ABSTRACT
The concept - window of lung fields - is introduced in this paper. Definition and automatic calculation methods are also included. Using this concept, four applications are discussed: initial parameters setting of Active Shape Model (ASM) algorithm, a widely used algorithm in medical image analysis; auto focusing, which can be used in radiographic examination; asymmetry detection of lung fields and image compressing. All these applications are nice and easy provided that windowing technique is implemented, especially the automatic segmentation of lung fields: experiment results show that in most cases, only a few iteration steps are needed to find contours of lung fields. Other applications are also discussed and analyzed.

KEY WORDS
window of ROI, image analysis, lung segmentation, active shape model, asymmetry detection

1. Introduction
Availability of large digital medical images depository, brought by implementation of picture achieving and communication system (PACS), and advances in imaging processing and analysis have made computer aided diagnosis a valuable tool for detecting subtle abnormalities in chest radiographs\[1\][3]. Pulmonary diseases may be detected through examining chest radiographs, especially posterior & anterior (PA) images \[1\][2]. One of the most important steps in most CAD systems and medical image analysis systems is automatic segmentation of lung fields. Grey level based and flexible template matching are two main categories of segmentation algorithms. Noise has a big impact on grey level based algorithms. An accurate initial position setup influences the segmentation result of ASM badly, which is a template matching algorithm. This paper will introduce an important concept - window of lung fields - to improve the robustness and efficiency of ASM.

Auto focusing, a technique used in chest radiography to track the thorax position of a patient automatically, can be performed easily provided that the window of lung fields is pre-calculated. Automatic abnormal asymmetry detection in digital chest radiographs can help physicians to make decision on the abnormalities in X-ray images. We will show that a simple formula is fairly good to measure the asymmetry. Another type of chest radiograph image compression can be derived from this new concept.

2. Window of Lung Fields
2.1 Some Symbols
Digitalized chest radiography image is represented by a $m \times n$ grey level matrix: $X_{mn}$, where $m,n$ stands for the height and width of the image respectively. Let $X_{ij}$ be the $i$th row, $j$th column of the image. If a column vector $x = [x_1, x_2, \ldots, x_n]^T$ is n-dimensional, we write $x \in R^n$. The symbol $x^T_j$ denote the $j$th component of the $i$th vector.

2.2 Definition
Each PA X-ray chest image comprises two main parts: the left and the right lung fields separated by vertebral column. These two parts take up most part of the PA image. No rigorous definition is given in [8,9], and only pixels’ grey value are used to get the contour of lung fields. Here we define the region of interest (ROI) as these two lung fields and later will show that ASM gives better result. Ideal representation of the ROI is using two continues close contours. But this analog representation cannot be stored and processed by computer. One simple solution is to use coordinates of key points to express it.

Definition (ROI vector) If $n$ key points are used to outline the contour of ROI, then a vector $x \in R^{2n}$ can be used to represent the ROI, where:

$$x = [x_1, y_1, x_2, y_2, \ldots, x_n, y_n]^T$$

$x_i, y_i$ denote the x coordinate and y coordinate of key point $i$, $1 \leq i \leq n$.

The definition of ROI is depicted in Figure 1. All $n$ key points, also known as landmark points, are denoted by $P_i, P_n$ in Figure 1. The choosing of key points number: $n$ depends on accuracy requirement of application. In our
practice, a typical X-ray image is about 2048 times 2048 in height and width, so larger n is needed.

**Definition (window of lung fields)** Let the column vector $\mathbf{x} \in \mathbb{R}^{2n}$ represents lung fields of an X-ray chest radiograph, the window of lung fields is five elements vector $\mathbf{w}$ in $\mathbb{R}^5$ defined as:

$$\mathbf{w} = \{\text{row}_1, \text{row}_2, \text{col}_1, \text{col}_2, \text{sp}\}^T$$

In which:
- $\text{row}_1 = \min\{y_i, 1 \leq i \leq n\}$: the upper bound of $\mathbf{w}$;
- $\text{row}_2 = \max\{y_i, 1 \leq i \leq n\}$: the lower bound of $\mathbf{w}$;
- $\text{col}_1 = \min\{x_i, 1 \leq i \leq n\}$: the left bound of $\mathbf{w}$;
- $\text{col}_2 = \max\{x_i, 1 \leq i \leq n\}$: the right bound of $\mathbf{w}$;
- $\text{sp}$: where the vertebral column is located.

