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Automatic detection of the lung orientation in digital PA chest radiographs

Kie B. Nahm
Dept. of Physics, Hallym University, Kangwon, Chunchon 200-702, Korea

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An image processing algorithm is presented that can identify the orientation as well as the left/right side (parity) of the digitized radiographs. The orientation was found by computing the mean square deviation between the sampled gray values along the center and their best-fit linear regression relations. The parity was determined by comparing the area difference between two thresholded images of the left and the right side around the heart, which is assumed to be around the center of the image. This method was tested with 86 images with their orientations intentionally rotated. The rotation was limited to multiples of 90 degrees, as this was the way the rotation is most likely to happen in the clinical environment. We obtained positive responses for 85 out of 86 images subject to the screening.

I. INTRODUCTION

The Picture Archiving and Communications System (PACS) represents a new technological advance in managing vast number of images over connected computer networks. Especially interested in the possibility of this technique are hospitals: the ever-increasing number of medical images increasingly burdens the hospitals with the legal responsibility to maintain and track individual cases. A fully digitized image archive would enable management of an image library within the framework of the existing computational capability. In spite of its high initial cost and limitations, such a system has distinct advantages over the conventional screen film. Images can be made available over the network without the physical film, making multiple viewing sessions at differing locations possible without loss of details. Also archiving the image on the long term storage media has the added advantage of providing a redundant record to prevent loss or damage.

Both computer-aided diagnostics (CAD) and applications described above require images in digital formats. Once the images are in digital formats, there are numerous operations and applications one can apply to extract the desired information. The new generation radiographs from computed radiography (CR) systems are produced in digital formats. The majority of the images in the current film libraries are to be converted to digital format through a digitizer. While obtaining and handling these images, some of them can be rotated or flipped either by mistakes or by other unavoidable circumstances. Unlike the conventional film where the orientation of the images could be corrected manually rather easily for reading, these misoriented images on the display terminal will burden the reader by requiring a few extra unfamiliar key strokes to correct the orientation. They could cost extra computing time, if subjected to a CAD routine, when the routine tries to outline the search boundary in the pre-defined section of the misoriented image.

To avoid the problems associated with the misoriented images, we have developed an algorithm that is capable of finding correct orientations in chest radiographs. The area occupied by the heart shows on the image relatively lighter than the lung but darker than the area around mediastinum. This algorithm detected the heart area by thresholding the image below and above the gray scale values of this area and taking the difference of the two. This results in the differential area. The side with the larger differential area is most likely to be the right side of the patient, from the observer's perspective. This method requires a central axis to define the left and the right. The spinal column is assumed to be located reasonably close to the central section of the image, though the routine will later locate the most probable location. Of the 86 images tested, this method produced correct orientation for 85 images. The only failure came from an image with a severe asymmetry between the lungs.

II. TEST IMAGES

All the 86 clinical chest images were in the archive of ISIS center, Georgetown University Medical Center, in digital formats. The randomness of the sample and the nature of the disease were not considered in choosing images for the test. The original images with 2K$\times$ 2.5K pixels were reduced to the size of 512×620 (77cases) and 512×421 (9cases). Three of the images were rotated 90 degrees and in one case, the parity was

