRI distortions

Different solutions were proposed to characterize MRI distortions from physical devices (phantoms). Doran et al. and Tanner et al. [21,22] have proposed a Linearity Test Object (LTO) built from contrast agent filled rods suspended in the phantom. Another LTO consists of cylindrical bars placed in a tank filled with a contrast agent (e.g. copper sulfate). The bars are thus observed as hypo-signal (Fig. 1). A similar phantom is commercialized by Elekta (Elekta, Stockholm, Sweden) to check the MRI distortions for radiosurgery planning [24]. Stereotactic frame can be set-up on this phantom to assess geometric distortions induced by the frame. Nevertheless, because of its configuration, it only enables to observe distortions in a single plan. Analyzing others plans requires changing the orientation of the LTO in the tank.

In the context of interventional MRI with open low-field magnet, Daanen et al. [20] have proposed a device able of characterizing large FOV. This calibration phantom consisted of 750 spherical glass balls (15 mm in diameter) arranged in a regular cubic pattern with 30-mm side length. The phantom dimensions were $400 \times 210 \times 300$ mm^3 (patient coordinates: LR $\times$ AP $\times$ HF, spatial coordinates: horizontal (X) $\times$ vertical (Y) $\times$ horizontal (Z)), which corresponds to typical FOV sizes for abdomen examinations. Fig. 2 shows the image acquired in a large FOV configuration with this device. This device was also applied by Viard et al. [19] to characterize the distortions of a 0.2 T open magnet MRI. For instance, Fig. 3 presents iso-values of the radial distortions before and after image correction. (The radial distortion is estimated from the theoretical position of the center of mass of a ball and its actual position measured on the images.)

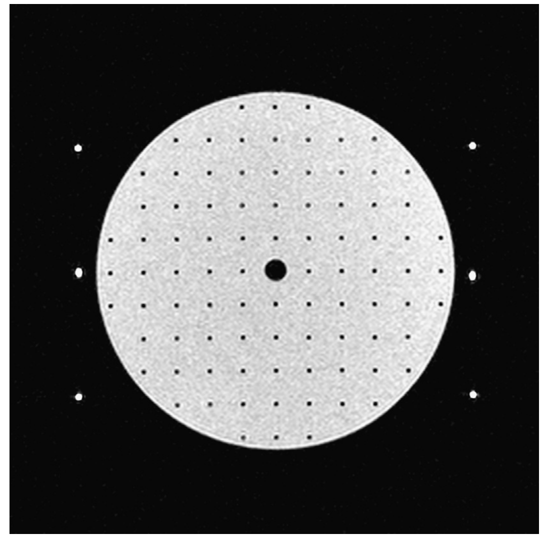

Fig. 1. T1 weighted MR image with a phantom similar to the LTO but with plain bar.

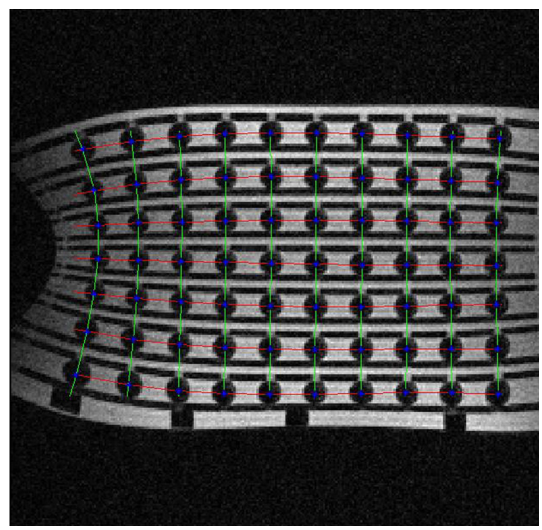

Fig. 2. MR axial image and control points detection from the calibration phantom designed by Daanen et al. with a regular cubic pattern: 30 mm distance between each point. (Image from [19], MR sequence: Fast Spin Echo – TR: 3500 ms – TE: 15 ms – Flip: angle 30° – FOV: 350 mm – Slice thickness: 5 mm – 256×256 pixels.)