Image Reconstruction for Awake Animal SPECT Imaging

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Abstract– **Imaging of unanesthetized, unrestrained small animals can provide unique capabilities for biomedical research by eliminating the impact of anesthetic on the animal brain function and reducing the stress to the animal. An image reconstruction algorithm for an awake animal SPECT imaging system has been designed and implemented. The imaging system itself utilizes a real-time optical tracking system with three infrared cameras to provide time stamped pose data of the awake mouse head during the SPECT scan. The gamma events also are time stamped and a third file provides information on the gantry position as a function of time. Information from these three files is used in an iterative list-mode maximum likelihood expectation maximization algorithm. A calibration phantom with optical reflectors and radionuclide point sources enables the transformation between the tracking reference frame and the gamma camera reference frame to be determined. During image reconstruction the image volume is transformed from the gamma camera reference frame to the tracking reference frame for motion correction. The calibration phantom was imaged with and without motion, and reconstructed with and without motion compensation. The spatial resolution (FWHM) of the moving point sources with motion correction is only about 0.1 mm worse than that of the point sources imaged without motion. Reconstructions of an awake animal scan with and without motion compensation were performed. Visual comparison of the reconstructed head volume reveals significant improvement of image quality when motion corrections are implemented.**

I. Introduction

Imaging of unanaesthetized unrestrained small animals can provide unique capabilities for biomedical research by eliminating the impact of anesthetic on the animal brain function and reducing the stress to the animal. Studies of animal brain functions are essential in the development of methods of early diagnosis of brain diseases and testing of new drugs to cure them. Awake animal imaging presents a challenging task for hardware and software developers alike. This paper focuses in particular on design and implementation of SPECT image reconstruction software that takes into account animal motion.

II. Methods

The awake animal SPECT imaging system being developed by Thomas Jefferson National Accelerator Facility and Oak Ridge National Laboratory, and sited at Johns Hopkins University, is comprised of three major subsystems: gamma radiation detectors, animal motion tracking system and rotating gantry [1] and [2]. An imaged animal is confined to a transparent tube. The tube's location can be adjusted for proper positioning of the animal for imaging. Two gamma-ray detectors are mounted on the gantry. Both detectors are based on a 4 by 2 array of position-sensitive photomultiplier tubes (Hamamatsu H8500) coupled to a pixellated array of NaI scintillator. One of the detectors is equipped with a pinhole collimator with interchangeable inserts, another one utilizes a parallel hole collimator. The motion tracking subsystem consists of three compact infrared cameras with a ring of LEDs around them. The camera assembly is statically mounted on the gantry, overlooking the study animal. Three retroreflective markers are attached to the head of the animal. Images of those three markers are taken at a frequency of 15 frames/sec, centroids of each marker are calculated and the centroid data are used to calculate translational and rotational offsets from an arbitrary starting position. Further details of the system are provided in a separate submission to this conference.

The data acquisition process is divided between three CPUs. One is controlling gantry motion, another one is receiving and analyzing animal tracking data and the last one is acquiring list-mode gamma data. Each PC contains a PCI-SyncClock32 Universal board (Brandywine Communications, Santa Ana, CA) to synchronize timing information of each subsystem. The gantry controlling computer outputs a log file with timed gantry angular positions, the animal tracking unit provides a time-stamped animal pose file and the gamma acquisition PC records a file that contains a time-stamped list of energy and x and y positions of detected gamma particles.

Image reconstruction software, implemented on an Apple Macintosh computer using C++ and OpenGL, is a generalization of a histogrammed list-mode maximum likelihood expectation maximization algorithm. The following stages are performed in order to reconstruct the activity distribution.

During a preprocessing step, the software reads in the data from the entire subsystems and sorts gamma events into separate image frames according to animal poses, recorded in gantry and tracking files. Each pose is defined by a gantry location and an animal head position, conveyed by the tracking file. An animal head position is characterized by three orthogonal translations (x, y and z) and three rotation angles (roll, pitch and yaw convention). All six orientation parameters must not vary by more than preset amounts for gamma events to be sorted into the same image frame. Preset values can be defined for every execution of the reconstruction code; values of 0.1 mm for translational and 0.1 degrees for rotational offsets are used most commonly.

In the geometric coordinate system for image reconstruction the detector and collimator are positioned

according to their initial geometric arrangement and their coordinates remain stationary. The image volume is rotated and translated to model the motion of an animal and rotation of the gantry. Since animal tracking and gamma detection system are operating in their own frames of reference, TRF and GRF respectively, a method of relating those has been implemented.

