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A method of RF inhomogeneity correction in MR imaging

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Abstract

A direct postprocessing method for correcting RF inhomogeneity in MR imaging is proposed. First, two images with different flip-angles of θ and 2θ are obtained. Next, the spatial distribution maps of the sensitivity of the surface coil and the B_1 field intensity are produced by employing those images. Finally, the correction of the MR image is achieved, dividing the original image by distribution maps of the coil sensitivity and the B_1 field intensity. The method was applied to images obtained by a gradient echo sequence and the corrected image is presented.

Keywords: MRI; RF inhomogeneity correction; Post-acquisition inhomogeneity correction; Flip angle; Surface coil

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1. Introduction

The image quality in magnetic resonance imaging (MRI) is linked to the spatial homogeneity of the electromagnetic B_1 field produced by radiofrequency (RF) coils or resonators. The presence of the inhomogeneities in RF magnetic fields is a significant obstacle to quantitative analysis and image processing. Such inhomogeneity can be caused by the instrument itself rather than by the object.

The possible sources of inhomogeneity of the image are:

1. the transmitted B_1 field (which determines flip angle);
2. the received B_1 field (which determines the sensitivity of the coil);
3. the electric field (which causes energy loss in the object).

Previous approaches to remove such inhomogeneity as described above are to estimate the degree of non-uniformity solely from the acquired MR data [1–4], to employ reference phantoms [5,6], to use a body coil image for correcting a surface coil image [3], to introduce an appropriate dielectric into the coil-to-shield space of the scanner [7], and to use the mathematical modelling of signal non-uniformity to perform retrospective correction [1,2,4,8].

We present a very simple and presumably the most direct method of correcting inhomogeneity primarily caused by a non-uniform B_1 field and coil sensitivity. This method does not require uniform phantoms, precise information of the coil positioning, or equipment modification. By applying this method the non-uniformity of the B_1 field and the coil sensitivity can be compensated and the intensity of the corrected image can represent the value originated from the tissue.

2. Principle

The correction of the image is achieved by using two

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images obtained with different flip angles, θ and 2θ. The flip angle, θ, for RF pulses of duration τ and the gyromagnetic constant γ is expressed as

$$\theta(\vec{r}) = \gamma \int_0^{\tau} |\vec{B}_1(\vec{r}, t)| \mathrm{d}t \qquad (1)$$

The signal intensity obtained by a gradient echo sequence is expressed as

$$I(\vec{r}) = k\rho(\vec{r})S(\vec{r})\sin\theta(\vec{r}) \times X(T_1(\vec{r}), T_2^*(\vec{r}), TR, TE) \qquad (2)$$

where k is a system constant, $\rho(\vec{r})$ the spin density, $S(\vec{r})$ the coil sensitivity, $\theta(\vec{r})$ the flip angle, and $X(T_1(\vec{r}), T_2^*(\vec{r}), TR, TE)$ a term describing the T_1 and T_2 relaxation.

When the same coil is used both as a transmitter and receiver, the function of spatial sensitivity of the coil, $S(\vec{r})$ is proportional to the flip angle, $\theta(\vec{r})$ [9]. $S(\vec{r})$ is then expressed as

$$S(\vec{r}) = m\theta(\vec{r}) \qquad (3)$$

Where m is a constant.

Then the signal intensity obtained by a gradient echo sequence is expressed as

$$I(\vec{r}) = km\rho(\vec{r})\theta(\vec{r})\sin\theta(\vec{r}) \times X(T_1(\vec{r}), T_2^*(\vec{r}), TR, TE) \qquad (4)$$

To produce a corrected image, two images (I_1, I_2) with different flip angles $(\theta, 2\theta)$ are obtained by a gradient echo sequence. The signal intensity of these two images are expressed as

$$I_1(\vec{r}) = km\rho(\vec{r})\theta(\vec{r})\sin\theta(\vec{r}) \times X(T_1(\vec{r}), T_2^*(\vec{r}), TR, TE) \qquad (5)$$

$$I_2(\vec{r}) = km\rho(\vec{r})\theta(\vec{r})\sin 2\theta(\vec{r}) \times X(T_1(\vec{r}), T_2^*(\vec{r}), TR, TE) \qquad (6)$$

Using these two images, the spatial distribution maps of functions, flip-angle θ is calculated as

$$\theta(\vec{r}) = \arccos\left(\frac{I_2(\vec{r})}{2I_1(\vec{r})}\right) \qquad (7)$$

