# IN VIVO PULSE SEQUENCE DESIGN FOR ACCELERATION OF T2 MAPPING USING COMPRESSED SENSING WITH PATCH-BASED LOW-RANK PENALTY

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**Purpose**

MR parameter mapping (MRPM) is a useful imaging tool to characterize the intrinsic information of tissues. Since MRPM provides more information about the normal tissues and lesions than T1 or T2 weighted image does, the clinical value of this quantitative imaging technique is increased especially for the detection and classification of neurodegenerative diseases, acute stroke and so on[1-2]. Unfortunately, the practical utility of T2 mapping is limited because usually it needs multiple acquisition of images at multiple echo time (TE). The long acquisition time is the critical weakness of MRPM because the time saving is the most important point in clinic especially for acute ischemic stroke patients who need the therapy as soon as possible. Thus, we design a new pulse sequence of undersampled multi-echo spin echo (ME-SE) which commonly used for T2 mapping to reduce the scan time less than several minutes which is acceptable range for clinical use. Then, compressed sensing algorithm with patch-based low-rank penalty[3] is applied for the reconstructing in vivo images of human brain to obtain T2 map.

**Method**

The multiple sets of T2WI of normal human brain were scanned at multiple TEs in Cartesian coordinate with 3T MR scanner (Siemens; verio) using 2D ME-SE sequence. The undersampling scheme was designed on the pulse sequence program by applying appropriate size of variable phase encoding (PE) gradient between acquisitions of each echoes to travel the k-space by random trajectory (Fig.1). For the ME-SE sequences, PE rewinder gradient which has same size but opposite polarity with the each additional PE gradients is necessary before applying each 180 degrees RF pulses. The following parameters were used T2 mapping measurement: ME-SE sequence, TR 4000 ms, 256x256 matrix, 6 z-slice with 5mm slice thickness, 4 coils, FOV 240x240mm, 32 echoes with 20 ms echo spacing (ESP). Full sampled data of ME-SE sequences were also acquired to verify the performance of the pulse sequence and the reconstruction algorithm. For the initial image reconstruction of T2WI, k-t FOCUSS algorithm is applied[4]. Then, patch based low rank (PL) algorithm[3] used to improve the reconstruction result. Since the images collected with different TE parameters have similar anatomical structure with different contrast, this reconstruction can be solved by rank minimization problem of patches by exploiting the self-similarities along the echo direction[5].

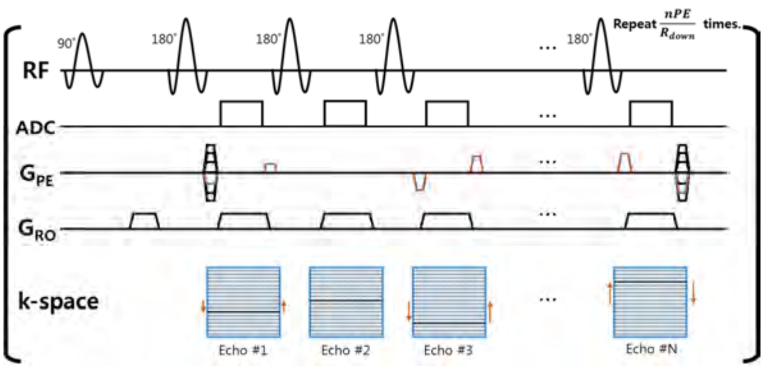


**Figure 1. Pulse sequence diagram of ME-SE**

The algorithm minimize the following cost function: $C(W,x) = \|y - Fx\|^2 + \sum_p \lambda_p \left\{\frac{1}{\mu}\left\|V_p(x) - W_p\right\|_F^2 + \left\|W_p\right\|_{g_{\mu,\nu}}\right\}$ where y is measurement in k-t domain, F is 2D Fourier with sampling and x is unknown images in x-t space. The second term is patch based low rank penalty which represented as summation of each patch penalty multiplied by regularization parameter $\lambda_p$ with patch index p. $V_p(x)$ is the temporal patch groups extracted from the images and $W_p$ is derived using half-quadratic regularization technique for Huber-based non-convex low rank penalty for $V_p(x)$. The solutions W and x are resolved by alternating minimization. The reconstruction scheme is as following: initial reconstruction which is done by kt-FOCUSS with KLT undergoes PL algorithm. After the reconstruction, the mapping was performed by voxel-wise fitting to mono-exponential decay model. The images are acquired with reduction factors of 4, 8, 12.8 and 16 to clarify the effect of undersampling and find the limit of acceleration rate.