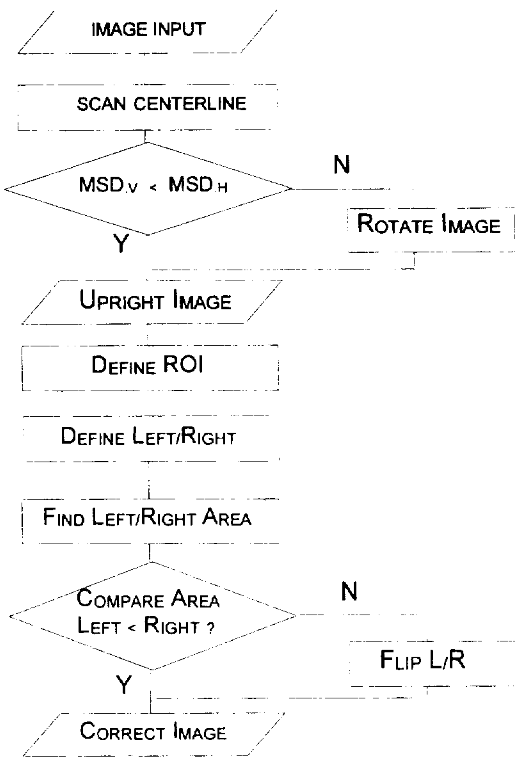


Fig 1. The overall scheme for detecting proper orientation.

reversed (flipped). The 12 bit resolution as they came out of the digitizer was converted to 8 bits and images were stored in TIFF format for processing with the MATLAB environment under Silicon Graphics (SGI) Onyx system. For test purposes, all images were flipped (left<-->right) and rotated by 90, 180 or 270 degrees before the processing began. The typical chest radiograph had a relatively weak contrast and all the images were preprocessed through histogram equalization. This enhanced the contrast considerably.

III. METHODS

The steps of detecting lung orientation can be presented as shown in Fig. 1. The procedure consists of two major sub-processes: one to detect the rotation of the image and the other to determine the parity. Around these blocks are auxiliary routines to help visualize the processes.

1. Determination of the orientation

This routine determines whether the image is upside down or simply lying on its side with respect to the normal image. The parity of the image is disregarded here. The best fit line for the pixel values along the center is used to find the orientation. First, 10 to 20 sample points are chosen over 80% of the image height, depending on the length of the image (the sam-

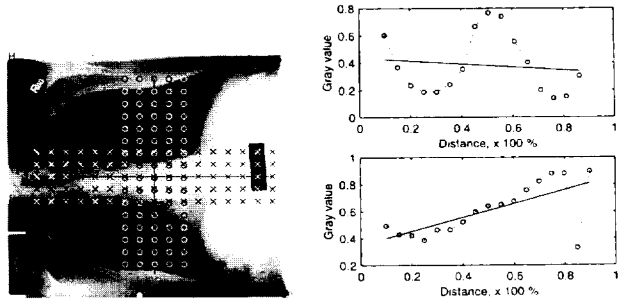


Fig 2. The test image with its sampling grid. The image was intentionally misoriented. b) Vertical (top) and c) horizontal scan (bottom) and their linear regression lines.

pling interval was 5% of the image height). Representative gray scale values for these points were found by summing the pixel values of the middle and the 2 lines on each side of the mid-vertical line, each separated by 5% of the image width. (Fig. 2a) Thus, each of the sample points used in Fig. 2 b),c) is actually is the average of the five points shown in Fig. 2 a). From these points, best-fit linear regressions were found for each direction. For the scan along the spinal column, this regression line is in reasonable agreement with the sample points. The scan across the chest usually gives "W" or "M" shaped plots, and the linear regression from this data produces a relation far from the actual data values. Fig. 2 b), c) illustrate these relationships. We utilized the fact that the mean square deviation (MSD) of the actual data, defined as the sum of the deviation squared between data and the regression divided by the number of samples,

$$MSD = \frac{\sum_{i=1}^{N}(I_i - I(x_i))^2}{N},$$

is always smaller for the scan down the center of the chest than the one across. Here, I_i is the gray value and the $I(x_i)$ the value of the linear regression at the point i. The algorithm computed the MSDv for the vertical and MSDh for the horizontal to pick the one with the smaller MSD to be along the spinal column. A quick check on the slope of this regression line tells if the image is inverted : upright if the slope were positive. The images found to be rotated by $\pm 90^\circ$ were corrected according to the average slope of the horizontal scan (along the spinal column).

An incorrect decision could be made when the rotated image has a severe asymmetry between the lungs. If the scanned portion of the rotated image contains abnormally bright areas due to disease, the slope criteria adopted in this routine might produce a false result. Also, any artificial objects shown on the image could alter the outcome. 31 of the test images had rectangular identification makers located some distance directly below the heart and it was observed that they did affect the result.

