Abstract— The appearance of the infected zone on the digital chest X-ray image for pulmonary tuberculosis (PTB) does not conform to standard shape, size or configuration. This study uses phase congruency (PC\(x\)) values to gather information from transition of adjacent pixel values that may be used as features to represent known disease type. The feature vector consisting of the average, variance, coefficient of variation and maximum PC\(x\)-values was found to be able to detect PTB with high accuracy.

I. INTRODUCTION

Economic consideration dictate the situation where the digital chest X-ray is widely use in many medical institution for the detection of pulmonary tuberculosis (PTB) [1]. The problem of interpreting the chest X-ray is well-known [2],[3]. The problem is compounded further because PTB is known to recur and is infectious when appropriate treatments or conditions are not applied.

Phase congruency value has been used in new and interesting technique in the recent decade to extract image features [4]-[9]. Certain properties of phase congruency values allow the development of better imaging methods for example better edge detection can be created because of its independence of image illumination and magnification [5].

Another property of phase congruency is that values close to one indicate large transition and values close to zero indicates mild transition between pixels. This property provides an opportunity to develop feature vectors for the detection of PTB. The appearance of PTB on the X-ray image does not conform to obvious or consistent shape, size and configuration. As such the definition of features for PTB is made difficult because the selection of the region of interest is nontrivial.

In this study a novel approach explores the ability of phase congruency to provide a quantitative measure of the transition between pixels as a technique to extract features for PTB.

II. MATERIALS AND METHODS

The chest X-ray films which are collected by the research group in the Institute of Mathemathical Sciences in University of Malaya collaborating with the Institute of Respiratory Medicine, Malaysia is used as data set. The X-ray chest films were digitized by Kodak LS 75 scanner into DICOM format (12 bits per pixel). Two radiologists verified the infected area which is classified as the region of interest (ROI) in this study. One hundred patients’ digitized chest X-ray were studied in which 80 patients provide the control data set and 20 patients provide the test set.

In the control data set, 40 from Normal Lungs group (NL) and 40 from PTB Group were selected randomly to develop the feature vector. Ten PTBs and ten NLs were used as the test set. However for each NL image two sub-images were derived, firstly NL healthy tissue and NL rib-bone.

Fig.1(a) shows an example of digital X-ray image of infected lung by PTB.

A. Phase Congruency Model

In image segmentation to describe some image features such as edges or corners, we should use a dimensionless quantity which is invariant to image illumination, brightness or contrast. Phase congruency is one of these methods which satisfies the terms contrary to gradient- based edge detecting methods which are sensitive to changes image illumination, blurring and magnification. Phase congruency (PC) is a frequency- based model that instead of searching for points, considers both amplitude and phase of the individual frequency components in a signal.

Phase congruency value of pixel \(x\) in an image is computed by [9]:

\[
PC(x) = \frac{\sum_o \sum_n W_o(x) A_{no}(x) \Delta \Phi_{no}(x) - T_o}{\sum_o \sum_n A_{no}(x) + \varepsilon}
\]
where \( o \) and \( n \) denote the index over orientation and wavelet scale respectively. The function \( \lfloor \ast \rfloor \) follows Kovesi’s notation [9], returns its enclosed quantity when the value is positive and zero otherwise. \( W \) is a weighting function for phase congruency, \( A_n \) is the amplitude of the transform at the given wavelet scale \( n \). \( A_n(x)\Delta \Phi_n(x) \) is a measure of phase congruency presented by Kovesi [9]. \( T_o \) compensates for the effect of noise in the phase congruency calculation. The \( \epsilon \), a small positive real number, has been added to denominator to prevent division of zero. Fig. 1(b) shows the transformed image using equation (1) using appropriately selected parameters of image on Fig 1(a).

PC(\( x \)) has a value between zero and one. The value close to one represents a high transition on the pixel which is a high changes in pixel intensity in the real image.

**Fig. 1(a).** A sample of chest X-ray infected with PTB (Source: Institute of Respiratory Medicine, Kuala Lumpur)

**Fig. 1(b).** Transformed image of Fig.1 (a) using Kovesi’s phase congruency

**B. Feature Extraction**

Each image from the PTB control group, has been divided to six zones namely: R-U (right-upper), L-U (left-upper), R-M (right-middle), L-M (left-middle), R-L (right-lower) and L-L (left-lower).

From the NL images two regions of size 32 \( \times \) 32 pixels were selected randomly and cropped using MATLAB to represent the rib-bone and healthy tissue respectively.

Similarly for the PTB images a region of size 32 \( \times \) 32 pixels was selected to represent the infected tissue.

In each of the region of size 32 \( \times \) 32, the pixel values were transformed using equation (1), thus giving the phase congruency values at each pixel \( x_{i,j} \) (henceforth labeled as PC(\( x_{i,j} \))-values for \( i=1,\ldots,32 \) and \( j=1,\ldots,32 \)). Four summary statistics were calculated as follows:

i. Average, \( \bar{x} = \frac{1}{N} \sum_{i} \sum_{j} PC(x_{i,j}) \) where \( N=32 \times 32 \).

ii. Variance, \( S^2 = \frac{1}{N-1} \sum_{i} \sum_{j} (PC(x_{i,j}) - \bar{x})^2 \)

iii. Coefficient of Variation, \( cv = \frac{S}{x} \)

iv. Maximum PC-value.

