ASSESSMENT OF ASYMMETRY IN DERMOSCOPIC COLOUR IMAGES OF PIGMENTED SKIN LESIONS

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ABSTRACT
Skin cancer is the most commonly diagnosed type of cancer in all people, regardless of age, gender, or race. One of the most common malignant skin cancer is melanoma which is a dangerous proliferation of melanocytes. In the last several years an increasing melanoma incidence has been observed worldwide, and the diagnosis and deaths are increasing faster than those of any other skin cancer. Only in UK around 12,800 new cases of malignant melanoma were diagnosed in 2010. This paper presents a new approach to the assessment of asymmetry of the pigmented skin lesion. Asymmetry is one of the most important indicators and contributes substantially to the diagnosis of melanoma in the commonly used diagnostic algorithm, ABCD rule. This paper describes a complex algorithm containing following steps: image enhancement, border detection, lesion segmentation, positioning of axes, and calculation of the asymmetry parameters. The automated asymmetry assessment is based on definition and calculation of the geometry parameters and colour variation (pigmentation, texture) of the lesion. The algorithm has been tested on a database of 100 images (30 malignant lesions and 70 benign lesions). The effectiveness of the proposed method is shown through experiments and compared to diagnosis results by clinical experts. The sensitivity and accuracy have improved significantly.

KEY WORDS
Skin lesion, melanoma, medical image processing, image measurement, diagnosis support

1. Introduction
Skin cancer is the most commonly diagnosed type of cancer in all people, regardless of age, gender, or race. One of the most common malignant skin cancer is melanoma which is a dangerous proliferation of melanocytes. Malignant melanoma (Latin: melanoma malignum) originates in pigment producing cells called melanocytes, which derive from neural crest. This tumour occurs mainly in skin, but it can be also found in mucous membranes of the gastrointestinal tract and even in the eye [1, 8, 12]. Melanomas are fast-growing and highly malignant tumours often spreading to nearby lymph nodes, lungs and brain. In the last several years increasing melanoma incidence has been observed worldwide and the diagnoses and deaths are increasing faster than those of any other skin cancer. Only in UK around 12,800 new cases of malignant melanoma were diagnosed in 2010 [12]. Malignant melanoma is predicted to become one of the most common malignant tumours in the future, with even a ten times higher incidence rate. In the last several years increasing melanoma incidence has been observed worldwide. One of the major contributors to the development of melanoma is ultraviolet radiation (long-term sun exposure and sun-burn) that causes damage to the cell DNA. Also the negative influence of quality of life is of great importance. Due to high skin cancer incidence, dermatologic oncology has become a quickly developing branch of medicine. One of the main tasks of modern dermatology is the detection of melanoma in its early stage of development, because the survival rate after identification of less than 0.75 mm thick melanomas is near 100% [1, 8, 13]. Treatment of advanced malignant melanoma is performed from a multidisciplinary approach, multidisciplinary, such as chemotherapy, radiation therapy or immunotherapy, are not efficient when the melanoma is in advanced stage. Progress is visible both in primary research concerning pathogenesis of tumours (the role of genes or viruses in tumour development) and in the development of new, more efficient methods of diagnosis. In the light of the above data, prevention and early diagnosis of melanoma (tumour thickness below 0.75 mm) become an extremely important issues.
Figure 1. Lesion observed with the naked eye in comparison to the dermoscopy examination. The global and local features become visible. (Based on [1])

The term "dermoscopy" was introduced in 1920 by Johann Saphier, a German dermatologist. Dermoscopy (also known as dermoscopy or epiluminescence microscopy, ELM) is a non-invasive, in vivo medical examination that uses optic magnification to visualize the features of the pigmented skin lesion that are invisible for the naked eye (fig. 1) [1, 8]. The magnification range from 10x, 40x even up to 100x.

The diagnostic instrument commonly used for dermoscopic examination are the dermatoscope and the videodermatoscope (digital dermatoscope) that is connected with a computer (fig. 2). Videodermatoscope allows the medical image processing and analysis, image storage and indirect visualization of the skin lesion on a monitor in a high quality. Compared with the diagnosis by the naked eye, the considerable improvement of the diagnostic accuracy (10 % to 30 % higher sensitivity) has been observed [1].

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Score</th>
<th>Weight</th>
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<tbody>
<tr>
<td>A-asymmetry</td>
<td>Number of asymmetry axes</td>
<td>0-2</td>
<td>1.5</td>
</tr>
<tr>
<td>B-border</td>
<td>Number of octants with irregularity</td>
<td>0-8</td>
<td>0.1</td>
</tr>
<tr>
<td>C-colour</td>
<td>Number of colours</td>
<td>1-6</td>
<td>0.5</td>
</tr>
<tr>
<td>D-diameter</td>
<td>Diameter larger than 6mm</td>
<td>0-5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

One of the main parameters of the ABCD rule is asymmetry which has the highest weight factor (1.3) and the correct assessment is crucial for the calculation of total dermatoscopical score (TDS) [1, 13].