Then the corrected image $(\rho(\vec{r})X(T_1(\vec{r}), T_2^*(\vec{r}), TR, TE))$ compensating theinhomogeneity of the B_1 field and the coil sensitivity is expressed as

$$\rho(\vec{r})X(T_1(\vec{r}), T_2^*(\vec{r}), TR, TE) = \frac{I_1(\vec{r})}{km \arccos\left(\frac{I_2(\vec{r})}{2I_1(\vec{r})}\right)\sin\left(\arccos\left(\frac{I_2(\vec{r})}{2I_1(\vec{r})}\right)\right)} \qquad (8)$$

3. Materials and method

MR imaging of a spherical water phantom ($T_1 =$ 300 ms) with a diameter of 3.5 cm were obtained using a 7 T MRI system (18.3 cm caliber). The object was placed on a single-turn circular coil (2.4 cm diameter) and both excitation and reception were performed by this surface coil. The image orientation was set parallel to the surface coil, as shown in the Fig. 1.Two images are obtained by a gradient echo sequence ($Tr = 1600$ ms, $Te = 5$ ms) with different flip angles (θ and 2θ). The excitation RF pulse output of the second image is set to be twice stronger than that of the first image. Using those images, a distribution map of the B_1 magnetic field and the corrected image compensating the inhomogeneity of the B_1 field and the coil sensitivity were calculated using Eqs. (7) and (8).

4. Results

The original image obtained by a gradient echo sequence with the first flip angle is shown in Fig. 2(a), the original image with the second flip angle in Fig. 2(b), the distribution map of $\theta(\vec{r})$, or the intensity of the B_1 magnetic field, in Figs. 3 and 4 and the corrected image in Fig. 5. The corrected image proves the effectiveness of this method.

5. Discussion

We have introduced the method of correcting the RF field inhomogeneity. It does not require uniform phantoms, precise information of the coil positioning, nor equipment modification. For the image correction it requires only two images obtained with two flip angles θ and 2θ. It can be carried out with the object in the same geometric positioning. While previous

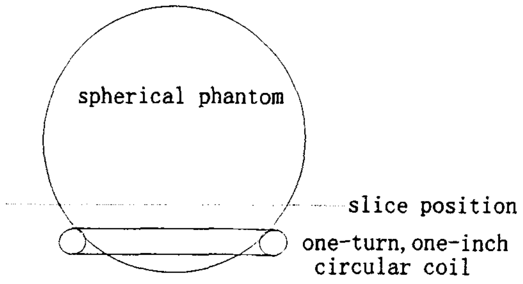

Fig. 1. Positioning of the phantom.

