SinoCor: Motion Correction in SPECT

Debasis Mitra[1], Daniel Eiland[1], Mahmoud Abdallah[1], Rostyslav Bouthcko[2], Grant T. Gullberg[2], and Norberto Schechtmann[3]

[1] Department of Computer Science, Florida Institute of Technology, Melbourne, FL 32901, USA

[2] Lawrence Berkeley National Lab, 1 Cyclotron Drive, Mail Stop 55, Berkeley, CA , USA

[3] MIMA, Melbourne, 1223 Gateway Drive, Melbourne, FL 32901, USA

Abstract. Motion is a serious artifact in Cardiac nuclear imaging because the scanning operation takes a long time. Since reconstruction algorithms assume consistent or stationary data the quality of resulting image is affected by motion, sometimes significantly. Even after adoption of the gold standard MoCo(R) algorithm from Cedars-Sinai by most vendors, heart motion remains a significant challenge. Also, any serious study in quantitative analysis necessitates correction for motion artifacts. It is generally recognized that human eye is a very sensitive tool for detecting motion. However, two reasons prevent such manual correction: (1) it is costly in terms of specialist's time, and (2) no such tool for manual correction is available currently. Previously, at SPIE-MIC'11, we presented a simple tool (SinoCor) that allows sinograms to be corrected manually or automatically. SinoCor performs correction of sinograms containing inter-frame patient or respiratory motions using rigid-body dynamics. The software is capable of detecting the patient motion and estimating the body-motion vector using scanning geometry parameters. SinoCor applies appropriate geometrical correction to all the frames subsequent to the frame when the movement has occurred - in a manual or automated mode. For respiratory motion, it is capable of automatically smoothing small oscillatory (frame-wise local) movements. Lower order image moments are used to represent a frame and the required rigid body movement compensation is computed accordingly. Our current focus is on enhancement of SinoCor with the capability to automatically detect and compensate for intra-frame motion that causes motion blur on the respective frame. Intra-frame movements are expected in both patient and respiratory motions. For a controlled study we also have developed a motion simulator. A stable version of SinoCor is available under license from Lawrence Berkeley National Laboratory.

Key Words: Image restoration and enhancement; Motion Analysis; Patient and respiratory motion estimation and correction; User-friendly *ImageJ* plugin.

1. Introduction

Motion is a serious artifact in Cardiac nuclear imaging. Reconstruction algorithms typically assume consistent or stationary sinogram. Also, any serious research in quantitation necessitates correction for motion artifacts. Several types of motions affect a study: periodic (respiratory and cardiac), linear (heart creep), random and bounce (fidgety patient movement). [1] In a diagnostic scenario, data with large patient motions are often discarded and the patient is sent for a repeat scan, which results in extra radiation and chemical dose to the patient, additional costs, and delayed treatment. [http://www.pharmstresstech.com/techtips/10/] Motion correction algorithms currently used are identified as automatic, semi-automatic, and manual. The primary focus of most of the past works in motion correction is on automatic approaches. *MoCo*® from Cedars-Sinai Artificial Intelligence in Medicine (AIM) [2] is the current gold standard. It is an automated algorithm, licensed and deployed by most scanner vendors. The algorithm iteratively uses filtered backprojections to smooth over the motion. Schumacher and Fischer [3] use an innovative approach to reconstruct the motion-blurred frame(s) via the image computed from the partial consistent sinogram and forward projection, presuming that the sinogram without the motion-frame(s) is self-consistent that may not be the case as can be seen in the two motion-examples we described here. Attempts have also been made to embed motion model into reconstruction algorithm [4] that needs accurate knowledge of the model. Various gating techniques with aggregation of frames over time-phases of motion remain a popular alternative that are not necessarily good for quantitation objectives [5, 6].

It is generally recognized that the human eye is a very sensitive tool for detecting motion [1]. One can easily recognize some types of motion artifacts on a sinogram. Thus, given appropriate tool motion correction may be an easy pre-processing step that may be performed while checking the quality of the acquired sinogram, which is a routine operation done immediately after a scan. However, two reasons prevent such manual corrections: (1) manual correction is costly in terms of specialist's time, and (2) no such tool for manual correction is available currently.

In the SPIE-MIC 2011 conference we presented SinoCor, a user-friendly software that provides the capability for rigid-body motion correction for two simplest types of patient movements: translational motion in three dimensions and rotation about x and y axes (we denote z-axis as the direction of patient table motion). Even heart creep (linear motion) may be corrected with such a manual intervention technique [7]. This is achieved through a real-time sinogram correction (hence, SinoCor), where the input parameters for correction may be interactively determined and applied by the user. Usage of SinoCor will not interfere with any reconstruction and subsequent processing.