All these parameters are depicted in Figure 2.

![Figure 1: Definition of ROI](image)

![Figure 2: the Window of Lung Fields](image)

The window of lung fields plays a central role of this paper. This definition is only for illustrative purpose. Generally, the window of lung fields is used as the first step of segmentation procedure. Both [8,9] use pixel grey level as the criterion, [9] also uses derivative. The calculation given in next section is fast and more importantly, less experiential value are used.

### 3. Calculation of the Window

Most segmentation algorithms, whenever using derivative approach or template matching, should have an initial setup for where the search or segment begins. Windowing technique gives a better initial search region. Five parameters need to be deduced: the left and right bounds, the upper and lower bounds and vertebral column location.

Simple methods described here can be used to fulfill this task.

#### 3.1 Left and Right Bounds of Window

Calculation of $\text{col}_1, \text{col}_2$ is easy if a vertical imaginary scan line runs through a chest radiograph from left to right. Then plotting mean grey level of the scan line against its location as in Figure 3. The lower curve in Figure 3 is profile of the standard deviation (std) value of each scan line. Further information may be got from this curve, but this paper will leave it alone.

![Figure 3: Plots of Mean and std of Each Column](image)

When the scan line runs from left to right, the first peak is met when it enters the right lung field, that’s where the left bound of window $\text{col}_1$ is located. Where the SP in Figure 3 points to is the vertebral column located ($\text{sp}$). The rightmost peak shows the location of the window’s right bound $\text{col}_2$. The horizontal dotted line (mean of mean, mm) in Figure 3 is plotted to give a fast calculation method of $\text{col}_1$ and $\text{col}_2$. The value of mm is:

$$\text{mm} = \frac{s}{m \times n} \sum_{i=1,m}^{l=1,n} X_{ij},$$

$s$ is a scaling factor chosen to make the calculation more flexible. In practice, $s$ is chosen between 0 and 1 to ensure that no part of lung region is cutoff.

#### 3.2 Upper and Lower Bound of Window

The simple plot of each column’s mean grey value does not fit the task of calculating the upper bound of window: $\text{row}_1$, nor the std plot as in Figure 3. But two observations can be found after a close examination of chest radiography:1. Above the shoulders of patients, rows of $X_{mn}$ are approximately lateral symmetric; 2. The lower bound of window $\text{row}_2$ can be deduced if prior knowledge, such as ratio of width to height of lung fields, is applied. Let a horizontal scan line runs from top to bottom of an image, then plot each row’s skewness($skew = \frac{E(x - \mu)^3}{\sigma^3}$) versus row number as in Figure 4.
Observation 2 can be used to calculate the lower bound of window by using this formula:

\[ \text{row}_2 = \text{row}_1 + (\text{col}_2 - \text{col}_1) \times (r \pm \delta) \]

where \( r \) stands for the ratio of width to height of a window, \( \delta \) is used as a correction factor to reach more accurate result. Both \( r \) and \( \delta \) are experiential data which can be obtained by simple statistics from sample set.

### 3.3 Median Line Location

The value of \( sp \) is easy to calculate provided that the left and right bounds of window have been deduced. From Figure 3, the valley between two maximum peaks shows where the median line is located. To further illustrate this point and to improve the accuracy in calculation, Figure 5 is used.