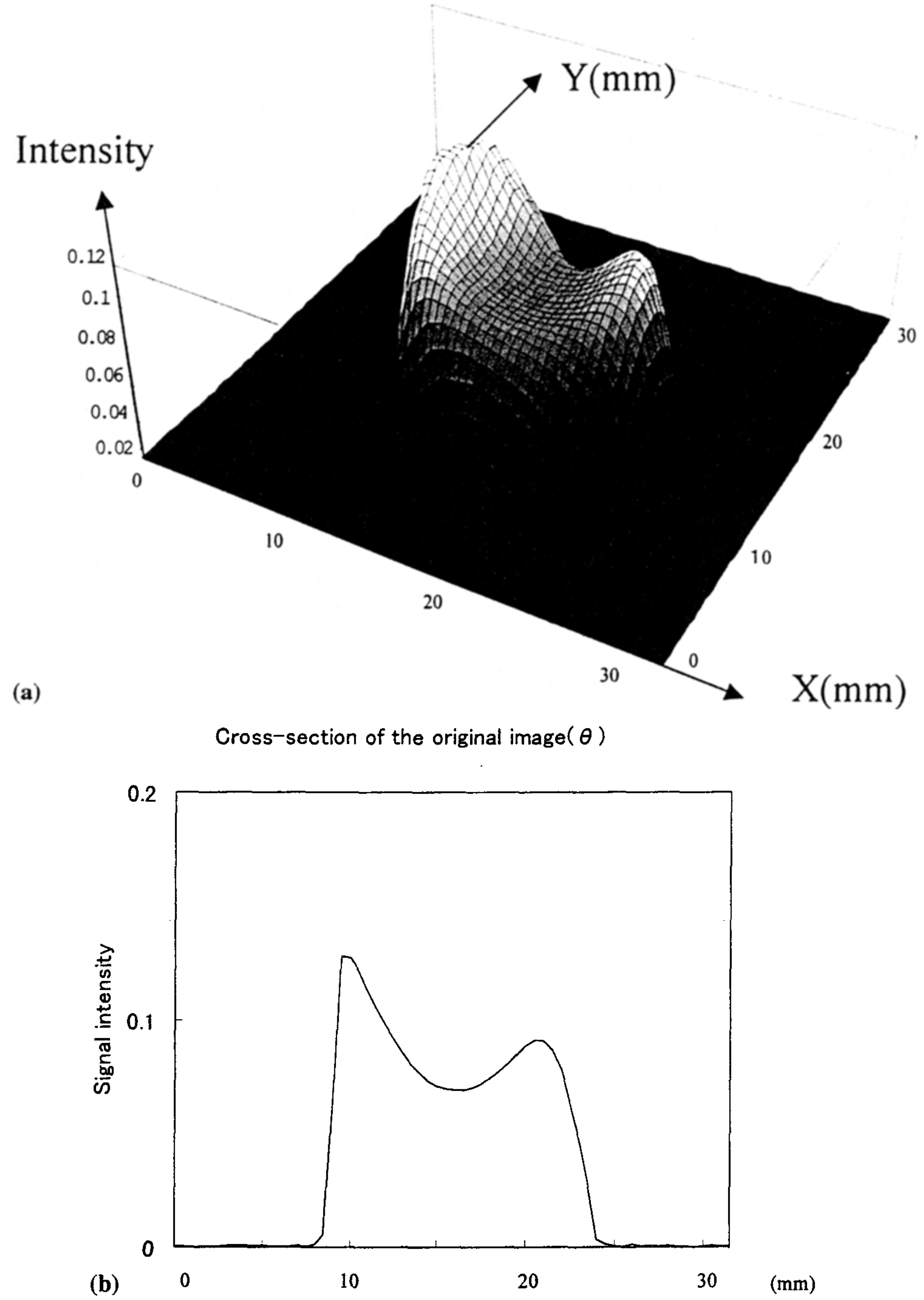

Fig. 2. (a) Original image 1: an image obtained by the field echo sequence ($Tr = 1600$ ms, $Te = 50$ ms) with the first flip angle θ. (b) Cross-section of the original image 1.

works removed inhomogeneity in MR images, the corrected signals were inevitably associated with the sensitivity characteristics of the instruments [10–12]. In contrast, this paper provides a direct method to correct the RF field inhomogeneity.

In a quantitative analysis of MR images, the RF field inhomogeneity is the main problem to be addressed [13]. An ideal solution is to produce a homogeneous RF field and develop a coil with uniform features. On the other hand, the use of a surface coil is still practical.

