

Development of a Motion Detecting System for Respiratory-Gated PET Using Laser Optical Displacement Sensor

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Abstract—A respiratory motion during whole-body imaging has been recognized as a source of image degradation and induces distortions in Positron Emission Tomography (PET) study. The aim of this study is to evaluate respiratory motion using lung simulator and to develop a respiratory motion detecting system using optical laser sensor. We utilized a commercially available laser optical sensor to detect respiratory motion during PET scanning. Each respiratory cycle is divided into 4 bins defined as average peak interval and irregular peak within the patient's breathing motion. The acquired data within the time bins correspond to different positions within the breathing cycle and stored for the post motion correction. Artifact of breathing motion was evaluated with the phantom study. In the images of a human subject, the blurring artifact due to breathing motion was divided by our detecting system. This technique improves the quantitative specific activity of the tracer which is distorted by the respiratory motion.

I. INTRODUCTION

POSITRON emission tomography (PET) has gained widespread acceptance in clinical oncology for the detection of metabolic and functional abnormalities at an early stage of disease. Recently, PET using ^{18}F -fluorodeoxy-glucose (FDG) has become a routine imaging tool for the evaluation of oncology patients [1]. However, during whole body PET scanning, the PET image shows an average of different organ positions during the breathing cycles. It is a major challenge for accurate localization and quantification of PET images. Respiration causes the lesion to be smeared and the image to be blurred. Smearing may

reduce image quality, quantification of FDG uptake [2-4]. Motion produced image blurring degrades the quality and reduces the quantitative accuracy of PET, resulting in the misidentification of the lesions. Also, distortion of the lesion shape and volume can potentially compromise the efficacy of PET in radiotherapy planning [5]. Respiratory gating techniques have been utilized in Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and radiotherapy. Those studies have shown that gating improves target localization and permits reduction of tumor margins with a consequent reduction in the volume of normal tissue irradiated [6-7]. CT is the most common imaging technique for providing anatomical information on the size and location of tumors in the body. However, PET has a higher sensitivity and specificity than CT for the detection and staging of cancer [8]. In this paper, we are to evaluate whether respiratory motion artifacts exist at the level of the interface of the diaphragm and lung in PET images, and to develop a respiratory motion detecting system to correct blurring effect due to breathing during PET scanning using a laser optical displacement sensor and gated data acquisition mode.

II. MATERIALS AND METHODS

A. PET Data Acquisition

GE advance PET scanner was used (General Electric Medical Systems, Milwaukee, WI) to acquire gated-PET data. The GE advance scanner has 18 detector rings corresponding to 35 image planes with an axial field of view (FOV) of 15.2 cm. The axial and the transaxial image resolutions are, respectively, 4.2 and 4.2 mm full width at half-maximum (FWHM) at the center of the gantry. All data presented in this study were acquired in 2D mode.

B. Motion Data Acquisition

A commercially available laser optical sensor (NCDT 1400, Micro-Epsilon Inc., Germany) was utilized to detect respiratory motion during PET scanning (Fig. 1(a)). The optical motion tracking sensor can measure displacement of subject respiratory cycle with 40 μm in resolution and 200 mm in measurement range. It has 100 g weight and linearity of $\pm 0.4\%$. A visible point of light is projected onto the

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subject surface by a laser diode and is observed at a narrow angle by receiving optics and focused on a position sensitive element (CCD array).

C. Monitoring Motion

As shown in Fig. 1(b), a motion tracking sensor is attached on the gantry. A patient wears reflective belt and during PET scanning, respiratory motion was detected by optical motion tracking sensor.

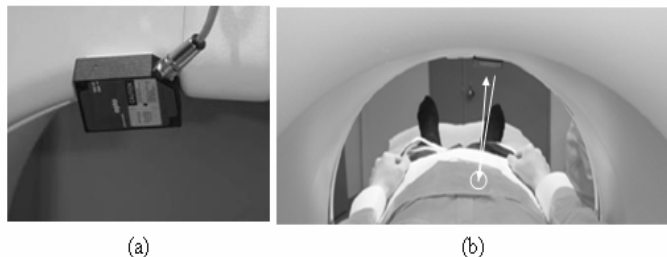


Fig. 1. CCD (Charge-Coupled Device)-type laser optical sensor for detecting the displacement of respiratory motion (a) and an illustration of the respiratory motion detecting (b).

D. Gating System

The PET scanner is designed to operate with cardiac gating, using heart beats to trigger the gating cycle. We have built a trigger circuit has as input, the output of the optical sensor relay, and as output a 0 V, which is switched into a +5 V only while the relay is in the on mode. The number of time bins and the duration of each bin are set prior to the scan on the PET console. Each respiratory cycle is divided into 4 bins defined as average peak interval and irregular peak within the patient's breathing motion.