#### Figure 5: Calculation of Median Line

The maximum value of Figure 3 is extracted. Say, the first maximum value is located at \( \text{max}_L \). Then a vertical strip around \( \text{max}_L \) is masked for further steps. A second finding of maximum value is carried out. This time another location \( \text{max}_R \) will be got. The median line location can be calculated via

\[ sp = (\text{max}_L + \text{max}_R) / 2 \]

Symbol \( D \) in Figure 5 is the spine column width. This is also an experiential figure which can be obtained by simple statistics. The vertical band masked in the second step is defined by

\[ \text{max}_L - D / 2, \text{max}_L + D / 2 \]

### 3.4 Remarks

Calculation of the window of lung fields is provided in this section. All five components of \( w \) are obtained in simple plot and intersection fashion. Only a few experiential data are needed. Although this is only an approximation of ideal window, our experiment showed that the calculation is effective and it is fast.

### 4. Applications

In this section, four applications are analyzed to demonstrate the concept of window of lung fields and its usage.

#### 4.1 Image Segmentation

Automatic segmenting out ROI is virtually mandatory before any computer analysis of X-ray images take place because the lung fields of chest radiograph contain so much information that we should focus our attention on what interests us. Thresholding, edge detection by masks, region growing algorithms, morphologic method, to name a few, is not suitable for the segmentation of chest radiograph. Knowledge based algorithms are especially useful to segment medical images. Active Shape Model (ASM)[5] is a widely used methods in medical image analysis. A training set is built to get the mean shape and to capture its variances. Then three shape invariant operations are performed upon this mean shape in order to match new images. To improve robustness and efficiency of ASM, Multi Resolution ASM[7] and some other improvements have been proposed. But we found that the key step in ASM is to find out proper initial parameters before any further action is taken. If the initial template is far away from where the target ROI is, convergence of ASM cannot be assured.

There are four parameters to be initialized: the translation of mean shape by \( t = (dx, dy)^T \), rotation by \( \theta \) and scaling by \( s \). Setting the rotation parameter \( \theta = 0 \) is well enough in most cases. The translation and scaling parameters can be calculated by the following formula if the window of lung fields has been obtained:

\[
\begin{align*}
(dx, dy)^T &= (X, Y)^T - (\bar{X}, \bar{Y})^T \\
\text{and} \quad s &= f(s_x, s_y)
\end{align*}
\]

The following procedure is used to determine these parameters.

1. \((X, Y)^T\) is the target centroid of target shape which can only be approximated by \((X', Y')^T\):

\[
X' = \frac{1}{2} (\text{col}_1 + \text{col}_2), \quad Y' = \frac{1}{2} (\text{row}_1 + \text{row}_2)
\]

2. \(\bar{X}, \bar{Y}\) is the centroid of mean shape template calculated in similar manner as in step 1;

3. Define the width and height of mean shape template as:

\[
\bar{W} = \max \{x_1, x_2, \ldots, x_n\} - \min \{x_1, x_2, \ldots, x_n\}
\]

\[
\bar{H} = \max \{y_1, y_2, \ldots, y_n\} - \min \{y_1, y_2, \ldots, y_n\}
\]

4. Define the width and height of window of lung fields as :
5. Set the scaling parameter of X and Y axis as:
\[ s_x = W / W_x, \quad s_y = H / H_y \]

6. Choose a function \( f \) to combine \( s_x, s_y \) into \( s \). For example, \( f = 0.9s_y \) is satisfactory in our test.

The key idea behind this forenamed procedure is using window of lung fields as a frame to initialize parameters of ASM: setting the scaling factor and translating displacement.

Using the window of lung fields will improve the robustness and make the ASM converge in only a few steps. Figure 6 shows two X-ray chest radiographs. The left one is overlapped with initial mean shape template, no window is used. If the procedure proposed ahead in this subsection is used, then the initial shape is almost acceptable as final result. Figure 7 shows the first 8 iterations of ASM. Figure 7(a) uses default mean shape template as the initial position as the left image of Figure 6. Though ASM can converge to target contour only in several steps, Figure 7(b) demonstrates that only two or three steps are needed for the convergence if the window of lung fields is calculated and used to set initial scale and translation parameters. 561 X-ray chest radiographs were used in our experiment. Results showed that in more than 90% cases, only a few iterations were enough. The other cases were caused by bad photographing, children images or some extreme cases.