Our current enhancement with SinoCor involves developing capability of automatically correcting intra-frame rigid-body motions. Such motion causes blurring of the respective frame, as well as shift of the object position as was targeted in our previous study [8]. Below we describe our past approach briefly and elaborate our subsequent works on intra-frame motion correction. Some results with simulation and real data are also included here. Finally we present the future direction for SinoCor.

2. Methods

We briefly discuss here the algorithm for detecting single instance of relatively large patient-motion (two or more detector pixels). The underlying assumption here is that once moved the patient remains in the same place for rest of the scan. After detection of motion, the algorithm estimates the motion-parameters [7, 9] using the scanning geometry. Currently we are working with only SPECT data acquired using parallel beam collimators. However, the approach may be generalized to other imaging modalities easily.

2.1 Geometry-based Correction algorithm for large one-time movement (Patient motion)

Let (x,y,z) be the image space coordinates of a point inside the reconstructed volume. The detector space is defined by (θ, u, v), where θ is the gantry rotation angle, and (u,v) are 2D detector plane coordinates:

$$\underline{u} = x \cos \theta + y \sin \theta, \quad v = z. \qquad (1)$$

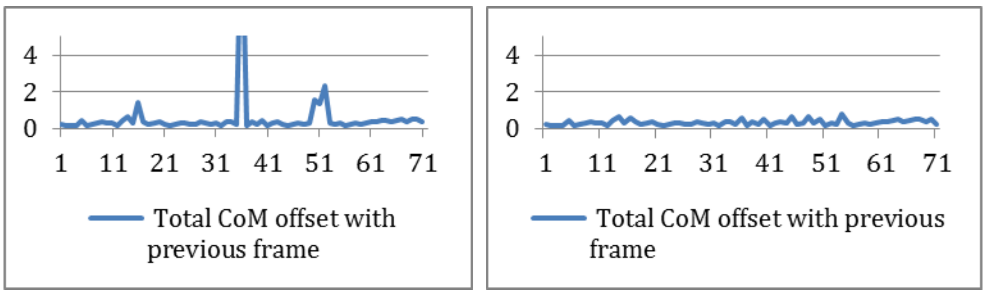

***Figure 1**. Frame-to-frame com (Ctr. of mass) offset in sinogram (left) and corrected sinogram as measured from the respective com's (significant patient movement in dual head SPECT). Movement seen on 15^{th} (1^{st} head) & 52^{nd} (2^{nd} head) frames (left). Head changes on 36^{th} frame.*

Translation. This type of motion is the simplest to correct for and is the main working formula in the first version of SinoCor. If at gantry rotation angle θ_0, the imaged object shifts along a displacement vector $\Delta\mathbf{r} = (\Delta x, \Delta y, \Delta z)$, then, as seen from (1), it is sufficient to shift the sinogram view by

$$\Delta\underline{u} = -\Delta x \cos \theta - \Delta y \sin \theta \quad \text{and} \quad \Delta v = -\Delta z \qquad (2)$$

in the detector plane for gantry rotation angles $\theta > \theta_0$.

Rotation. Small angle rotation about an axis within the *xy* plane can be approximately represented (and corrected for) at a sinogram-level. E.g., if the imaged object rotates by a small (order of $\leq 1^o$) α in *xz* plane, it's projection onto a detector at θ=0 or θ=π should be scaled in *z* direction by cos α, and its projection at $\theta = \pm\pi/2$ should be rotated by α. At other values of θ, a combination of both corrections should be used. More detailed discussion of the approximate correction approach is beyond the scope of this abstract. The first version of SinoCor implements only translational motion correction. Rotation feature will be added to SinoCor in the future, however, we do not plan to include patient rotation about *z*-axis. While trivial, correction for this type of motion requires slight modification of the reconstruction algorithm and cannot be confined to only sinogram space.