Schematic diagrams of the present gating system are shown in Fig. 2. The motion tracking sensor provides the trigger signal to the PET scanner in order to initiate the gating cycle. The acquired data within the time bins correspond to different positions within the breathing cycle and stored for the post motion correction. The gated PET scan was corrected using segmented attenuation data of the conventional transmission scan [9]. A Gaussian filtering (8 mm) was performed for smoothing of image. The gated PET images were reconstructed using ordered subsets expectation maximization (OSEM) algorithm with 2 iterations and 28 subsets.

E. PET Experiment

In order to evaluate the present technique, phantom and human studies were carried out. All PET scans were performed in 2D mode acquisition.

a) Phantom Study

Respiratory motion measurements were performed using three phantom having 3 mm, 5 mm and 10 mm in diameter, respectively, with an activity concentration of 10 MBq. A human respiratory motion simulator, developed in this study was used to set each of the phantoms. The maximum

amplitude was approximately 20 mm, 10 mm and 6 mm, respectively, diaphragm, upper and side (Fig. 3(b)).

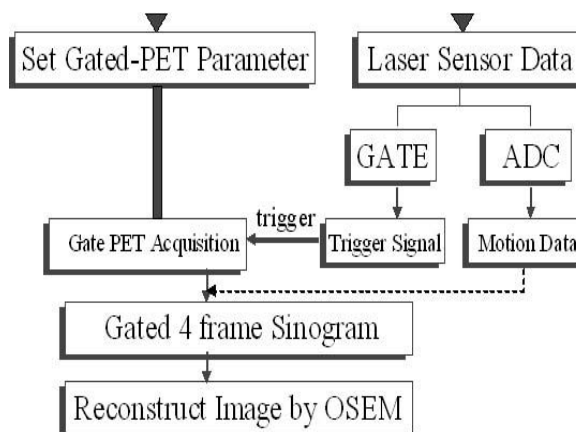


Fig. 2. Schematic diagram of respiratory gated PET detecting system. The gated respiratory images were acquired by trigger signal according to breathing cycle.

In all cases, a 1.5 min transmission scan, a 3 min nongated emission scan, and a 10 min gated emission scan, with the trigger set at the beginning of the stationary states in the phantom.

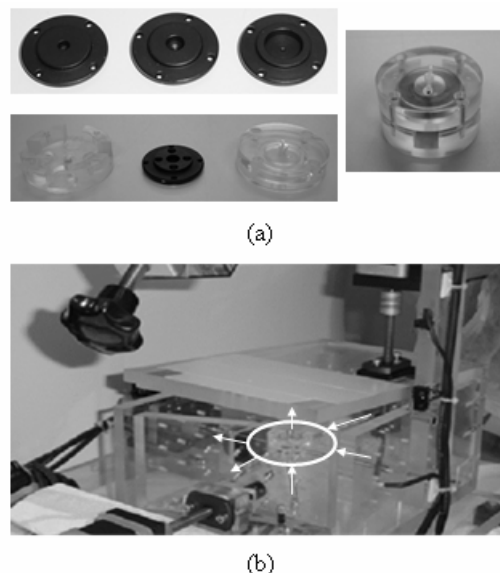


Fig. 3. Lung simulator using three x, y, z axis. (a) Point source phantom of 3 mm, 5 mm and 10 mm in diameter. (b) Motion simulator installed the three phantoms.

b) Normal Volunteer Study

In the human study, a healthy normal volunteer was intravenously injected with 330 MBq of F-18 FDG. After a transmission scan during 5 minutes, emission scans performed for 7 minutes each. The patient first received a nongated PET scan according to our routine FDG scan procedure. The total scan time took 35 min (7 min/bed-

position). A gated PET scan was acquired using the respiratory gating system to track the motion of a gating block on the volunteer's chest.

III. RESULTS

A. Various Respiratory Cycle

The motion tracking sensor has enough resolution for generating trigger signal and acquisition of respiratory motion data. Fig. 4 shows output waveforms of the optical motion tracking sensor generated by various motions from a patient.