4.2 Asymmetry Detection

Asymmetry detection could be used to pre-screen chest radiographs to bring obviously abnormal cases to the immediate attention of radiologist [4]. Area comparison ratio of left to right lung field is one factor. But we discovered that after the window of lung fields had been obtained, another simple factor could be introduced to add one dimension of asymmetry detection: the bilateral ratio which’s definition is given below.

**Definition (bilateral ratio)** The bilateral ratio of chest radiograph for asymmetry detection is defined as the ratio of left lung width to right lung width.

Direct calculation of bilateral ratio is difficult. But if we know the window of lung fields \( W \), the calculation is simply easy and can be written in an equation:

\[
blr = \frac{|col_r - sp|}{|sp - col_l|}
\]

Absolute value is used to prevent negative value. Let \( e_l \) and \( e_r \) stand for the left and right criteria value respectively. They represent the tolerance of abnormality. Three cases of \( blr \) may turn up.

- \( blr < e_l \): The region of abnormal. In this case, the right lung field is larger than the left one because \( e_l < 1 \).
- \( e_l \leq blr \leq e_r \): Then normal region.
- \( blr > e_r \): The region of abnormal. In this case, the left lung field is larger than the right one because \( e_r > 1 \).

All these regions are depicted in Figure 8. X axis is the logarithm of \( blr \) value ranges from 0 to positive infinity. Y axis is the scale of abnormality normalized from 0 to 1. Three regions are divided by two tolerance value: \( e_l \) and \( e_r \), as described before.

4.3 Image Compressing

PACS plays a central role in modern radiology information system and hospital information system. In all modalities, the digital X-ray images make up 40 percent of all conventional diagnostic radiographic procedures [2]. As an example, one of our cooperate hospital is now accumulating at least 1G digital images daily. It costs much to store these data. This explains why data compressing techniques are widely used in storing images in PACS. We will see that one different image
A compressing method is possible if applied to PA chest radiographs.

In most cases, the physician’s description and examinations are based on the main part of a PA chest image. This is a coincidence with the definition of window given in this paper. If we cut off the original images and leave only the part contained in the window, most diagnosis information will be reserved and poorly topic related pixel can be discarded.

This thought can be illustrated by Figure 2. Suppose a digital X-ray chest image $X_{mn}$, whose height and width of the image may be large. If only the part included in the window of lung field, then $X_{mn}$ can be reduced to $X_{m'n'}$, where $m' = row_2 - row_1, n' = col_2 - col_1$. Compression ratio can be calculated by:

$$cr = \frac{m' \times n'}{m \times n}$$

In general, chest radiographs is very large, say 2048x2048 or higher resolutions. The compression ratio of Figure 2 is about 52.49%. For the consideration of lost important information, larger region than the window of lung fields is used practically. Experiments show that the average compression ratio is 67.87($\pm$0.974)%.

### 4.4 Auto Focusing

Auto focusing is another application of the new concept: window of lung fields. Suggest a patient standing in front of an X-ray machine. It will take some time for the physician, especially inexperienced one, to move the screen in all directions in order to find the best position. This is a boring task though many types of electronic assistant equipments are available.

If automatic calculation of the window of lung fields is embedded in X-ray machine or installed as an auxiliary function, the physician only need to set a rough position of X-ray machine when taking radiographs. Automatic lung fields' window calculation will make the task of minute adjusting relatively easy.

### 5. Conclusion

The window of lung fields, a new concept proposed in this paper, and its application in medical image segmentation, asymmetry detection, compression and auto focusing are discussed. Calculation of the window is quite easy. Its efficacy has been demonstrated in this paper.

Despite the benefits it brings us, we found that the calculation of window is based on grey level pixel value, which may be influenced by image quality. This explains why there are 10% cases failed in segmenting out lung fields.

The improved ASM algorithm and data compression have been combined into one of our research project – data mining in PACS.

Future applications may include: automatic zoom-in in chest radiograph processing workstation, spine column analysis, area calculation of lung fields, etc..

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### References:


