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Evaluation of Methods to Produce an Image Library for Automatic Patient Model Localization for Dose Mapping During Fluoroscopically-Guided Procedures

Josh Kilian-Meneghin^{a,b}, Z. Xiong^{a,b}, A. Oines^{a,b}, S. Rudin^{a,b,c}, and D.R. Bednarek^{a,b,c}

^aToshiba Stroke and Vascular Research Center, University at Buffalo, Buffalo, NY, USA

^bDepartment of Physiology and Biophysics, University at Buffalo, Buffalo, NY, USA

^cDepartment of Radiology, University at Buffalo, Buffalo, NY, USA

Abstract

The purpose of this work is to evaluate methods for producing a library of 2D-radiographic images to be correlated to clinical images obtained during a fluoroscopically-guided procedure for automated patient-model localization. The localization algorithm will be used to improve the accuracy of the skin-dose map superimposed on the 3D patient-model of the real-time Dose-Tracking-System (DTS). For the library, 2D images were generated from CT datasets of the SK-150 anthropomorphic phantom using two methods: Schmid's 3D-visualization tool and Plastimatch's digitally-reconstructed-radiograph (DRR) code. Those images, as well as a standard 2D-radiographic image, were correlated to a 2D-fluoroscopic image of a phantom, which represented the clinical-fluoroscopic image, using the Corr2 function in Matlab. The Corr2 function takes two images and outputs the relative correlation between them, which is fed into the localization algorithm. Higher correlation means better alignment of the 3D patient-model with the patient image. In this instance, it was determined that the localization algorithm will succeed when Corr2 returns a correlation of at least 50%. The 3D-visualization tool images returned 55–80% correlation relative to the fluoroscopic-image, which was comparable to the correlation for the radiograph. The DRR images returned 61–90% correlation, again comparable to the radiograph. Both methods prove to be sufficient for the localization algorithm and can be produced quickly; however, the DRR method produces more accurate grey-levels. Using the DRR code, a library at varying angles can be produced for the localization algorithm.

Keywords

Dose; Matlab; Digitally Reconstructed Radiograph; Localization; Fluoroscopic; Visualization

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1. INTRODUCTION

1.1 Dose Tracking System Localization

A dose tracking system (DTS) has been developed that displays a color-coded mapping of the patient's skin dose during fluoroscopically-guided interventional procedures as seen in Figure 1.¹ The dose is calculated by determining the intersection of the x-ray beam with a graphic representation of the patient. All geometric parameters of the hardware components of the imaging system are determined in real time from the messages on a digital CAN bus. The position of the patient graphic is placed relative to the imaging system table and can be manually adjusted using a software GUI. To make the positioning of the graphic relative to the x-ray beam automatic without the need for operator input, a system is being developed to recognize the patient position on the fluoroscopic procedure images. The procedure image is then aligned with "projection images" of the graphic patient representations contained in a library of 3D models categorized by sex, height and weight. For this alignment, projection images of the patient models must be available. This work evaluates several methods for producing a library of radiographic projection images for automated patient graphic localization relative to the x-ray beam in real-time during fluoroscopic procedures. The localization algorithm will be used to improve the accuracy and speed of model placement for the DTS. The system currently relies on the operator to select an appropriate patient model from a graphic library and then to align that graphic on the imaging table. Human error in graphic selection and localization can introduce errors in skin dose distribution calculation. With the automatic localization algorithm, the first images from the procedure will be correlated to the reference library to select, align and scale the patient graphic used for skin dose calculation in the DTS.

2. METHODS

2.1 Images

To simulate the localization algorithm's application during a procedure, this study compares six images, three lateral and three anterior/posterior to their matching fluoroscopic views. The images used are shown in Table 1.

2.2 Methods of Image Acquisition

Lateral and AP fluoroscopic images of the SK-150 phantom⁸ (Phantom Labs, NY) were acquired on a Toshiba Infinix C-Arm system. These fluoroscopic images were compared to radiographic images obtained from the Siemens Healthcare website⁵ and radiopaedia.org⁶, as well as images projected from CT datasets of the SK-150 phantom using Plastimatch and the 3D-visualization tools. The CT datasets consisted of a matrix of $1.27 \times 1.27 \times 2.5$ mm voxels reconstructed from a scan with a Toshiba Acquilion Scanner.

2.3 Methods of Projection Image Generation

2D projection images were generated from CT datasets 1) using Schmid's 3D visualization tool within ImageJ and 2) using Plastimatch's digitally reconstructed radiograph (DRR) code:

1. The ImageJ 3D visualization tool³ uses volume rendering to provide a 3D effect. The tool places a stack of DICOM image slices one behind another, separated by a uniform distance. Depending upon the original pixel's CT number, each voxel is assigned a transparency value using a Z-buffer algorithm which meshes the intensities along a projection ray, giving priority to the closer voxels. This method aims to reproduce depth perception, or in this case, the look of a radiograph. The viewing angle can be manipulated to provide different projection images based on transparency.
2. The incremental Siddon algorithm², utilized in the Plastimatch⁴ code, projects a digitally reconstructed radiograph (DRR) image using the attenuation values from a CT dataset (listed below). The DRR method utilizes ray tracing from the source to a detector plane, following transformation of the CT numbers to linear attenuation coefficients. The line integral of the linear attenuation coefficients along the ray is computed, and then the process is repeated for different rays until the image is generated. The algorithm takes kVp, voxel size, and reconstruction matrix dimensions as input variables from the DICOM file. When the calculation begins, the angle of projection may be chosen.