Such a method uses a quality control (QC) phantom comprised of three retro reflectors and three radioactive point sources. Sealed spherical sources of Co-57 are embedded in a Lucite block and retro reflectors are glued on it too. Another coordinate system is introduced, one associated with the phantom. The coordinates of all of the retroreflectors and radioactive sources are known from the phantom design. The static QC phantom is imaged by the gamma system while it being tracked. The gamma data is reconstructed in the GRF. Utilizing the intermediate coordinate system of the phantom, in which coordinates of the retroreflectors and radioactive sources are known, a conversion transformation from the tracking reference frame to that of gamma system is calculated. This matrix is then used to calculate the volume position in gamma reference frame according to the formula:

$$x(GRF;t) = R_{TG}[R_{pose}(t)R_{pose}^{-1}(t_0)$$
$$\{R_{TG}^{-1}[x(GRF;t_0) - t_{TG}] - t_{pose}(t_0)\} + t_{pose}(t)] + t_{TG}$$

where x(GRF;t) is an arbitrary point in the gamma reference frame at time t, R_{TG} and t_{TG} are rotational and translational transformations from the tracking to the gamma reference frame, R_{pose} and t_{pose} are rotational and translational transformations of the volume according to the tracking system, and t_0 is the scan starting time point. The above equation describes the process of applying tracking information to a point in GRF. An inverse transformation tracking-to-gamma is applied first to determine coordinates of a point in the TRF. Rotational and translational offsets are applied and finally the coordinates are transformed back from the TRF to the GRF.

The system response matrix is calculated analytically using idealized model of pinhole collimator response $g = d^2 \cos\theta / 4\pi r^2$, where d is the diameter of the pinhole, r is the distance from a source voxel to the collimator and θ is an angle between pinhole axis and a radius vector of a source voxel. A Siddon-like algorithm [3] of ray tracing has been implemented to obtain detection probabilities at every pose. The ordered subsets acceleration method has been added to reduce reconstruction time.

Several scans of the QC phantom have been performed. During some of the scans the phantom was constantly moved to imitate animal motion. Phantom data were reconstructed with and without motion corrections. In order to assess reconstructed spatial resolution of the system scans of a static and moving Ultra-Micro Hot Spot Phantom (Data Spectrum Corp, Hillsborough, NC) have been carried out. Phantom hot rods' diameters were 0.75, 1.0, 1.35, 1.7, 2.0 and 2.4 mm. Total activity in the phantom was ~ 17mCi. Phantom was imaged from 120 anglesFinally, scans of a live mouse, injected with Tc99m-MDP, were performed. In this example a white female BALB-C 32.1g mouse was injected through a tail vain with 3.3 mCi of Tc99m- methylene diphosphonate (MDP). The mouse was imaged ~3hr post injection using a 1 mm diameter pinhole collimator with 1.5x magnification. List-mode data were acquired at 120 gamma stops over 360 degrees, at 20 sec /position.

III. Results

One-dimensional projections of reconstructed volumes of the QC phantom scans are shown in Fig. 1. In non-motion corrected reconstruction one cannot distinguish individual point sources as they are completely blurred.

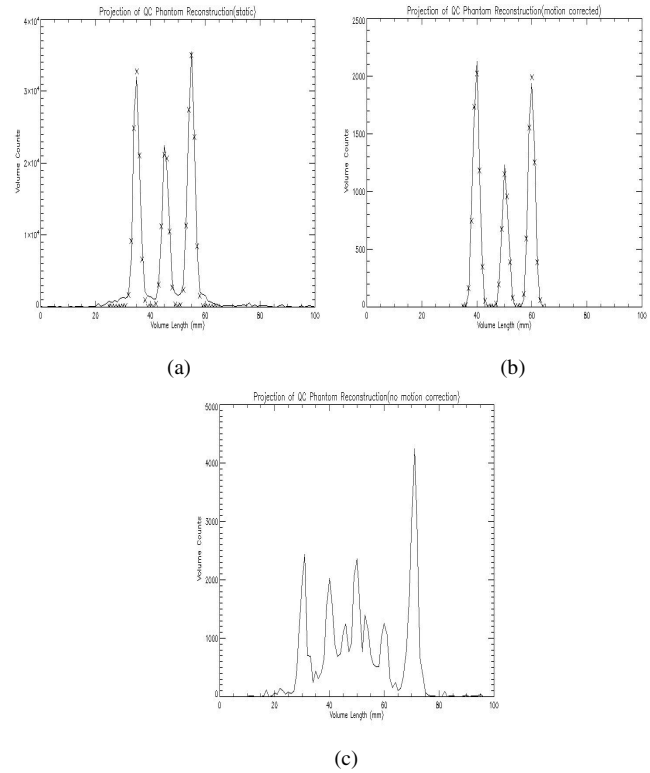


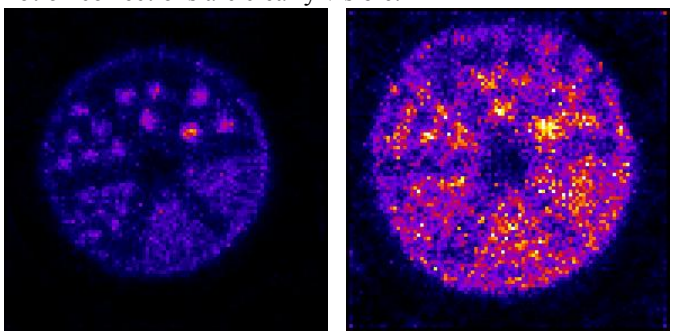
Fig.1. 1-dimensional projections of static phantom data set (a), moving phantom data set with (b) and without (c) motion corrections

Table 1 lists the full width at half maximums for a profile taken through each of the three point sources in the volumes for static and motion corrected cases. As can be seen from the data, motion compensation reconstruction delivers the spatial resolution almost as good as that of static scan.

TABLE I
FULL WIDTH AT HALF MAXIMUMS OF PROFILES TAKEN THROUGH EACH GAMMA SOURCE

	Static FWHM (mm)	Corrected FWHM (mm)
Point 1	1.93	2.07
Point 2	2.03	2.11
Point 3	1.95	2.01

Fig. 2 shows axial slices through the reconstructed volume of Ultra-Micro Hot Rod phantom. Slices are 0.5 mm thick. Without motion correction the reconstructed image is blurred and distorted, while motion corrected slice reveals distinguishable rods down to 1.35 mm diameter. Montage of maximum intensity projections of volumes obtained by scanning a mouse is presented in Fig.3. Improvements due to motion corrections are clearly visible.



(a) (b)

Fig.2. Axial slices thought the reconstructed volume of Ultra-Micro SPECT phantom, motion corrected (a) and uncorrected (b)

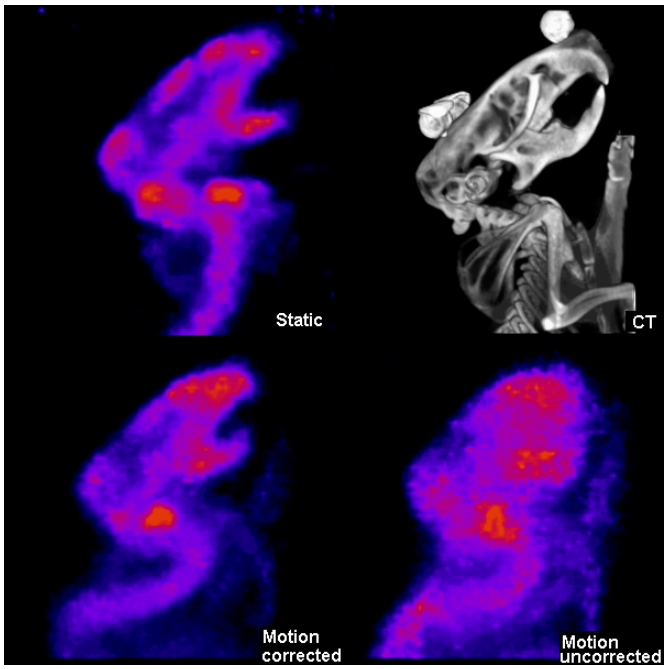
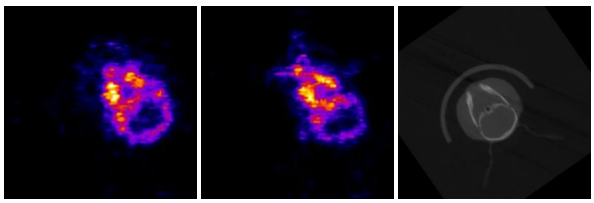


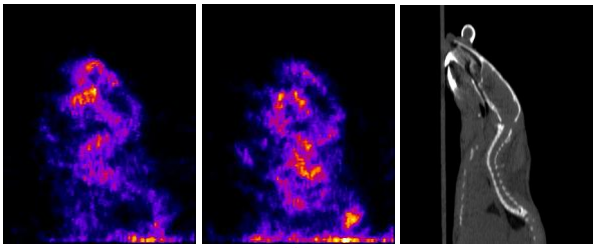
Fig.3. Maximum intensity projections of reconstructed mouse volumes with X-ray CT MIP for orientation.

Fig.4 and 5 exhibit slices taken through the mouse volumes in case of corrected and uncorrected reconstructions. Distortions are evident in both axial and saggital views.



(a) (b) (c)

Fig. 4. Axial slices through corrected (a), uncorrected (b) and X-ray CT (c)



(a) (b) (c)

Fig. 4. Saggital slices through corrected (a), uncorrected (b) and X-ray CT (c)

IV. Conclusions and Future Work

A motion compensation reconstruction code that allows for imaging awake unrestrained animals has been implemented. We observed that image resolution degradation in a moving object is not significant compared to the static case. The use of this algorithm in removing motion blur is demonstrated for both phantoms imaging a live awake animal study. Future plans include implementation of scanner calibration and a user-friendly interface. Preparations for a real study of a live animal brain function with and without anaethesia are under way at Johns Hopkins University.

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