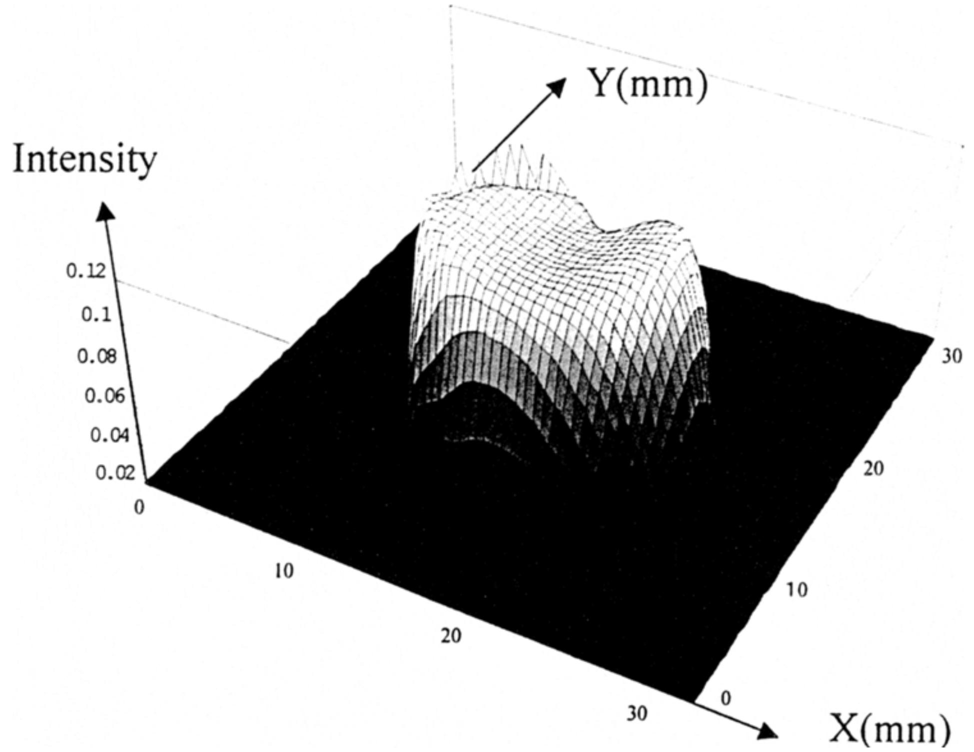

Fig. 3. Original image 2: an image obtained by the field echo sequence ($Tr = 1600$ ms, $Te = 50$ ms) with the second flip angle 2θ.

In such a case, the postprocessing method presented in this paper is very effective. No matter how inhomogeneous the RF field is, a corrected image can be produced by this method, because the signal intensity in Eq. (8) is independent of the receiving function and the B_1 field intensity, (i.e. $\theta(\vec{r})$ and $\sin\theta(\vec{r})$, respectively). In

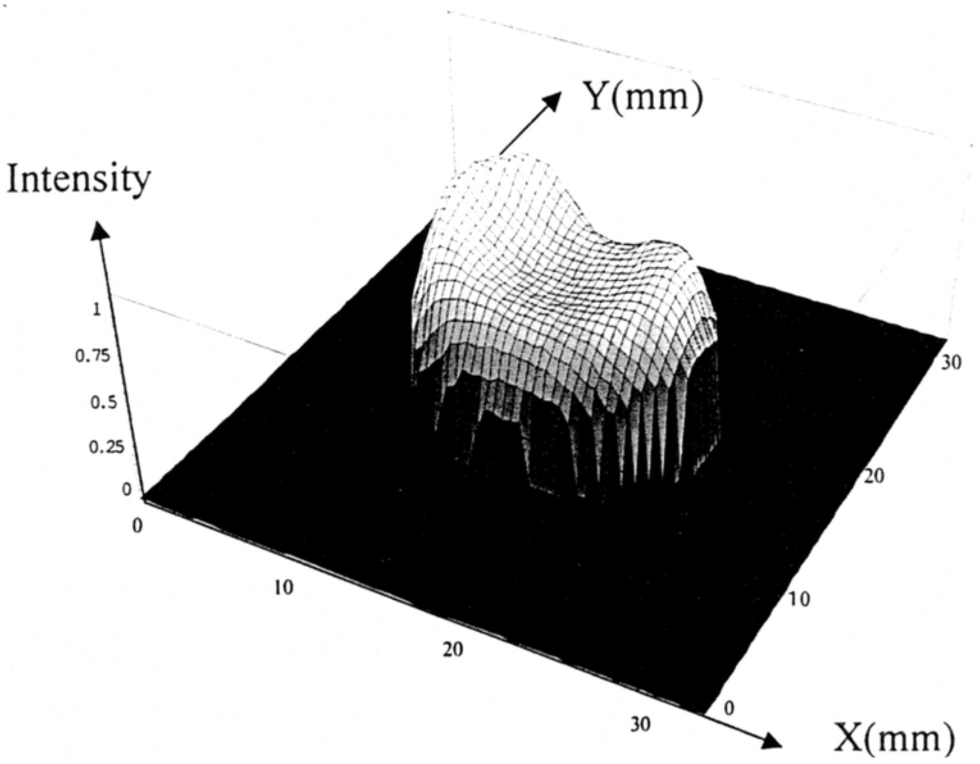

Fig. 4. θ image: This image indicates the distribution map of the flip angle, the intensity of the B_1 magnetic field, and the receiver sensitivity $\theta(\vec{r})$.