2.4 Correlation Testing Procedure

The projection images, as well as the radiographic images, were compared with the fluoroscopic images of the SK-150 phantom taken to simulate an interventional procedure, using the Corr2 function in Matlab to correlate images. Corr2 returns a value, from 0–100%, for the correlation coefficient between input variables A and B, which are image matrices of the same size that are being compared. Correlation is calculated using the function⁷:

$$r = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\left(\sum_m \sum_n (A_{mn} - \bar{A})^2\right) \left(\sum_m \sum_n (B_{mn} - \bar{B})^2\right)}}$$

Prior to correlation matching, each image was processed with no filter, a Gaussian filter of standard deviation of 1.5, and two dimensional, Sobel method edge detection to determine the effect on image correlation.

2.5 Correlation Success

A correlation of 50% (correlation coefficient) or greater between the fluoroscopic and radiograph/reconstructed images has been found by experimental evaluation to provide a match for the localization algorithm. Figure 2 displays a test to reproducibly measure how correlation coefficient relates to a successful correlation between the tested images. Correlation values from the Corr2 function of fluoroscopic images and the same image with increasing variance of added noise were recorded. The 'correlation coefficient' series is the average correlation coefficient of three tested images with equivalent values of added noise. A successful correlation is defined as the program identifying a peak of correlation (similarity of pixel intensity in a discrete area) between the images; the images are then

registered and transformed to match each other. If the algorithm does not find a peak of correlation, it will reject the image pair. As a result, if the image is transformed it will be a near perfect match. Visual inspection is then completed to confirm the match and transformation, and the transformed image is then run through the algorithm once more to confirm 100% correlation. The data used to transform, rotate, and translate the image can then be used for patient graphic localization. The selected library image (radiograph, Plastimatch, or visualization) can be correlated to match the physical dimensions of the imaged object to the dimensions of a skin dose model within the Dose Tracking System.

3. RESULTS AND DISCUSSION

3.1 Lateral Test

The lateral view projection images acquired using each of the methods were compared to the fluoroscopic image using Matlab and the correlation coefficients were recorded. Figure 3 shows the correlation coefficient obtained for each comparison with the various image processing methods applied. The radiograph had a correlation to the fluoroscopic image of 56–60% on the successful correlations. This radiograph was a high quality image with very little noise, but of a dissimilar patient. The 3D visualization tool image had a correlation of 55–59% on the successful correlations. Finally, the Plastimatch image had a correlation of 61–65%. The 3D visualization tool and the Plastimatch images are of reduced image quality compared to the radiograph, but the fluoroscopic image and the reconstructed images are from the same “patient” phantom.

3.2 Anterior Posterior Test

The test was run a second time with Anterior/Posterior (AP) view images to verify the method. Figure 4 shows the correlation coefficients obtained for the AP view comparisons with the various image processing methods applied. For this view, the radiograph and the visualization image had nearly identical correlation coefficients, when each was correlated to the fluoroscopic image. With no filter, the coefficient for both was around 77% and was increased to 81% by applying a Gaussian filter. The Plastimatch image fared better, at 86% correlation and 90% with the Gaussian filter.

3.3 Image Discussion

The fluoroscopic images have image sharpness that is nearly as good as that of the radiographs and this provided an advantage in correlation when comparing the two, even though they were images of different “patients”. However, the Plastimatch, and the visualization tool images, although not as sharp, originate from the same phantom as the fluoroscopic images. However, the method of production that is best able to match the fluoroscopic images is the one that will be selected to provide the reference images.

The radiographs have the best image quality of all tested. The detail in the teeth and vertebrae demonstrate the large differences between the radiograph and the CT based images. Although this image features sharp edges, the edge filter did not improve the correlation most likely due to the difference in subject (SK 150 and another skull). It is unlikely such an aggressive edge filter will continue to be employed in the program.

The visualization tool simulates a projection effect within the input CT slice stack. The resultant “projection” is not a true x-ray projection, but was included in this study to evaluate if such a method can prove sufficient for the algorithm. The image is greatly blurred when compared to the fluoroscopic image, but the edge filter failed to improve the correlation. However, a Gaussian filter applied to the fluoroscopic image or both images improved the correlation.

Plastimatch utilizes the ITK library, and can generate images like the ones displayed in well under a second. The mathematical projection is more accurate in terms of x-ray modeling, as compared to the visualization tool images. That said, the correlation coefficients were similar in both view tests for the two CT based methods of production, with Plastimatch being slightly better.