2. Selection of the region of interest(ROI)

This is a loosely defined term, meaning the area around the heart. Since the major difference between the left and the right lungs is the shadow cast by the heart, it is logical to concentrate on this area. The extent of coverage around the heart, though, is not critical. The current setting is a rectangle, covering half the width and height, centered on the mid-point of the image. This region could include only portions of the heart.

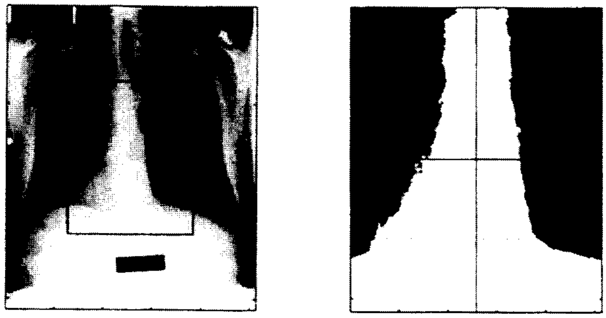
This algorithm depends on the difference of the differential area between the left and the right, and the selection of the middle line is rather critical. The ROI chosen as above had no fixed relation to this reference line. Once this region of interest is determined, the routine sets out to see if the ROI is reasonable. First, gray level sums for columns within 20% of the width from the mid-center of the ROI are obtained. It was assumed that the vertical line with the largest sum would be close to the spinal column. Since the spinal column is the radio-densest material in this region, this assumption generally holds. Once this "reference line" is determined, the ROI was re-defined along this line as per the method mentioned above.

This methods of finding the reference line is rather sensitive to spinal geometry: a curved or tilted spinal column would definitely render an incorrect result. However, no such adverse effect was found in the images subjected to this algorithm.

3. The lung bottom and the image pre-screening

The ROI chosen as above may involve, depending on the lung size and the location within the image, a large area of bright levels corresponding to the abdomen in the lower half. To determine the lower end extent of the lung, the image of the ROI is binarized at the threshold level of 0.5(1.0 is the brightest value). This will leave most of the lung black, while removing the rest of the images-heart, vessels-from the image. Now the lower bound of each side of the lung could be determined. The right and the left lung were tested separately. Of the two bottom lines, the higher one, was chosen as the overall lower limit.

If was found that a few images have an abnormal size difference between the left and the right lungs. Since the method adopted in this routine depends on the differential area, this abnormal disparity in the lung size will inevitably introduce an unacceptable error. A



(a) (b)

Fig 3. a) selection of ROI and b) the determination of the low end limit of the lung, denoted by the dotted line).

routine to monitor the lung size was needed. Measuring and comparing the lung size was reported by Armto et al[7]. In this work, instead of adopting such an elaborate method, this routine simply compares the location of the left and the right lower bounds. If the locations differed by more than the pre-set threshold, the image was considered "abnormal" and was rejected from further processing. It should be noted that this is not the true bottom end of the lung : it is the low end of the thresholded image.

The comparison of the lung area was not the goal of this algorithm and the approach adopted here proved to be sufficient for detecting the significant size disparity. In one test image, though, the rectangular ID tag was place too close to the bottom of the lung, confusing the routine and resulting in a false rejection. Also, for the image rotated by some angles, like 10 or 20 degrees, this routine gave bottom lines sufficiently different to stall further processing. This false signal would be corrected with the adoption of a subroutine that corrects for a rotation of this magnitude.

4. Determination of the parity

The gray level of the heart shadow in images after the histogram equalization was found to lie between 0.5 and 0.8. If the image were thresholded at 0.4, the shadow of the heart would disappear from the resulting image. By subtracting two images thresholded at 0.4 and 0.8, one could obtain the differential area between the two as shown in Fig. 4.