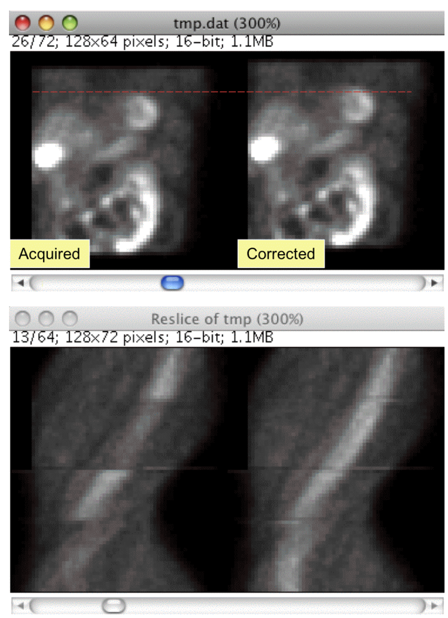

***Figure 2**. Acquired and corrected sinogram view-frames (top) and resliced view (bottom).*

2.2 Motion detection with SinoCor

Patient-motion data shown in the figures here are from a SPECT imaging with L-configuration dual head (90-degree offset), parallel-hole collimator, where each head moves for about 100 degrees. For each 2D frame of the sinogram we compute the center of mass (*com*) coordinate by intensity weighted average X (u) and Y (v) coordinates. Fig. 1 displays the absolute values of the movement vectors from one frame to the next on the sinogram. Movements are clearly visible around the fifteenth and fifty-second frames for the two heads respectively. Large movement at the center (thirty-sixth frame) is where the sinogram for second head starts. Two same view-frames of the acquired and corrected sinograms (before and after motion) are shown in Fig. 2 top. Two 2D resliced sinograms (uncorrected and corrected) are shown in Fig. 2 bottom left. The same view for the corrected sinogram by SinoCor is shown on Fig. 2 right. Since large patient-motions are easily detectable the user can use sliders on SinoCor GUI panel to apply appropriate *xyz* displacements (for patient) to correct the sinogram for the patient movement from any chosen frame onwards. Corrections are applied to all frames subsequent to the motion frame. Each action on the sliders triggers geometrical recomputation according to the description above (Fig 6). Sinogram for two heads are treated independently. Once the modified sinogram achieves desired level of consistency (right on Fig. 2), it is saved for the subsequent application of image reconstruction software. SinoCor can also work in automatic mode – detecting such large motion and applying the appropriate correction to sinogram.

3. Repetitive small motion (Fidgety or Respiratory motion)

Fig. 4 is a zero-shifted stacked plot over Y coordinates of the *com* of each frame of the sinogram from a patient having significant respiratory motion. This data was kindly provided to us by a local medical professional. Fig. 5 is the corresponding corrected version.

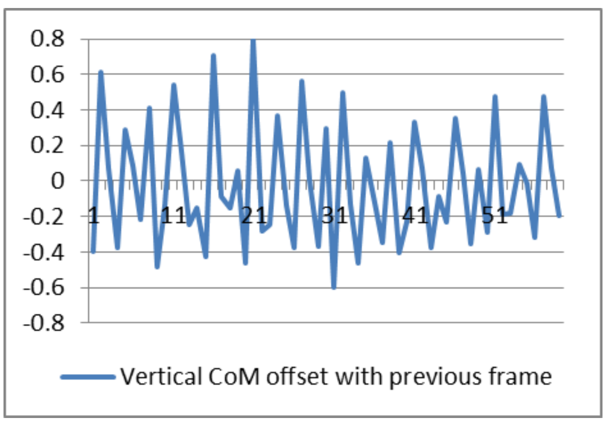

Figure 4. *Plots of vertical CoM offsets between frames of a sinogram for uncorrected respiratory motion*

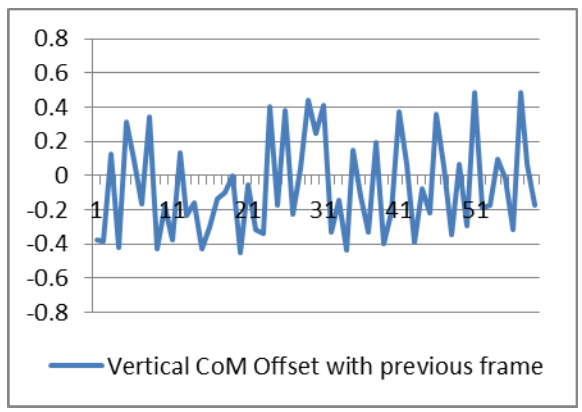

Figure 5. *Plots of vertical CoM offsets between frames of a sinogram for respiratory motion corrected by SinoCor*

Our hypothesis is that the uneven *com* movement from one frame to the next, specially observed on Y(v)-axis, is due to the respiratory motion, whereas there exists a general trend of long range *com* movement over the frames in sinogram that is caused by the usual Radon-transformation of the imaged volume. Hence, the objective of our respiratory motion correction is to shift frames such that this general trend is preserved but the *com* plots become smooth with less high frequency component.

The corrections are applied frame-wise locally and not transferred to other frames as is done in the geometry-based recomputation (for a large one-time patient movement). Current smoothing correction of SinoCor is based on previous frame's *com* value. Obviously, SinoCor only works in automatic mode for correction of such repetitive motions, as it is virtually impossible to apply so many small corrections manually.

4. SinoCor software description

SinoCor is written in JAVA and acts as an *ImageJ* [10] plugin and works as any other plugin of the latter. The appropriate *jar* file needs to be located in the plugin directory and can be launched from the plugin menu. Additional GUI opens up for interactive correction (Fig. 6, different from the previous version presented [8]). Patient movement correction and periodic motion (respiratory) correction are two different modes. The former may be done manually or automatically. Center of rotations offset correction is also possible for a dual head sinogram.

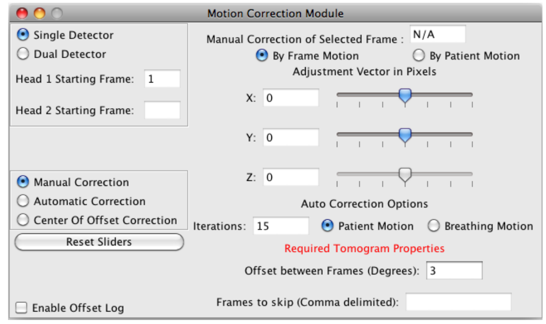

***Figure 6**: A typical SinoCor GUI panel*

5. Intra-Frame Motion

Our present work has also focused around motion that occurs during the capture of a sinogram frame. When the patient moves during the SPECT capture process, it causes a change to the point spread function (PSF) of the system. To simulate this effect, we have created a tool that allows motion to be introduced to a volume during the SPECT imaging process. The effects of which can be seen in Fig. 8, where left one is a frame from an NCAT simulation of pinhole SPECT, and the right one is from the sinogram modified by our motion simulator software. The intra-frame motion is visible as a blurred image. All the subsequent frames in sinogram reflect the motion. Existing literature avoids the intra-frame motion problem but it is quite prevalent in nuclear-imaging scan.

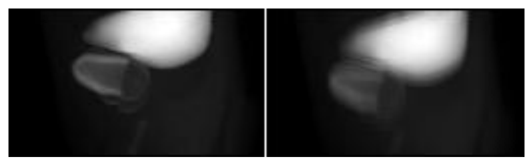

***Figure 7**: A frame before and after blurring*

We detect the blurred frames based upon their gradient values. A gradient image, G_i, is acquired by applying a *Sobel* filter [11] to each frame in the sinogram. Using the following criteria:

$$\sigma_i = stdev(G_i)$$

$$U_i = \frac{1}{2w+1}\sum_{j=-w}^{w}\sigma_{i-w}$$

$$D_i = stdev(\sigma_{i+j}, for: -w \leq j \leq w)$$

Where *i* is a frame index and *w* is the number of surrounding frames considered

A frame is classified as blurred when its value of σ_i is lower than $(U_i - D_i)$. A lower σ_i value indicates that there is less variation on the *i-th* frame with respect to *w* frames before and after *i*, and implies that the frame has less sharpness than expected. Fig. 8 displays a plot the σ value for a sinogram with blurring in frames 15 and 51 (for two detector heads).

Our immediate future work will address de-blurring of the detected frames with intra-frame motion, and correcting the sinogram accordingly.

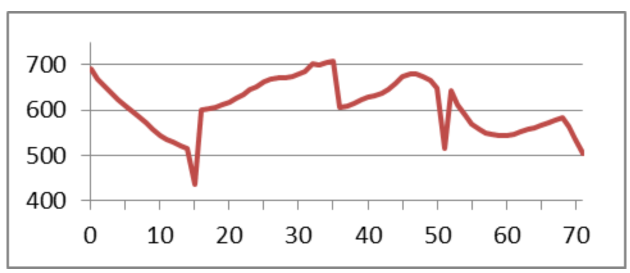

***Figure 8**: σ-value for sinogram with blurring*

6. Conclusion

A simple clinical tool (*SinoCor*) is being developed for pre-correcting sinogram (before reconstruction) that addresses sudden and observable patient movements during a nuclear-imaging scan. We present results on SPECT data. Using SinoCor one may check quality of scan data visually and at the same time apply correction for patient's fidgety or respiratory movement(s), either inter-frame or intra-frame. We expect *SinoCor* to save resources and improve the reliability of imaging in a clinical or in a research set up.

7. Acknowledgement.

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Disclaimer: This work has not been presented to any other forum so far.

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