Development of GPU-based fast reconstruction algorithm for Gamma ray imaging with insufficient conditions

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The purpose of this study is to develop a graphic processing unit (GPU)-based fast reconstruction algorithm for nuclear medicine image under insufficient conditions, and verification of the developed algorithm is carried out to achieve the purpose. Simple-pattern water phantoms containing isotopes were designed using Monte Carlo simulation. Then, single-photon emission computed tomography (SPECT) and positron emission tomography (PET) scanning processes were simulated to acquire the projection data. The image reconstruction was performed using the GPU-based algorithm. After the image acquisition, to verify the performance of the algorithm, an analysis of the image profile, signal-to-noise ratio (SNR), and reconstruction time was performed by comparing the reconstructed images under different conditions. The image reconstruction times for SPECT and PET using the GPU were 449 and 811 times faster than those using the central processing unit (CPU), respectively. The contrast and SNR results in three radioisotope uptake regions of the image using the GPU-based fast iterative reconstruction algorithm were clearly better than those using the CPU-based filtered back projection algorithm. We confirmed the good performance of the developed GPU-based algorithm in that image reconstruction can be conducted in significantly short time and with relatively good image quality, compared with that using a conventional CPU-based algorithm under the same conditions.

I. INTRODUCTION

Because the algorithm for image reconstruction is based on a probabilistic model, the true signal with a high likelihood is indeed intensified but the signal with a low likelihood, such as noise, is weakened in the expectation and maximization steps [1]. For this reason, even though the iterative reconstruction algorithm has an advantage that it is possible to reconstruct an image with a low projection number, a long calculation time is unavoidable. Moreover, because of its applications in other fields such as the fusion imaging technique, there have been many studies of fast acquisition in nuclear medicine imaging [2]. To realize fast image acquisition, two factors should be considered, i.e., short reconstruction time and short projection time (or low projection number). If these two factors are shortened, it is possible to apply fast image acquisition to radiation therapy. Particularly, in a previous study carried out in our institute, prompt gamma-ray imaging for tumor monitoring in boron neutron capture therapy (BNCT) has been performed to reconstruct images with low projection and low effective event number because of treatment time [3, 4]. Graphics processing unit (GPU) is one of the acceleration methods for image reconstruction. The many small threads of a GPU share the computing work in parallel processing [5-7]. Thus, the purpose of this study is to develop a GPU-based fast iterative reconstruction algorithm for nuclear medicine image under insufficient conditions such as low projection and low effective event number.

II. METHODS AND RESULTS

II .1. Application of the Developed Reconstruction Algorithm

Because the image variable λ can be calculated in the iteration by updating an old image variable, to reduce the reconstruction time and overcome a lack of effective events, the E-step and M-step should be corrected [3]. Thus, in this study, we attempted to improve the two factors for the reconstruction algorithm. We assigned the subset calculations to each thread in the GPU as following Eq. (1).

$$\sum_{N(global)} Thread\,Variable = \sum_{T_n} \sum_{T_m} \sum_{i \in S_L} Subset\,Variable \qquad \text{Eq. (1)}$$

where T denotes the thread in the GPU, m and n are the numbers of horizontal and vertical threads, respectively, N is the number of global memory in the GPU, and SL is the degree of the subset. Each subset calculation occupied a part of the image domain. These calculations are performed in parallel at the same time. This calculation method is similar to the 'puzzle making', where many people are attending simultaneously as the individual parts in one place at the same time. Each subset performs the reconstruction work in the assigned domain using Eq. (2).

$$\sum_i C_{ij} = \frac{1}{\lambda_j}\sum_i \left(\frac{C_{ij}\lambda(old)_j}{\sum_k C_{ik}\lambda(old)_k}\right) \quad \text{Eq. (2)}$$

λ = image variable
Cij = system matrix (i: event from source, j and k: source pixels)

For conventional iterative reconstruction algorithms, the whole image domain is used to reconstruct the image because the maximum likelihood values are focused on the whole projection data. For this reason, the maximum image value in the reconstructed image is one, and it is hard to reconstruct the image with low effective events. However, if there is a maximum value at each subset, degradation of the weak intensity signal by excluding noise can be prevented. This parallel calculation can reflect the weak true signal caused by the lack of effective events. After the calculation in each subset, the calculation results are collected in the global memory. To assign the reconstruction calculation at the CPU level to the GPU, the order equation is defined as following Eq. (2).

$$\lambda_{j(global)} = \frac{\lambda(old)_{j(global)}}{\sum_{T_n}\sum_{T_m}\sum_{i\in S_L} C_{ij(mn)}}\sum_{T_n}\sum_{T_m}\sum_{i\in S_L}\left(\frac{C_{ij(mn)}}{\sum_{T_n}\sum_{T_m}\sum_{k\in S_L} C_{ik(mn)}\lambda(old)_{k(mn)}}\right) \quad \text{Eq. (2)}$$

When the original iteration number is larger than 120th, because the image variable value is larger than the maximum likelihood value, the original iteration condition was set at the 120th iteration. Moreover, the performance of eight subsets shows the fastest reconstruction time among several other options. Hence, the 15th iteration number was applied to reconstruct the image when the developed algorithm was used.

III. CONCLUSION

In this study, we developed a GPU-based fast iterative reconstruction algorithm for nuclear medicine image under insufficient conditions such as low projection and low effective event number. We confirmed the good performance of the developed GPU-based algorithm in that image reconstruction can be conducted in significantly short time and with relatively good image quality, compared with that using a conventional CPU-based algorithm under the same conditions.

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