To determine the degree of asymmetry of the segmented skin, lesion is bisected by two 90° axes (major and minor axis) into four parts (fig. 3). The geometric parameters as well as the colour variation are calculated and compared between the divided parts. Benign nevus are mostly symmetric while melanomas are generally asymmetric along both axes.

A can take the value of:
- 2 (no symmetry on two axes),
- 1 (symmetry on one axis),
- 0 (symmetry on both axes).

Figure 3. Asymmetry of the shape. In a) symmetry is on both axes A=0, in b) symmetry is only on one axis A=1, in c) both axes are asymmetric A=2.

Different groups are developing diagnostic systems and improving the detection algorithm to provide distinction between benign and malignant melanocytic lesions [13]. Asymmetry is a very interesting study areas and researchers are searching for the best solution for many years. One of the most commonly used asymmetric measurement of skin lesion is circularity. This parameter has been used for many years, however, this measurement depends very much on the accuracy of the segmentation result. In 1997 Ng and Cheung investigated the use of symmetry distance (SD) to improve the measurement of the asymmetry [3]. Six years later the same group of researchers published a work based on artificial neural network model to improve the measurements of the asymmetries of lesions that may have fuzzy borders [4]. Most of the studies over the last 10 years describing the asymmetry parameter concentrate only on the geometrical aspect [3, 8, 16, 19]. An interesting problem is the determination of optimal major and minor axes. Seidenari

Since 1950s when the portable dermatoscope was developed by Goldman and firstly used to diagnose pigmented skin lesions, many different diagnostic models have been proposed. The most widely used diagnostic algorithms are the ABCD rule described in 1993 by Stolz et al and 7-point checklist proposed by Argenziano and colleagues in 1998 [1].
et al. [22] segments a lesion across 128 axes and Andreassi et al. [23] evaluates contour symmetry based on the variance of area difference between 360 segments [21]. It is difficult to judge the accuracy of the developed algorithms because the presented results mostly describe the complete operational system. The maximum reported diagnostic accuracy of lesion asymmetry was 86.6% [21]. The highest correct location of the major and minor axis was 92% [24].

In this work we try to add the colour variation as an important parameter to distinguish between benign and malignant lesions. The colour analysis among the detected area will give us information about the local structures distribution and will be crucial for the improvement of the correct assessment of the asymmetry. The novelty of this research lies in the combination of color and geometric features as symmetry criteria.

This paper is organized in 5 chapters as follows. Chapter 2 describes the main image processing algorithm, including pre-processing step, segmentation method based on the active contour model known in the literature as a "snake", and the major and minor axes determination. Chapter 3 presents feature extraction both for geometrical parameters and colour variation and the colour transformation method. In chapter 4 the conducted tests and results are described. Chapter 5 closes the paper with conclusions, discuss the results and highlights future directions.

2. Algorithm for asymmetry assessment

2.1 Introduction

The main aim of the algorithm for asymmetry assessment is to enhance and prepare the image for the measurement of the asymmetry features (chapter 3). For that reason an automatic image processing system has been developed and is based on the flowchart of the algorithm demonstrated in figure 4. The approach is divided into eight stages of pre-processing, segmentation, border extraction, major and minor axis calculation, colour transform, feature extraction, calculation of geometrical parameters and asymmetry calculation.

2.2 Pre-processing

The main aim of the pre-processing step is to refine the dermoscopy image, so that the border, colour and local features become easier to detect by the image analysis system. In other words, we reduce the image noise and increase the contrast of structures of interest (skin lesion). In our work we do not find it necessary to usedifferent noise removal filters (median filter, Gaussian function etc.) due to excellent quality of the images. The pre-processing step contains two operations. Firstly, the original true colour RGB image is converted into intensity (greyscale) by eliminating the hue and saturation. Secondly, the greyscale image is being enhanced by the contrast-limited adaptive histogram equalization (CLAHE) which applies the concept of whole-image histogram equalization to small, local data regions (tiles) 20x20 [5]. CLAHE is used to enhance the contrast of the small tiles of an image and to combine the neighbouring tiles using a bilinear interpolation which task is to eliminate the artificially induced boundaries. Also a contrast factor is used for the prevention of over-saturation of the image specifically in homogeneous areas [5]. These areas are characterized by a high peak in the histogram of the particular image tile due to many pixels falling inside the same gray level range. Figure 5 presents the original image and the outcomes of the pre-processing step.
2.3 Segmentation

Segmentation is the stage of the algorithm which delineate structures of interest and discriminate them from background tissue. The segmentation process is based on the outcome of pre-processing and is crucial for the correct asymmetry assessment because the other processing steps are based on the segmented region.