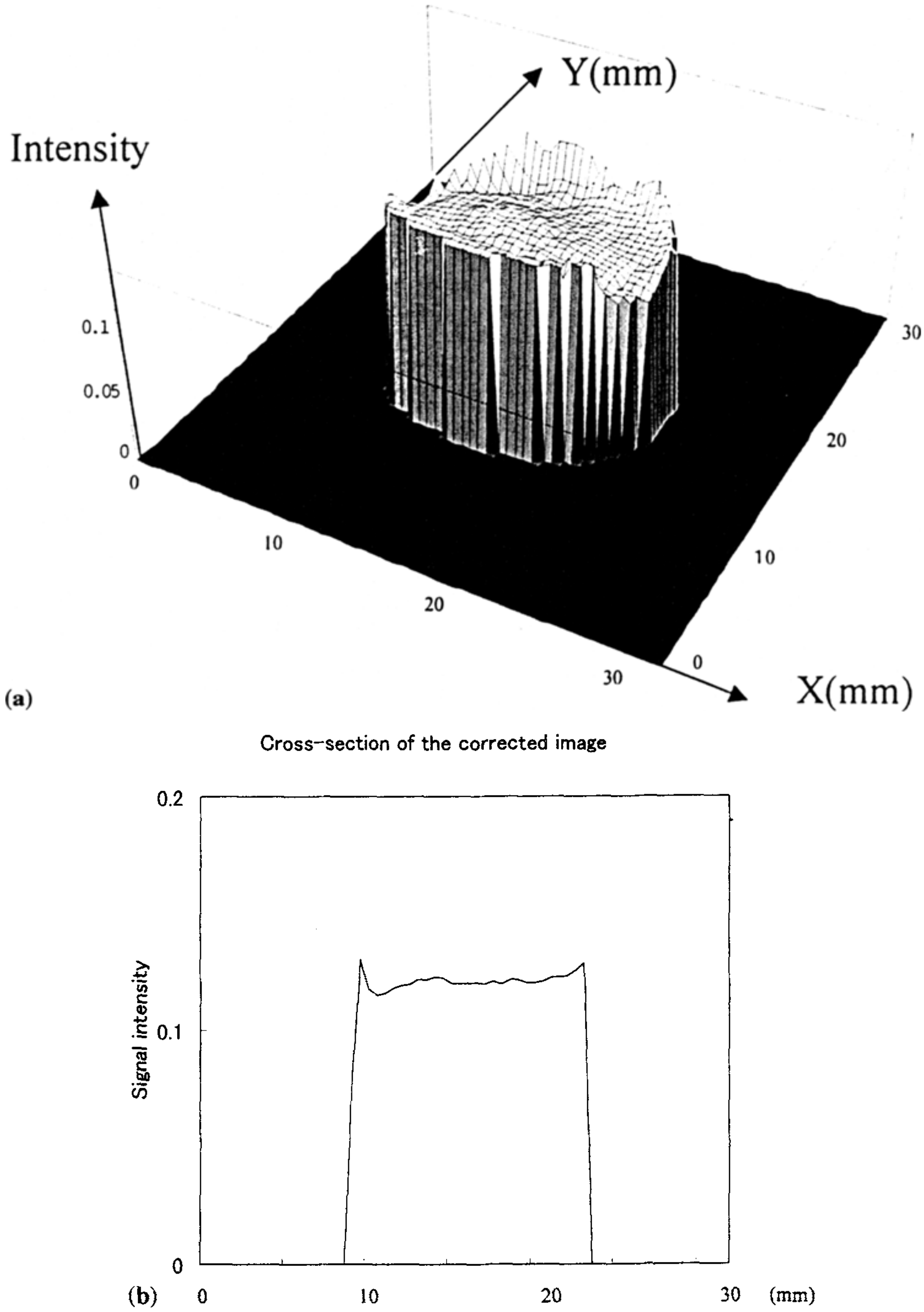

Fig. 5. (a) Corrected image: The corrected image which shows the distribution map of $\rho(\vec{r})X(T_1(\vec{r}), T_2(\vec{r}), TR, TE)$ calculated using Eq. (8). (b) Cross-section of the corrected image.

practice, flip angles θ and 2θ should be carefully chosen so that the flip angle of the first image, or $\theta(\vec{r})$, should be less than 90_, because the result of the function 'arccos' can be between − 90 and 90°. If the flip angle is near 0 or 180°, the signal intensity approaches to zero and may cause a numerical error. In acquiring the original image, Tr should be long enough to minimize the effect of T_1 relaxation.

By this method, the RF field inhomogeneity can be directly corrected.

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