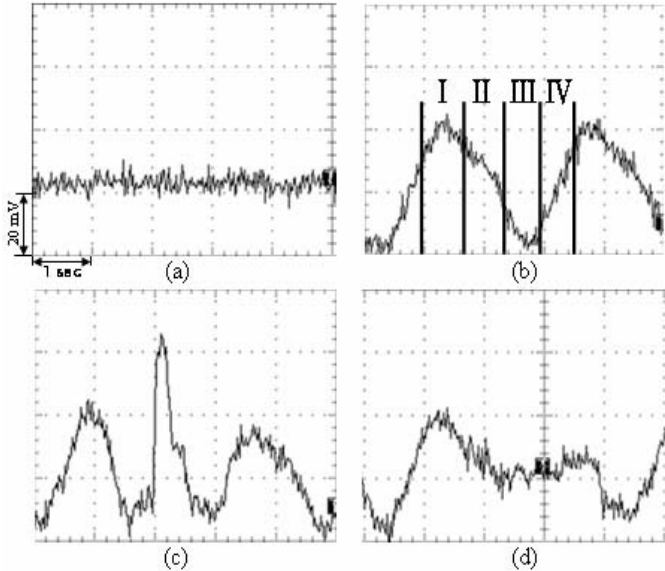


Fig. 4. Various waveforms. (a) Reference signal at a static status. (b) Normal respiratory motion divided into four bins. (c) When a patient coughed. (d) When a patient swallow saliva.

B. Phantom Study

Fig. 5 shows the effect of respiratory artifact. Fig. 5(a), (b), (c), (d), and (e) were obtained with movement of 3 mm, 5 mm, 10 mm, 15 mm, and 20 mm distance, respectively. Fig. 5(f) is maximum count and Fig. 5(g) is average count profile by 10 slices of center. In the 10 mm movement study, Fig. 6(a) is without motion, Fig. 6(b) is with 10 mm motion, Fig. 6(c) is gated inspiration image and Fig. 6(d) is full inspiration image by gating system. Fig. 7(a) shows maximum count profiles and Fig. 7(b) shows average count profiles by circle ROI on image.

C. Normal Volunteer Study

In the images of a human subject (Fig. 8), the blurring artifact due to breathing motion was divided by our detecting system. The distance between scan start level and lowest diaphragm level obtained from each bin were 23.3 mm (Fig. 8(a)), 27.2 mm (Fig. 8(b)), 29.1 mm (Fig. 8(c)), and 27.2 mm (Fig. 8(d)).

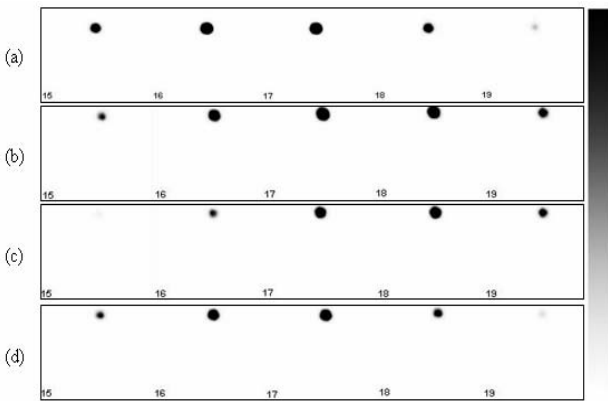


Fig. 6. Effect of respiratory motion artifact. (a) No motion. (b) 10 mm diaphragm movement during 1.8 sec. (c) Gated inspiration image. (d) Gated full inspiration image.

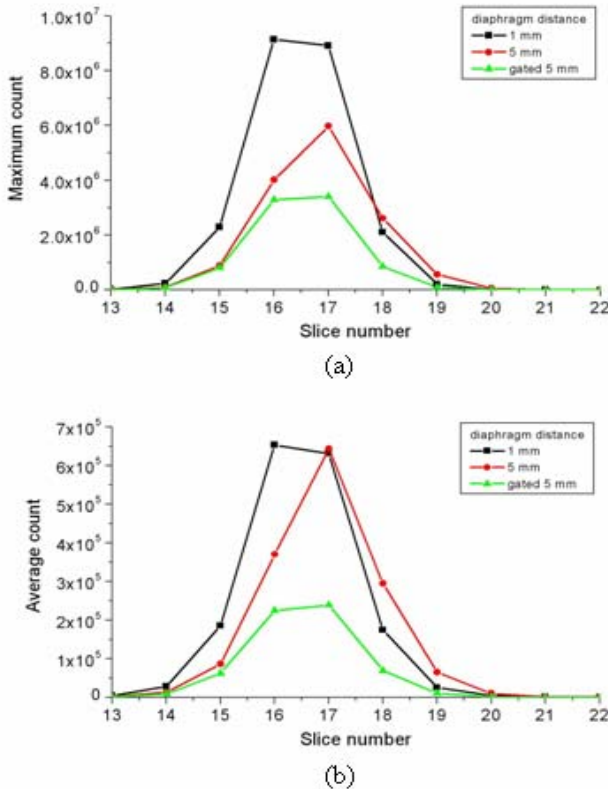


Fig. 7. Evaluation of Fig 6. (a) Maximum count (b) Average count.

