Pattern Recognition Method for Evaluation of Laser Transillumination Images for Therapy Monitoring in Case of Finger Joints Diseases

J. Bauer¹, E. Boerner², A. Suchwalko³, H. Podbielska¹

¹ Bio-Optics Group, Institute of Physics, Wroclaw University of Technology, Wybrane Wyspianskiego 27, 50-370 Wroclaw, Poland
² Department of Physiotherapy, University School of Physical Education, ul. Wittelona 25 a, 51-617 Wroclaw, Poland
³ Institute of Mathematics, Wroclaw University of Technology, ul. Janiszewskiego 14, 50-377 Wroclaw, Poland

Abstract

The early diagnosis of inflammatory processes of interphalangeal joints, is essential for proper treatment and monitoring of the therapy results. We have designed and constructed the apparatus consisted of He-Ne laser, special holder for patient finger, CCD camera and image processing system for images classification. The system was tested on ill, as well as on healthy persons. For classification the statistical pattern recognition methods were applied. It was demonstrated that the image processing and classification methods enable the differentiation between healthy and ill individuals with 95% accuracy and allow to monitor the therapy progress, as well.

Keywords: laser transillumination, statistical pattern recognition, interphalangeal joints

Introduction

Inflammatory arthropathies, mostly progressive, significantly decreases the quality of life of 1–2% of the population. The clinical examination such as X-ray or ultrasound imaging are performed when the pathology is more advanced. The proper diagnosis is essential for proper treatment, especially in early stages. Transillumination in visible or infrared light, called also diaphanoscopy, is one of the oldest diagnostic methods, based on the qualitative evaluation of organs' images obtained in transmitted light [1]. Transillumination again attracted attention as a possible diagnostic tool for evaluation of muscoskeletal system, especially for assessment of interphalangeal joints in rheumatoid arthritis [2]. Recently, we have demonstrated that transillumination can be exploited for diagnosis by comparing the mean gray levels of the transillumination images of finger joints of healthy and ill persons [3]. In the study described here, we used more sophisticated tool of analysis based on statistical pattern recognition.

Material and method

The examinations were performed on 25 healthy adult volunteers and 25 patients suffering from interphalangeal arthropathies, associated with the pain and motory disorder comfort. Among the patients, 16 were female (aged 25-80, mean age 51) and 9 male (aged 32-75, mean age 49). The 18 healthy volunteers were females (aged 21-71, mean age 50) and 7 males (aged 20-69, mean age 47). In 40% of patients the positive rheumatoid factor (RF) was stated. The deformity was observed in 24% of patients.
The patients were subjected to anti-inflammatory and anti-pain standard pharmacological therapy, as well as physiotherapy, including kinesitherapy and low-level-laser therapy with IR laser ($\lambda=980$ nm, output power 100mW, energy density 4J/cm$^2$) applied in 2 series, 5 days each with a 2 days break over the weekend.

For the study presented here, the special apparatus was designed and constructed, which consisted of the He-Ne laser with optics for collimated illumination, special holder for placing the finger (perpendicular to optical axis, dorsal site towards camera), and CCD camera. The captured images of interphalangeal joint of each person’s dominant hand’s third finger were presented in JPEG format with 1152x864 resolution. The images of patients were captured before therapy, after 5 and after 10 days (non shown). The initial pictures were converted into the gray scale bitmaps. The region of interest (ROI) was chosen, limited to the square sample of the central finger part as an image of the size of 280x280 pixels. Next, all samples were resized to 80x80 pixels pictures and stored in database.

The statistical pattern recognition methods were used for the recognition of transillumination images. First of all, the databases were randomly selected. The images were divided into two groups: learning database and test database. The recognition was performed for patients before the therapy and after 5 and 10 days.

The Linear Discriminant Analysis (LDA) for feature extraction (i.e. data dimensionality reduction) was exploited [4]. Then, classification based on the Nearest Neighbour method was performed [5]. LDA provides an extraction of these data features that are most specific for different classes (in our case – healthy persons or patients).

The recognition procedure, including database selection, recognition and evaluation of system performance was repeated 50 times (i.e. 50-fold random subsampling method was applied). Let us assume that we are going to classify a new transillumination image of a person to one of two classes: healthy person or patient. Euclidean distance from this new image to each of images of healthy and ill individuals in the learning set is calculated. Next, if the

### Table 1. Results of recognition. Significance level $\alpha=0,01$ (probability $P=0,99$).

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Average EAR [%]</th>
<th>Standard Deviation</th>
<th>Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>Before therapy</td>
<td>95,02</td>
<td>1,21</td>
<td>91,90</td>
</tr>
<tr>
<td>After 5 days</td>
<td>89,37</td>
<td>0,94</td>
<td>86,95</td>
</tr>
<tr>
<td>After 10 days</td>
<td>87,17</td>
<td>0,61</td>
<td>85,60</td>
</tr>
</tbody>
</table>

![Fig. 1. ROC curves for the patients before and after therapy](image-url)
closest image from the learning set is closer than a fixed threshold, we classified it as an image of the healthy individual. If not, it was classified as patient. The standard 2x2 diagnosis table (called also contingency table or confusion matrix) containing number of correct classifications and misclassifications was obtained. Similar methodology was used to assess effectiveness of the therapy.

The healthy person may be correctly recognized as a healthy one - True Positive Rate – TP or wrongly classified as a patient False Negative Rate – FP. The ill patient may be wrongly recognized as a healthy individual – False Positive Rate – FP or correctly recognized as a patient True Negative Rate – TN [6]. The performance of recognition system is reported on Receiver Operator Characteristic (ROC) by showing the trade-off between the True Positive Rate (Sensitivity) and the False Positive Rate (100%-Specificity) [7]. In our work, the Equal Acceptance Rate (EAR) as a measure of system general performance is employed [8]. The EAR is the rate, at which the TP is exactly equal to the TN also known as Specificity.

**Results and discussion**

Two main goals were the subject of this research. Firstly, we would like to check whether the system is able to differentiate between healthy and ill individuals and we calculated that it is possible with 95.02% accuracy (see Tab. 1). The second goal was to check whether the therapy can influence the system performance. If the therapy has positive influence, the transillumination images should resemble the images of healthy persons and system should more often classify them as belonging to the class of healthy individuals. In this case, the system should wrongly recognize ill person as healthy one, so EAR should decrease. First, the analysis was performed for the test data base consisted of transillumination images of patients after the 5 days of therapy. The average efficacy (mean EAR value) was 89.37%. The average efficiency in this case was 87.17%. Fig. 1 shows the ROC curves before and after therapy.

Our analysis concerns the estimation of parameter EAR, which informs us about performance of the recognition system. Since all experiments presented in this work were repeated 50 times, it was possible to perform the exact statistical analysis. Calculated confidence intervals give an estimated range of EAR values. The significance level was chosen to be $\alpha = 0.01$ level (1% level). The outcome of analysis is shown in Tab. 1. One can see that after the therapy, both lower and upper bounds of confidence intervals prove the described trend, what means that the values are lower for treated patients.

**References**