In the differential images as obtained in Fig. 4(c), 20% of the remaining lung length was chosen from the bottom of the lung for comparing the area between the two sides. (The two horizontal lines denote this span). This is the area that contains a good portion of the heart on one side. The differential areas are present on both sides since the lung itself has a continuous gradient of gray levels, but the area occupied by the heart, now occupying most of the differential area on one

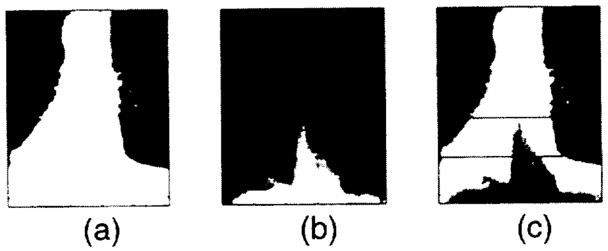


Fig 4. ROI thresholded at 0.4 (a), 0.9(b), and the differential area (c).

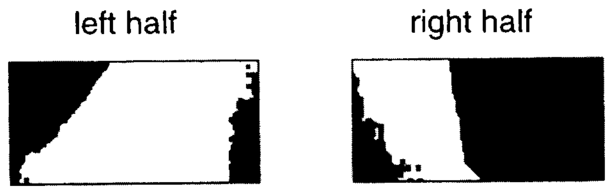


Fig 5. The differential area on both sides.

side, is by far larger than the counterpart on the other side. The side with the larger area corresponds to the left side of the patient. Fig. 5 clearly indicates this area disparity. Just before actually computing the area in this zone, an erosion operation was applied to remove spots of high gray levels. The information from this stage is utilized to find the parity of the image, bringing the image to a proper orientation, as shown in Fig. 6.

IV. Results and Discussions

The program was developed in the MATLAB language and was tested with 86 chest images. Only one came out with the wrong parity when the original images were subject to arbitrary rotations (90 degrees steps) and horizontal flips. The one that escaped the screening was found to have a severe degree of asymmetry between the left and right lungs.

The detection of the image orientation through the methodology introduced above proved to be very successful and error free on PA chest images. Though this routine produced a high success rate, there are some aspects to justify and prove to establish it as a successful routine. The most critical decision to make in this routine is the selection of the central reference, a line dividing the left and the right. Currently, its selection is solely based on the pixel sum in the vertical direction near the middle of the midiastinum area. This is based on the assumption that the spinal column is the most radio-dense material in this area for the X-ray energy generally used for chest radiography. There are other X-ray absorbants with varying absorption coefficients and thicknesses. Therefore, locating the center line based on the vertical pixel sum is a subject for further study. Yet, the result from the current study strongly suggests that our basic assumption generally holds for most PA

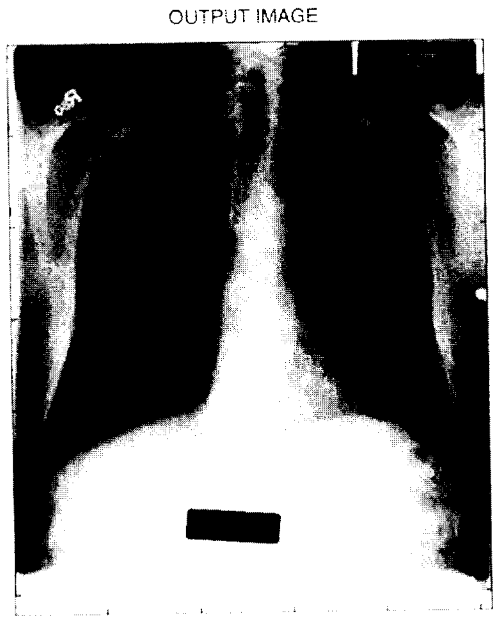


Fig 6. The output image with the proper orientation.

chest images.

The algorithms can tell on which side the heart is located in the images. This may be utilized to run a cardiac-CAD routine more efficiently. Such a routine will need information on the location and the extent on the shadow image that the heart occupies before actually processing the image to enhance and extract information. The work by Nakamori[5] is a good example of automatic cardiac contour detection.

V. ACKNOWLEDGEMENTS

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