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Automatic Cropping Method of Chest Radiographs Based on Adaptive Binarization

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Abstract— **General radiography systems are widely used for medical diagnoses. Since the size of image detectors of general radiography systems is standardized in several fixed sizes, relative size of target body parts differs according to patients. The spread of digitization of X-ray imaging forces radiological technologists to crop radiographs manually after measurement for suitable use on diagnoses. This cropping operation distracts attention of radiological technologists from measurement operations and from care to patients. The purpose of this study is to establish image processing method to achieve automatic cropping of X-ray images, which reduces the radiological technologists' burden in general radiography workflow. The proposed method utilizes adaptive binarization as pre-processing of radiographs. In this paper, we show the result of the proposed method applied for chest radiographs and the evaluation by radiological technologists.**

I. INTRODUCTION

Development of a computed radiography x-ray system with a large flat panel detector has been promoting the digitization of medical images. With the digitization of medical images, several operations that were essential in the era of analog imaging have become obsolete. Film development, work in a dark room, and maintenance of an automatic film developer are no longer required and are removed from a usual workflow of plain radiography. On the other hand, the digitization has brought additional operations for operating digital imaging system, such as adjustment of brightness or tone curve and image cropping for providing the clear and normalized images.

A workflow of digital plain radiography is roughly divided into two parts. One is an arrangement of a position of a patient relative to an x-ray detector to obtain a clear image of the target. In addition, a radiological technologist pays attention to the setting of x-ray radiation area and exposure intensity to minimize the exposure dose of the patient. The other is a fine adjustment of brightness, contrast, and cropping on a medical workstation after the acquisition of plain radiographs. These two operations are completely different and the latter work on a medical workstation is requested to be as simple as possible. Simpler operation on the workstation reduces the load of radiological technologists.

In this paper, we propose the automatic estimation method of a cropping area of a plain radiograph for normalization of the result of plain radiography. We also report the result of evaluation of the proposed method by comparing the result of cropping by the proposed method and the result by radiological technologists.

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II. RELATED WORKS

Several researches have been devoted to the automatic segmentation of a lung field from chest plain radiographs[1]. General image processing technologies, such as a graph cut[2] or SIFT features[3], have been applied to make a segmentation. However, most of the foregoing researches have focused on a specific region of a human body and have utilized the characteristic feature of the target region. Since a plain radiography is used for imaging of various regions, the cropping method should be independent from the characteristic features of specific regions of a human body. In this research, the proposed method uses no specific anatomical knowledge about the target regions. Therefore, the proposed method can be applied to various plain radiographs.

III. AUTOMATIC CROPPING METHOD

In the operation of plain radiography, the target organ is inside the patient's body and the x-ray radiation area is invisible. Hence, a radiological technologist cannot see the filming range of a radiography, so accurate framing is quite difficult due to the lack of visual clue. In addition, since the exposure intensity may change in accordance with target regions and constitution of patients, the brightness and contrast of plain radiograph may also change. Therefore, in the image processing of plain radiograph, we cannot assume that the position of the target and image intensity are in a certain narrow region.

Moreover, the slight difference in overlapping of structures inside body generates feature points which are not persistent. These temporal feature points imply that we should not use the information from details of X-ray images. This characteristics make the application of generic image processing methods difficult.

The proposed cropping method utilizes adaptive image binarization to absorb the difference of imaging condition particular to processing of radiographs.

A. Outline of Proposed Method

The proposed method generates template images from the images cropped by radiological technologists. Then the cropping rectangle is estimated by template matching.

The process of the proposed method consists of three steps. First, adaptive binarization is applied to all images as pre-processing. Second, the template images are generated. Finally, template matching is executed for deciding cropping margins from four boundaries of radiographs.

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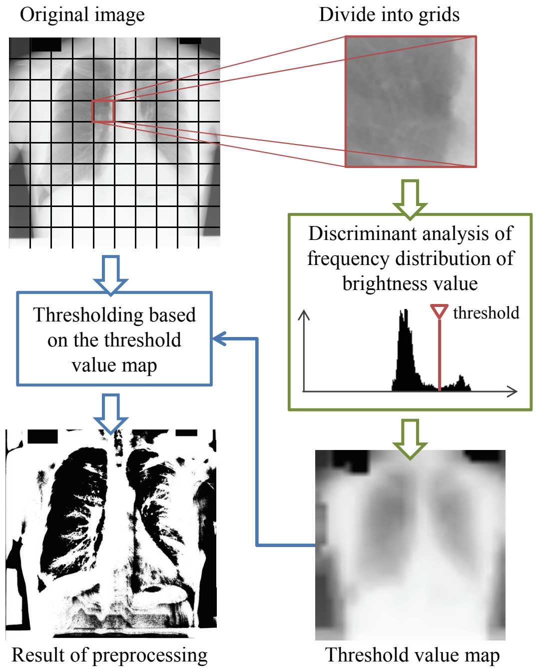


Fig. 1. Process of adaptive binarization

B. Adaptive Binarization

First, we think about the clue that radiological technologists use for deciding cropping margins from each boundary of the target radiograph. Even if the right half of the radiograph is hidden, the cropping margin from the left boundary can be decided. This fact suggests that local features, not global features, are important to determine the cropping margins.