Given \( m \)-regions for a given type of image (PTB, NL healthy tissue and NL rib-bone) \( m \)-replicates of average, variance, coefficient of variation and maximum were obtained.

Without loss of generality consider \( S^2_1, S^2_2,\ldots, S^2_m \).

When \( m \) equals ten a box-plot of \( S^2 \)-values was drawn. This process was repeated for \( m \) equals 15 up to \( m \) equals 40 with increments of five for \( m \). In total seven box-plots were drawn side by side. When the median of the box-plot remains stable with respect to increasing \( m \), this median may then be used as the appropriate \( S^2 \)-value to be used as a feature. Fig. 2(b) shows the results for variance.

This process was repeated for average, coefficient of variation and maximum (Fig. 2(a), Fig. 2(c), Fig. 2(d), respectively). These diagrams show that the values 0.095905, 0.009745, 1.041267 and 0.515374 may be used to represent average, variance, coefficient of variation and maximum PC for PTB.

All the above process was repeated for the NL rib-bone and healthy tissue and the main results is listed in Table 1.

**C. Feature Testing**

Let \( x_j^T = (x_1^j, x_2^j, x_3^j, x_4^j) \) represent the proposed feature vector consisting of average, variance, coefficient of
variation and maximum PC(x)-value from the control data. Similarly let \( y_k^T = (y_1^k, y_2^k, y_3^k, y_4^k) \) represents the same statistics from the test data. The letters \( j \) and \( k \) represent any of the three types of the images (PTB, NL healthy tissue and NL rib-bone). For fixed values of \( j \) and \( k \) the Euclidean distance \( d(j,k) = \sqrt{\sum_{i=1}^{4} (x_i^j - y_i^k)^2} \) was calculated and the smallest \( d(j,k) \) value implies that the \( k\)th-test sample has been identified as being the \( j\)th-type of image. Henceforth, misclassification probabilities were calculated using the test set consisting of ten PTB images, ten NL healthy tissue image, and ten NL rib-bone images.

![Fig. 2(a). Average of PC values](image-a)

![Fig. 2(b). Variance of PC values](image-b)

![Fig. 2(c). Coefficient of Variation of PC values](image-c)

![Fig. 2(d). Maximum of PC values](image-d)

![Fig. 2. Box-plot for variables of feature vector of PTB region.](image-e)

### III. RESULTS

The main results are the four dimensional feature vectors to represent PTB, NL healthy tissue and NL rib-bone. The component of the feature vector are the average, variance, coefficient of variation and maximum PC(x)-value for selected 32 x 32 pixels region. These feature vectors are given in the Table 1.

These feature vectors were verified with a test sample yielding 100% detection for PTB, 90% for NL healthy tissue and 50% detection for NL rib-bone.
TABLE 1
FEATURE VECTORS FOR PTB, NL HEALTHY TISSUE AND NL RIB-BONE

<table>
<thead>
<tr>
<th>Variable</th>
<th>PTB</th>
<th>NL Healthy Tissue</th>
<th>NL Rib-Bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average-PC value</td>
<td>0.095905</td>
<td>0.050905</td>
<td>0.053178</td>
</tr>
<tr>
<td>Variance-PC value</td>
<td>0.009745</td>
<td>0.00571</td>
<td>0.00508</td>
</tr>
<tr>
<td>Coefficient of variation-PC value</td>
<td>1.041267</td>
<td>1.464803</td>
<td>1.363074</td>
</tr>
<tr>
<td>Maximum-PC value</td>
<td>0.515374</td>
<td>0.419284</td>
<td>0.407197</td>
</tr>
</tbody>
</table>

IV. DISCUSSION AND CONCLUSION

The interpretation of digital chest X-ray images will still play a prominent role in many healthcare centres, simply due to economic reasons. The focus on PTB is because despite the existence of advanced medical treatment it is known to recur especially in underdeveloped nations.

The detection of PTB using chest X-ray largely depends on visual interpretation where inexperience on the part of medical practitioner may lead to a wrong or delayed diagnosis. This is partly due to the fact that the appearance of PTB on the chest X-ray does not conform to any standard shape, size and configuration. Since PC\(^x\)-values provide information on transition between pixels useful information can still be obtained which is independent of the shape, size and configuration of the infected area. Further the properties of PC\(^x\)-values is such that it is a dimensionless quantity invariant to different image brightness or contrast.

ACKNOWLEDGEMENT

We would like to acknowledge the contribution from Datin Dr. Hjh Aziah Ahmad Mahayiddin, Dr Ashhari Yunus, and Dr Azwayati Abas, The Institute of Respiratory Medicine, Kuala Lumpur. This research was supported in part by University of Malaya research grant (UMRG RG035 09AFR) and Universiti Teknologi Malaysia.

REFERENCES