3.4 Projection Generation Method Discussion

When the 3D visualization and DRR images are produced on a machine without a GPU, there is a small difference in the amount of time to generate a projection. The initial images produced using the 3D visualization tool in ImageJ take 1–7 seconds to generate, whereas the DRR images take under a second to generate for each projection. For the 3D visualization tool, once one angle has been generated, it is possible to change the viewing angle with a sub-second delay, putting it on par with the DRR code. Any angle changes with the DRR images require full recalculation, which could be done in under half a second. In a pre-calculated library, time, on this scale, is not of concern. Should a projection method be employed in near real-time, like during a fluoroscopic procedure, then the digitally reconstructed radiograph method would be more feasible, than the visualization tool. The advantage of the DRR code is that it fully calculates the attenuation values along each ray, which provides a more accurate representation of a radiograph. While both methods provide adequate visual information, the DRR code is slightly faster and more accurate.

3.5 Application to the Dose Tracking System

For application to the DTS, with the projection methods, CT datasets will be correlated to individual patient graphics that are matched to the patient undergoing a procedure and used to calculate the skin dose distribution. There is a library of patient graphics in the DTS and each graphic would be assigned a CT dataset of corresponding dimensions. A projection from the CT dataset of matched dimensions to the patient graphic will be compared with a clinical fluoroscopic image from the patient during procedure. The projection image will be rotated, translated, and scaled to match the clinical image. The data used to transform the image will be used to apply transforms to the DTS patient graphics, so that the position and scale of the patient graphics on the digital table matches the position and scale of the patient on the physical table. Localization of the projection image will facilitate localization of the graphic on the patient table for skin dose mapping using the beam projection information from the imaging system digital network.

Slight improvements in correlation were noted when the reference and test images were subjected to a Gaussian filter; whereas edge detection is seen to decrease correlation. The noted decrease is likely due to the large amount of high frequency structure found in the

fluoroscopic image. Preprocessing the images with a light Gaussian filter should be helpful to obtain correlation in the DTS.

The image production method with the greatest correlation with the fluoroscopic image will become the new library images in the localization algorithm. Based upon the results from the previous tests, Plastimatch would be the best method to use if a CT of the patient undergoing a fluoroscopic procedure with DTS is available. A greater correlation coefficient and the ability to match the angle of the fluoroscopic arm will yield better matches for localization. Should a CT scan not be available, a library of radiographs of generic patients of varying sizes and differing angles should suffice. If a radiograph of the patient who will undergo the procedure were available at the correct fluoroscopic C-arm angle, that image could replace the image of a generic patient's radiograph. Such a method could not provide the projection angles available angles in a pre-constructed library of radiographs or with DRRs reconstructed at any angle from a CT scan and this approach would thus have limitations.

4. CONCLUSIONS

The results of an investigation of the optimal means to generate the projection images associated with the patient graphic for a dose tracking system are presented. These images and correlation software will allow more accurate alignment of the graphic with the actual patient position relative to the x-ray beam to provide for accurate patient-specific skin-dose distribution determination in fluoroscopic interventional procedures. Using digitally reconstructed radiograph software, a library of images at varying angles will be able to be produced for the localization algorithm. Furthermore, due to the short calculation time, it could be possible to generate a digitally reconstructed radiograph projection that matches the patient projection during a procedure in near real-time to maintain patient graphic accuracy if the patient were to be moved on the table.

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Figure 1.
Example of the graphic display from the DTS software showing the skin dose distribution as a color-coded mapping.

Figure 2.

Relative correlation values from the Corr2 function of the fluoroscopic image and the same image with increasing variance of added noise. Correlation success (which is binary) fails when the correlation coefficient falls to about 50%. See image descriptions in Table 1.

Figure 3.

Relative correlation values from the Corr2 function of 3 images compared to the fluoroscopic image for the lateral projection. The fluoroscopic image is compared with itself for scale and verification. Each image was prepared with no filter (Unprocessed), a Gaussian filter (Gaussian), edge detection (Edge) and with both filters (Both). See image descriptions in Table 1.

Figure 4.

Relative correlation values from the Corr2 function of 3 images compared to the fluoroscopic image for the AP projection. The fluoroscopic image is compared with itself for scale and verification. Each image was prepared with no filter (Unprocessed), a Gaussian filter (Gaussian), edge detection (Edge) and with both filters (Both). See image descriptions in Table 1.

Table 1
Greyscale images used in correlation tests, lateral and anterior/posterior views.

Lateral Images	Anterior/Posterior Images

Fluoro – Fluoroscopic image of the SK 150 head phantom captured on a Toshiba Infinix C-Arm system.

Rad – Reference radiograph of the head from Siemens Healthcare (lateral) and radiopaedia.org (AP), used to represent a high quality projection image. (Greyscale inverted to match fluoroscopic image.)

Visual – Image “projected” from SK1-50 phantom CT data-set using the 3D volume tool implemented with ImageJ.	

Lateral Images	Anterior/Posterior Images

Plasti – Images projected from SK-150 phantom CT data-set using Plastimatch code to recreate 2D radiograph.	