In accordance with the consideration described above, the proposed method applies the image processing method that enhances the local features of original radiograph before searching for a cropping rectangle. The subsequent automatic cropping process uses the pre-processed images as input.

As the pre-process of the automatic cropping, we propose an adaptive binarization method. The proposed adaptive binarization method dynamically changes thresholding values for binarization based on distribution of intensity values in local area. A flow chart of the adaptive binarization is shown in figure 1. The process is divided into the following steps:

1) I denotes an original radiograph and $I(x, y)$ means the intensity at pixel (x, y). The resolution of image I is N_x pixels wide and N_y pixels height.
2) Split image I into a grid. The grid has M_x columns and M_y rows. We call the subimages $I_{p,q}(x, y)$ $(1 \leq p \leq M_x, 1 \leq q \leq M_y)$.
3) Apply discriminant analysis to $I_{p,q}$ to obtain the most relevant threshold value $T_{p,q}$ for the subimage $I_{p,q}$. Discriminant analysis is a method to find criteria for separating two or more classes of objects in statistics and machine learning. In image processing field, Otsu's method, which is the application of discriminant analysis to image binarization, is widely used to determine the relevant threshold value[4].
4) The collection of the threshold values $T_{p,q}$ can be considered as the image I_{T_0} that is M_x pixels wide and M_y pixels height, i.e., $I_{T_0}(p, q) = T_{p,q}$. Enlarge the image I_{T_0} to the image I_T that has the same size as the original radiograph I. The image I_T is a threshold value map that contains the relevant threshold value at each pixel.
5) Apply thresholding for each pixel (x, y) with the threshold value $I_T(x, y)$ and obtain an adaptive binarized image I_B.

$$I_B(x, y) = \begin{cases} 1 & I(x, y) > I_T(x, y) \\ 0 & I(x, y) \leq I_T(x, y) \end{cases} \tag{1}$$

C. Making Templates

Template images used for searching cropping margins are made from pre-processed images whose correct cropping margins is determined by a radiological technologist. The process of making the template images is as follows.

1) Crop the correct rectangle from the pre-processed radiographs.
2) Resize the cropped images to N_x pixels wide and N_y pixels height by bilinear interpolation because the sizes of the cropped images are not the same.
3) Calculate mean and variance for each pixel value and obtain mean image $I_0(x, y)$ and variance image $I_{\sigma^2}(x, y)$.
4) Convert the variance $I_{\sigma^2}(x, y)$ into the weight for each pixel that is used for evaluation of matching result. In the proposed method, the region whose variance is large is considered as the region varying among different individuals. Therefore, the region whose variance is small has more importance in evaluation of matching result. We define the weight w based on the variance

$$w(x, y) = \exp\left\{-\frac{I_{\sigma^2}(x, y)}{L}\right\} \tag{2}$$

where L is a positive constant. If we use smaller L, the region whose variance is large will be ignored more thoroughly in evaluation.

D. Search for Relevant Cropping Margins

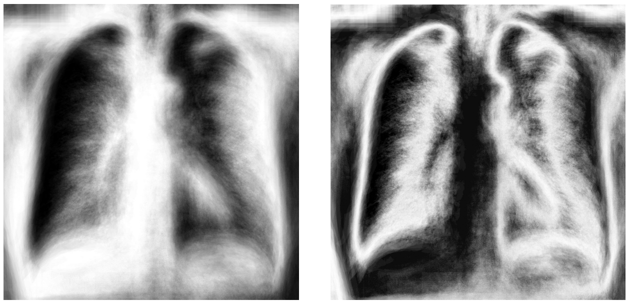
Cropping margins from four boundaries are determined by template matching.

In the search of the optimal cropping rectangles, the cropped image with a set of certain cropping margins is resized to the size of the original image. This image I is evaluated by a weighted square sum of differences between $I(x, y)$ and the mean image $I_0(x, y)$. The evaluation score E is defined as

$$E = \sum_x \sum_y w(x, y) \left\{I(x, y) - I_0(x, y)\right\}^2 \tag{3}$$

where $w(x, y)$ is a weight function calculated in the former section. The optimal set of cropping margins is the parameters which minimize the evaluation score E.

We execute this search for the optimal cropping margin hierarchically for speeding up the search process.



(a) (b)

Fig. 2. Template images. (a) mean of intensity (b) variance of intensity

IV. EVALUATION AND RESULT

In this section, we will describe the experiments and the results to evaluate the proposed method for cropping chest radiographs.

A. Preparation of Test Images and Templates

For the evaluation of the proposed method, we used the 145 sheets of chest radiographs from the standard digital image database created by the Japanese Society of Radiological Technology [5]. The size of the radiographs is 2048 by 2048 and the depth of intensity is 12bit. Some radiographs contain nodules or clinical instruments in a lung field.

The radiological technologist whose clinical experience is more than 10 years decided the cropping rectangle, which we consider as the correct cropping region.

78 radiographs (training set) were used for making the template images and 67 radiographs (test set) were used for evaluating the proposed method. We made the template image by applying adaptive binarization and making average. The template images are shown in figure 2. The left image shows the mean value of the intensity and the right one shows the variance of the intensity. In the image of the variance, the brighter pixel means that the distribution of the intensity value of the pixel has larger variance.

For preparation of weight function $w(x, y)$, we use $L = 0.2$, where the intensity is normalized to the range of $[0, 1]$.

B. Result of cropping

Several examples of the estimated cropping regions by the proposed method and the radiological technologist are shown in figure 3. In the result images, the red rectangular frame is the suggested cropping region of the proposed method and the yellow rectangular frame is the result by the radiological technologist.

The difference between the estimated cropping margins by the proposed method and the correct cropping margins by the radiological technologist on each boundary were gathered and the statistical indices were calculated. The histograms, mean values and standard deviations of the difference of cropping margins on each boundary are shown in figure 4.

On each boundary, the mean value of the error ranges from -3.0 to 3.6, which shows exact match between the result and the correct answer. The standard deviation ranges from 26.6 to 45.8, which is around 2% of the image size.

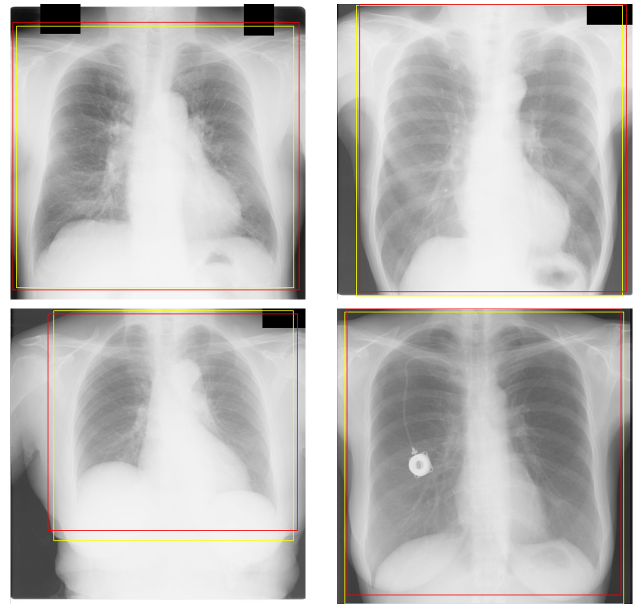


Fig. 3. Result images of automatic cropping. Red frame is the result of the proposed method. Yellow frame is the result by radiological technologist.

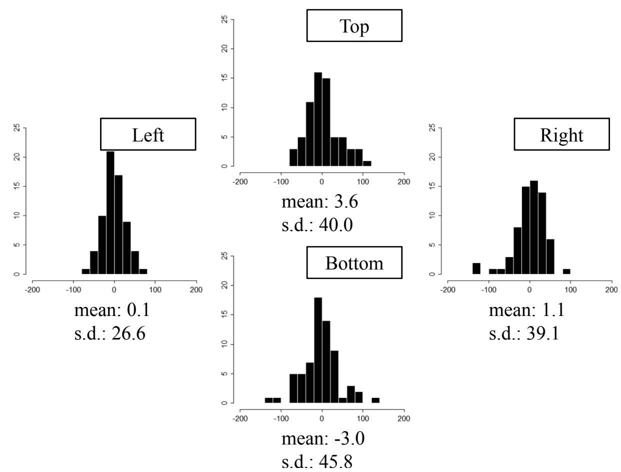


Fig. 4. Distribution of the cropping error on each boundary.

C. Quantitative Comparison with Radiological Technologists

To make a quantitative comparison of the proposed method with radiological technologists, we adopted the Jaccard similarity index. The range of the Jaccard similarity index is $[0, 1]$ and the larger value means good similarity between two regions. The Jaccard similarity index of two regions A and B is defined by the area of intersection of A and B divided by the area of union of A and B.

$$J = \frac{A \cap B}{A \cup B} \tag{4}$$

We obtained the Jaccard index 0.941 ± 0.032 of the proposed method.

