Optimization of Complex Field Estimation in the Self-Reference Temperature Imaging Method

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INTRODUCTION The purpose of this study is examination of error induced in the proton-resonance-frequency (PRF) based temperature mapping using the self-reference method (1). Unlike the conventional method, the self-reference method uses only an image taken during heating and estimates the phase distribution in a region of interest (ROI) before temperature change based on the phase distribution around the ROI. The estimated phase distribution in the ROI is subtracted from the original phase distribution. Since this self-reference method does not require any separate reference image acquired before temperature change, it may reduce the temperature misread caused by organ motion and distortion of the magnetic flux density. This method has several limitations, however, to work properly. In this paper, optimization of the estimation algorism and conditions are discussed.

MATERIALS AND METHODS To assess the error induced in the self-reference method, non-heating experiments with healthy volunteer livers were performed. Simple breath hold imaging was adopted with an optical abdomen wall position sensor (AZ-III, Anzai Medical Co. Ltd, Tokyo, Japan). A 0.5T open MRI (Signa SPi, GE Medical Systems, Inc., Milwaukee, WI) was used with Spoiled Gradient Echo (SPGR) of the following conditions: TR / TE, 32 / 12ms; slice thickness, 5mm; Field of view (FOV), 260 x 260 mm^2; Spatial Matrix, 256 x 128; and read out band width 15.6 Hz.

The phase distribution in ROI was evaluated by the polynomial function of x-y plane estimated the known phase distribution using the least-squares method in known area, and subtract the original phase distribution, so the phase and temperature different distribution were acquired. That was why the phase distribution based on the smoothness and continuity of the phase field except the heating point, blood vessels and so on, and the phase distribution was arctangent the ratio of the imaginary distribution to the real one, which it used to be able to do the Tailor deployment. Additionally, each real and imaginary images estimated to be lower error than the phase distribution. When estimated, the polynomial function's maximal degree was turned and acquired the optimal degree that was the least error of the real and imaginary images, or the phase distribution. The methods to seek the optimal degree and the phase distribution were four methods. First, it estimated the phase distribution. Second, it estimated the real and imaginary images each other, and made the phase distribution. Third, it estimated the real and imaginary images to be minimal norm, and made the phase distribution. And fourth, it estimated the real and imaginary images to use the degree that maximum x and y axis in polynomial function were independent, and made the phase distribution.

RESULTS Figure 1 shows the temperature images of Human body to use the four methods. Figure 2 shows the phase distribution and the temperature images when estimated by the phase image and the real and imaginary one. In these experiments, the size of ROI is in the circle with a radius of 18 voxels, and known area is in the circle with a radius of 30 voxels outside ROI. Table 1 shows the error average and standard deviation to use the each method. Figure 3 shows the error average and standard deviation graph of the voxels in the known area to the ROI ratio.

DISCUSSION AND CONCLUSION As is shown the Figure 1, there isn't so much of difference the temperature images when the four methods use to be estimated the ROI. From here onwards, we can confirm the phase distribution is smoothness and continuity, and self-reference method is valid. The results of temperature distribution using each method are that error average is about 5 degrees and standard deviation is about 4 degrees, so the optimum method cannot fix in this situation. These methods, however, don't always have a beneficial effect on. Figure 2 (1a) shows the phase image to go wrong for extrapolation. The reason to go wrong is thought that there is the discontinuous area to change the phase distribution in known area; this image can be seen to move from red to deep blue in the known area set between the inside and the outside circle. For this reason, it is difficult to estimate using the polynomial function. The temperature image (1b) based on the phase distribution also goes wrong, e.g. it is less than -100 degrees near the center of the ROI. Meanwhile, the phase image (2a) to use the real and imaginary images instead of phase distribution is good to estimate in the ROI. That is why the real and imaginary images are not always discontinuity even though the phase distribution is discontinuity. In deed, the temperature difference image (2b) based on (2a) can be acquired the comparable result of Figure 1. In this case, we can think that the method using the real and imaginary images is better than the method using the phase distribution when estimates the ROI. Table 1 shows the error average and standard deviation of the each method. In the table, each result is the nearly in case 1, but the method of 4 is the best in the case2. Therefore, the best method is to estimate the real and imaginary images to use the degree that maximum x and y axis in the polynomial function are independent. And as is shown the Figure 3, known area size mustn't be too small because the error temperatures are increased. The voxels in the known area should be acquired as same as, or more than the ROI. If the phase distribution in the organ is complicated, shimming may help.

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Table 1. Mean and standard deviation of the error temperatures in the ROI's shown in the methods of 1, 2, 3, and 4. (Unit indicator is degrees Celsius)

	Method	1	2	3	4
Case1	Mean	5.65	5.06	5.59	5.22
	SD	4.26	3.94	4.26	3.96
Case2	Mean	55.86	31.51	12.53	8.61
	SD	58.12	33.14	9.92	8.23

Case 1: the phase distribution is continuous in the known area
Case 2: the phase distribution is discontinuous in the known area

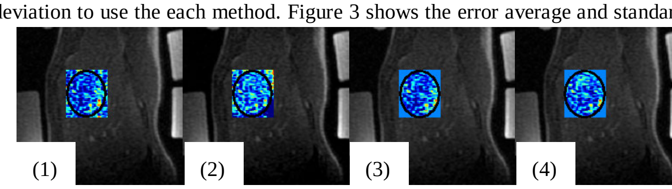

Figure 1. Temperature difference images of Human body without heating under respiratory control. Deep blue potion shows -10 degrees, and red shows 50 ones. (1) The result obtained by self-reference method with phase estimation. (2) The result obtained by self-reference method with complex estimation using independent polynomial function for real and imaginary parts. (3) The result obtained by self-reference method with complex estimation using a polynomial function with complex coefficients. (4) The result obtained by same as (3) but with independent maximum orders for x and y axis.

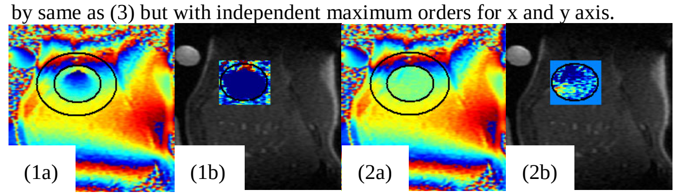

Figure 2. Phase difference and temperature difference images of Human body without heating under respiratory control. (1a) and (2a) are the phase difference images obtained by (1a) self-reference method with phase estimation and (2a) self-reference method with complex estimation using a polynomial function with complex coefficients but with independent maximum orders for x and y axis. Deep blue potion shows minus π and red shows π. (1b) and (2b) are the temperature difference images obtained by (1a) and (2a). Deep blue potion shows -10 degrees and red shows 50 ones

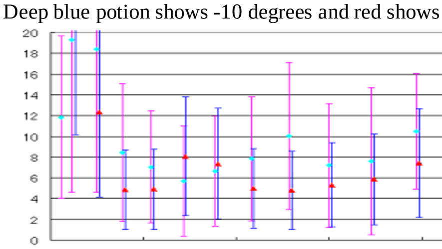

Figure 3. The error temperature and standard deviation graph of the voxels in the known area to the ROI ratio.