IV. DISCUSSION AND CONCLUSION

The compact sensor that could be closely located in subject allowed to acquire the accurate respiratory motion data. The result of this study demonstrates that image blurring can be reduced by the gated PET in synchronization with the respiratory motion data. It allows a more complete recovery of the true counts within the lesion and a more accurate estimation the lesion volume.

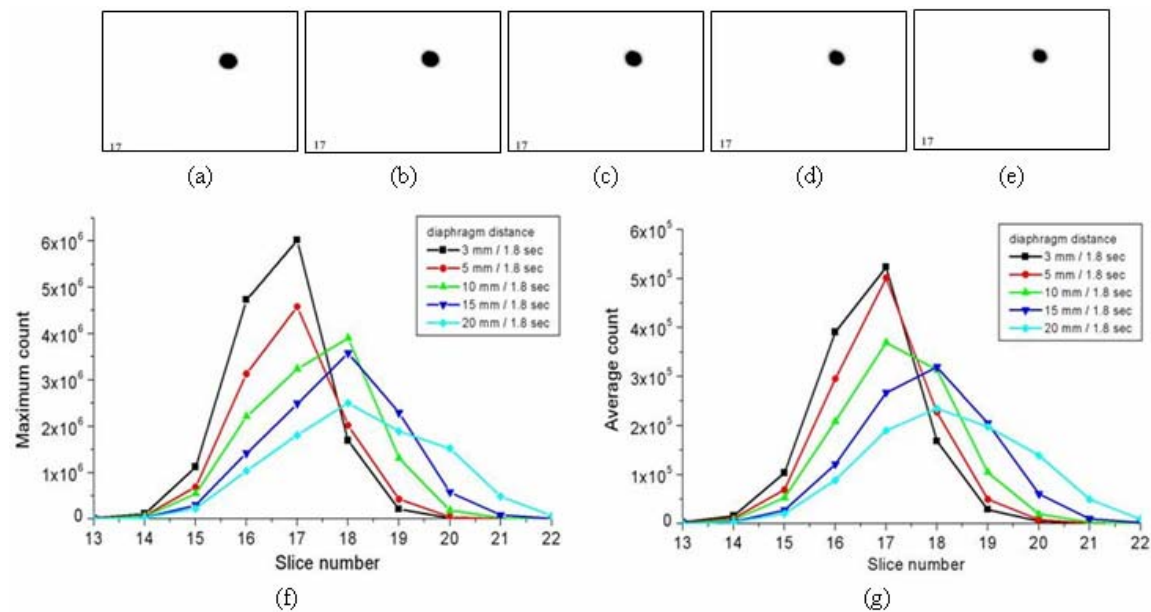


Fig. 5. 3.6 sec respiratory cycle. (a) 3 mm move. (b) 5 mm move. (c) 10 mm move. (d) 15 mm move. (e) 20 mm move. (f) Maximum count of each diaphragm distance. (g) Average count of each diaphragm distance.

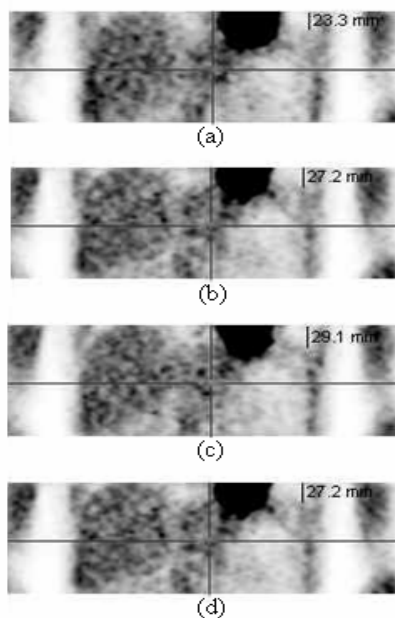


Fig. 8. Respiratory gated PET image obtained from each bin. (a) Bin I; full expiration (b) Bin II; from full expiration to full inspiration (c) Bin III; full inspiration (d) Bin IV; from full inspiration to full expiration.

Phantom studies show a dependence of the reduction in the smearing effect as a function of the lesion size and motion amplitude. This technique improves the quantitative specific activity of the tracer which is distorted by the respiratory motion.

V. ACKNOWLEDGMENT

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