Preliminary investigation of a Monte Carlo-based system matrix approach for quantitative clinical brain ^{123}I SPECT imaging

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***Abstract*—A next-generation, adaptive, dynamic multi-pinhole system, AdaptiSPECT-C, dedicated to clinical brain SPECT imaging, is currently under development as part of a collaboration between the universities of Arizona and Massachusetts. It has been shown that accurate modeling of the system matrix is a key aspect of SPECT image reconstruction as it has the potential to improve the imaging performance of any system. A straight-forward approach to modeling is based on the use of Monte Carlo simulation to pre-compute and store the system matrix. Generally, in clinical imaging, given the large sizes of detectors and volume of interests this approach faces critical memory storage issues despite the use of sparse structures to store the system matrix. The aim of this work was to investigate the feasibility of a Monte Carlo simulation pre-computed system matrix approach for ^{123}I clinical brain SPECT imaging with the AdaptiSPECT-C system. Our efficient method was evaluated using an XCAT brain perfusion phantom. The present approach's feasibility was fully demonstrated in case of clinical ^{123}I brain imaging.**

***Index Terms*—Clinical ^{123}I brain imaging, modeling of the system matrix, Monte Carlo simulation, quantitative SPECT imaging**

I. Background

In recent years, SPECT imaging of neurological disorders such as Parkinsonism using ^{123}I labelled pharmaceuticals has become a powerful diagnostic tool for the neuro-radiologist. Systems capable of dynamic and static imaging could potentially take full advantage of available agents, and thus further improve diagnoses and monitoring of treatment. In order to address these imaging needs, an innovative multi-pinhole system, called *AdaptiSPECT-C*, dedicated to adaptive brain SPECT imaging, is currently under development as part of a collaboration between the universities of Arizona and Massachusetts, and Z-Concepts. It is well-known that accurate modeling of the system matrix (SM) is a key aspect of SPECT image reconstruction [1], and has the potential to improve any system imaging performance. A straight-forward and well-known approach is based on the use of Monte Carlo simulation (MCS) to pre-compute and store the SM. A SM pre-computation-based approach has some significant advantages in terms of reconstruction speed and could thus potentially facilitate dynamic and adaptive imaging capabilities of *AdaptiSPECT-C*. However, there are two major drawbacks associated with it: excessive computation time and potential memory storage issues [1], [2]. Generally, in clinical imaging, given the large sizes of detectors and volume of interests (VOI), this approach faces critical memory storage issues despite the use of sparse structures to store the SM. The aim of this work is to first investigate the feasibility of an MCS pre-computed SM approach in case of ^{123}I clinical brain SPECT imaging using the *AdaptiSPECT-C* system.

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II. Material and Methods

A. System description

The preliminary *AdaptiSPECT-C* design, is composed of 23 hexagonal detection modules spherically arranged along 3 rings of detectors (Fig. 1) [3]–[5]. Each of these modules is associated to a single, 2.0 mm radius, knife edge pinhole collimator composed of tungsten alloy [3]. A detection module consists of two layers: a NaI(Tl) crystal part and a back compartment in order to model downscatter interactions from ^{123}I high energy photons.

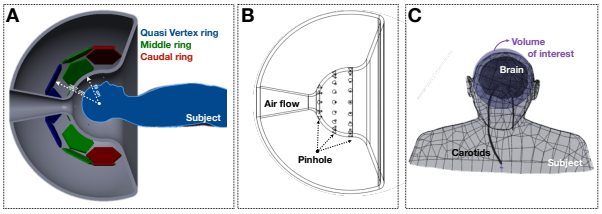

Fig. 1. (**A**,**B**) Schematic view of the preliminary *AdaptiSPECT-C* design. (**C**) Anatomical view presenting *AdaptiSPECT-C* spherical VOI of 21 cm diameter.

B. System Matrix computation

The main idea of this work is based on incorporating an accurate description of the physical phenomena occurring within the system into a reconstruction algorithm in order to significantly improve reconstructed images.

For this purpose, one straight-forward solution is to model using MCS, those effects into the system matrix $\mathcal{R}$, which

represents the mapping between the image and projection spaces.

The *AdaptiSPECT-C* image space was set to be 24 cm diameter sphere, sampled within a cube of 120^3 8 mm^3 voxels, allowing a reconstruction of the entire brain. Each of the 23 hexagonal detectors was defined as a square of 200 by 200 of 1 mm^2 pixels. In order to save disk space as well as to avoid potential memory issues, an efficient sparse structure containing only non-zero SM elements was developed. Given the random nature of MCS, statistical noise affects the estimation of each of the SM elements which then propagates from the matrix to the reconstruction [6]. We carefully investigated the impact of the SM statistical noise.

C. Figures of merits

An XCAT brain cerebral blood flow phantom with ^{123}I labeled IMP distribution [7] (Fig. 2) was used to assess the quality of the images reconstructed using the following system matrices,

- SM obtained using n detected counts. n values investigated below were 7.64, 12.7, 25.3, 44.3, 56.2, 78.2, and 90.0 $\times 10^9$ detected counts.

A simulated phantom was filled with an initial activity of 1.83 MBq/cc and data acquired for 30 sec. A total number of 4.25×10^7 detected counts were acquired over the 23 detection heads. Projections were reconstructed with a customized 3D-MLEM reconstruction software into image matrices of 120^3 8 mm^3 voxels.

III. Results and Discussion

First of all, we can highlight the overall accuracy and statistical robustness of the system matrices used (Fig. 2). Indeed, the approach produces images very close to the reference image (Fig. 2).

An emission statistic of 90.0 billions detected counts used to build the SM represents the best choice, a significant improvement of the reconstructions compared to lower SM emission statistics can be seen (Fig. 2).

The efficient developed SM sparse structure allows us to decrease the matrix size on disk from 6.4 TB (*storage of all SM elements*) to 36 GB. Associated reconstruction speed is fast, following an SM loading time of 6 min, only 12 sec per iteration are required using 8 parallel threads on a 3.6 GHz Intel Xeon multi-CPU computer.

IV. Conclusion

The present approach's feasibility, based on system matrix pre-computation by MCS, was demonstrated in the case of clinical ^{123}I brain imaging.

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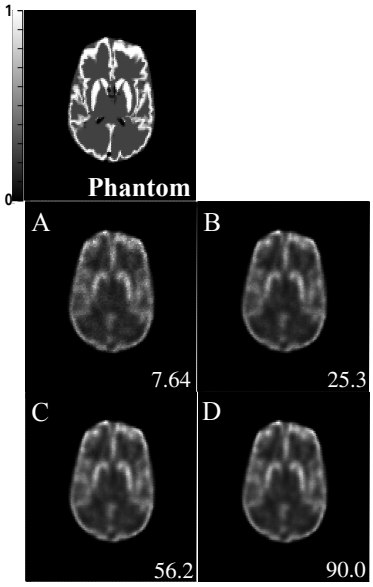

Fig. 2. Reconstructed images of the XCAT brain perfusion phantom using 7.64 [**A**], 25.3 [**B**], 56.2 [**C**], and 90.0 [**D**] ($\times 10^9$) detected counts used to build the system matrix (*Images are for 100 iterations*).

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