**Results**

The T2 weighted images are well reconstructed by proposed algorithm by exploiting the similarity and low rankness between each echo images (Figure.2). While the acceleration rate is increasing, the aliasing pattern and other artifact slightly show up in the difference images between the images from full data and reconstructed images from undersampled data. The reconstruction T2 map fitted from these images are displayed in Figure 3. Even though there are some differences on the part of prefrontal cortex and the volumes of cerebrospinal fluid, we found that the acceleration rate ×16 for T2 is still good enough for maintaining the structures and contrast. The quantification of T2 values are 10~20% decreased, which we believe came from a slight mismatch of echo time.

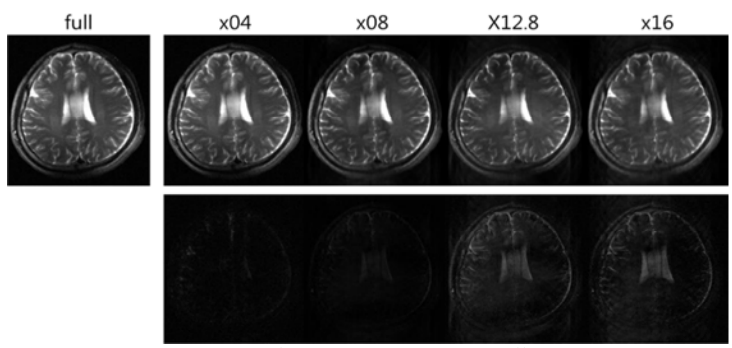


**Figure 2. Reconstruction images for each acceleration rate. Difference images compared to full image are listed under the each reconstruction images. (6th Z-slice, 6th Echo)**

**Conclusion**

The undersampled ME-SE for T2 parameter mapping are proposed in this study. Using k-t FOCUSS with KLT and PL algorithm, the prior knowledge of low rankness is applied for reconstruction method for T2 mapping from highly undersampled MR images. The structures and contrasts of T2 parameter maps are well reconstructed by proposed algorithm at high acceleration factor. This Cartesian random undersampling pulse sequence design could be applied to any other dynamic sequences. This acceleration scheme may improve the spatial or temporal resolution of dynamic MR imaging in given limited scan time. For the further research, the mask pattern should be optimized to the type of data and the source of the T2 quantification error will be investigated.

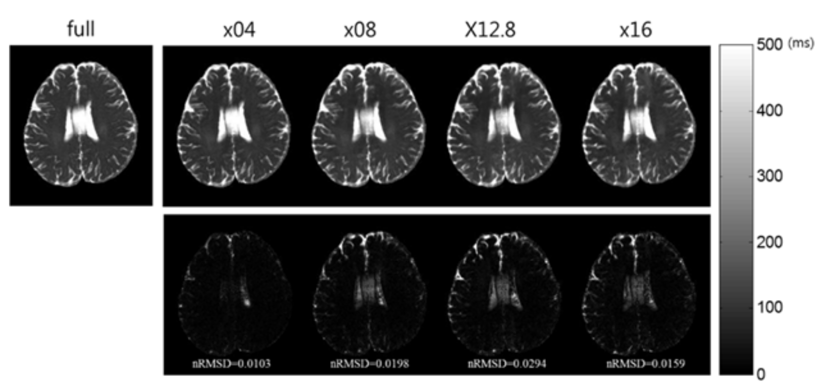


**Figure 3. Reconstructed T2 map of human brain for each acceleration factor. Difference map compared to map of full data listed below the maps.**

[1] Siemonsen, S, et al., Radiology, 2008; 979-986. [2] Wallis, L.I., et al., JMRI, 2008; 1061-1067. [3] Yoon, H et al., IEEE TMI, 33(11) 2014; 2069-2085. [4] Jung, H et al., MRM, 2009; 61(1): 103–116. [5] Lee, D, et al., ISBI, 2014; 645-648.