The key point of the proposed method is applying the adaptive binarization as pre-processing. This non-linear conversion of intensity values enhances the features that are

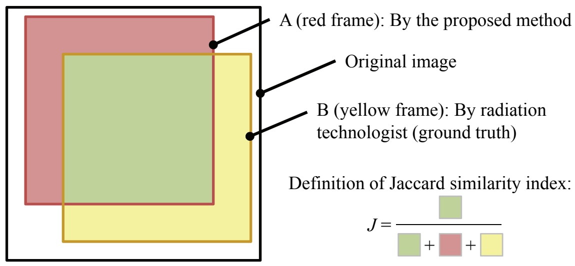


Fig. 5. Definition of Jaccard similarity index

useful for cropping. We change the pre-processing method to standardizing, which consists of subtracting the mean value from an individual value and then dividing the difference by the standard deviation. In case of using standardizing, the Jaccard index is 0.898±0.076 and a comparison showed significant difference ($p < 0.01$) in the index.

D. Evaluation by Radiological Technologists

The results of the proposed method were evaluated by radiological technologists. First, 50 chest radiographs were selected from 67 radiographs in the test set. We requested 19 radiological technologists who have 3 to 20 years of experience in clinical to decide cropping rectangle of 50 radiographs. The proposed cropping method also applied to the same set of radiographs. Next, 1000 cropping results, that is, 50 radiographs × (19 technologists + 1 algorithm), were evaluated by 16 radiological technologists. The cropping results were made anonymous and the order of evaluation was random. The rating was in three levels: score 1 is poor, 2 is acceptable, and 3 is excellent.

The scores are shown in figure 6. The average score of the proposed method is 2.83±0.24 and of the radiological technologists is 2.76±0.22. We applied Steel's test for non-parametric multiple comparison of the average scores. The results of the significant test showed:

- The score of the best radiological technologists is significantly higher than the score of the proposed method.
- The score of the five worst radiological technologists are significantly lower than the score of the proposed method.
- No significant difference between other technologists and the proposed method.

This experiment reveals that, in terms of the average capability of cropping, the proposed method has the same capability as the most of radiological technologists. On the other hand, the distribution of the score of the proposed method is wider than of the radiological technologists. This fact means that the proposed method fails miserably for a certain kind of radiographs.

V. CONCLUSIONS

In this paper, the proposed automatic cropping method was applied to chest radiographs. However, since the proposed method uses no information about site-specific anatomical knowledge, the proposed method is expected to be applicable for any sites of a body. Not only improvement of speed and accuracy, but also application to other sites are important issues for further development.

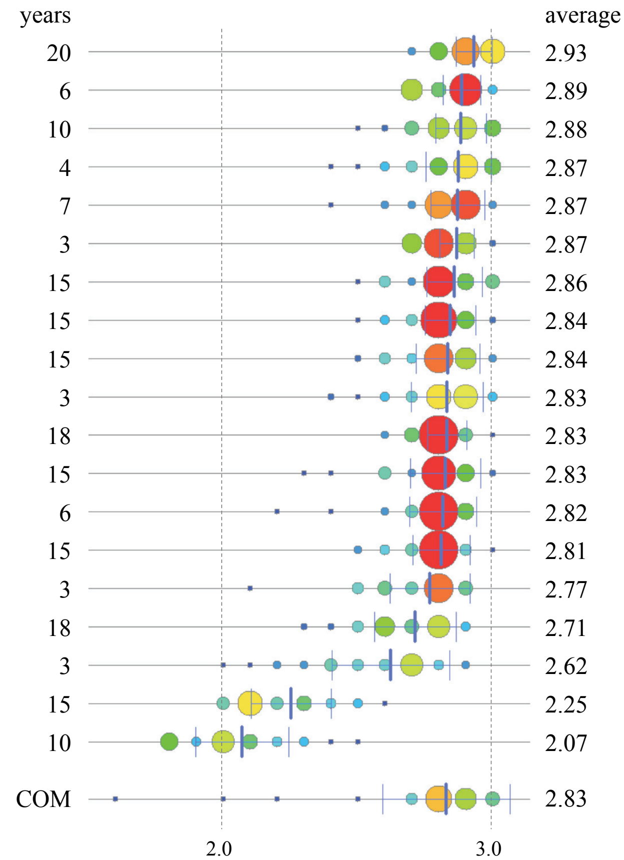


Fig. 6. Evaluation scores of radiological technologists and the proposed method. Years of experience in clinical are shown at the left side, average scores are shown at the right side.

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