For the segmentation of the skin lesion the active contour model (snake), which was firstly introduced by Kass et al in 1988, has been chosen. Active contour models are an attractive approach to boundary detection in medical images and are successfully used over the last 20 years [2]. A snake is a parametric curve that behaviour is specified through a function called energy function which contains of: internal deformation energy of the snake, image forces acting on snake and external constraint forces [2, 5, 7]. Representing the position of a snake by $v(s)=(x(s), y(s))$ where $s$ is the arc length and $x$ and $y$ are the image coordinates of the 2D-curve the energy function can be written as in equation 1 [2, 20]:

$$E_{\text{snake}} = \int_0^1 E_{\text{snake}}(v(s)) \, ds$$

$$= \int_0^1 [E_{\text{int}}(v(s)) + E_{\text{image}}(v(s))] + E_{\text{con}}(v(s)) \, ds$$

(1)

The energy function presented in equation 1 is defined in such a way that the minimum should occur on the boundary of the lesion. Equation 2 presents the internal energy of the spline:

$$E_{\text{int}} = \frac{(\alpha(s)|v_x(s)|^2 + \beta(s)|v_{xx}(s)|^2)/2}{2}$$

(2)

where $v_x$ and $v_{xx}$ are the first and second derivative of $v$ with respect to $s$. Parameter $\alpha(s)$ and $\beta(s)$ are very important and affect the behaviour and sensibility of the snake. $\alpha(s)$ makes the snake behave like a membrane and $\beta(s)$ like a thin plate [2, 5, 7, 20]. The function $\alpha(s)$ controls the first-order term of the internal energy: the elasticity. The function $\beta(s)$ controls the second-order term: the rigidity. Large values of $\beta(s)$ let the contour become smooth, small values allow the generation of corners [20].

Equation 3 presents the image forces which are pushing the snake toward image features:

$$E_{\text{image}} = w_{\text{line}}E_{\text{line}} + w_{\text{edge}}E_{\text{edge}} + w_{\text{term}}E_{\text{term}}$$

(3)

Equation 3 has three components: line, edge and termination. The line energy represents the intensity of the image, the edge energy will attract towards contours with large image gradients and the termination functional attracts the snake toward termination of line segments and corners.

The additional external energy $E_{\text{con}}(v(s))$ is an external constrained force, which provides the opportunity for individual forces at particular parts or points of the contour [20]. The final shape of the contour corresponds to the minimum of the energy of equation 1.

In most image processing examples the problem is to choose the correct starting point of the snake which will produce appropriate forces to find the boundary at the end. We don't have to handle this problem because every skin lesion lies in the centre of the image. Figure 6 presents the results for the segmentation step.

$$E_{\text{term}} = \frac{1}{2}$$

After the segmentation procedure the border is extracted and the binarization process takes place (fig. 7 and 8).
2.4 Major and minor axis

The geometric parameters and colour variation is measured across the skin lesion major and minor axis of symmetry. The axes are determined after the segmentation process and the detection of the boundary. We calculate the length of the major and minor axis of the ellipse that has the same normalized second central moments as the region. To analyse further steps we need also the angle (in degrees ranging from -90 to 90 degrees) between the x-axis and the major axis of the ellipse that has the same second-moment as the segmented area (fig. 9).

![Figure 9. The major and minor axis with the highlighted angles [5].](image9.png)

Major and minor axes of the segmented area which divide the region into four parts. Each of the part will be compared with the adjoining (fig. 10).

![Figure 10. Determination of optimal major and minor axes.](image10.png)

3. Feature extraction for asymmetry classification

To characterize and distinguish different types of asymmetry we calculate a vector of features containing geometric parameters and colour features.

3.1 Measurement of geometric parameters

The geometric parameters are one of the most commonly used for the assessment of asymmetry. Geometric parameters are extracted from the binary shapes obtained after image pre-processing step. We calculate the geometrical parameters both for the whole segmented area and for the regions divided by the axes [5].

Compactness is a common shape measure that quantifies how close is an object to the smoothest shape. It is computed by using the perimeter (P) and area (A) of the segmented skin region (eq. 4) [5].

$$C = \frac{P^2}{A}$$ (4)

For the skin lesion evaluation we use a normalized variant that is ranging between zero and one (eq. 5).
Compactness is independent of translation, zoom and rotation effects. This common metric is not always a robust estimator of shape complexity but often has a good correlation [5].

Geometric parameters for each of the four regions include: area (A), perimeter (P), minimal and maximal radius (Rmin, Rmax) and area difference across each axes (Ad) [5].

In addition, to increase the effectiveness of the asymmetry assessment a basic method for the estimation of the local features has been proposed. For the comparison of the local features lying on both sides of the axes we use the images after the pre-processing step (fig. 5d, 11).

Figure 11. Colour segmentation with the k-means clustering.

The greyscale level and the outstanding features are being compared between the four regions divided by the major and minor axes.

3.2 Estimation of colour features

The next parameter which is analyzed is the colour variegation. In malignant melanomas there can be found up to six or even more different colors. Six colours are considered to be most significant: white, red, light-brown, dark-brown, blue-gray, and black. Before extracting the local colour features we have to segment colours into homogenous regions. The colour segmentation contains two steps: converting the RGB image to L*a*b* colour space and classification of the colours using k-means clustering [17]. The letter of the L*a*b* colour correspond to a luminosity layer \( L^* \), chromaticity-layer \( a^* \), and chromaticity-layer \( b^* \) [17]. The goal of the k-means clustering method is to partition the skin lesion into \( n \) clusters in which each colour belongs to the cluster with the nearest mean (as close to each other as possible). Figure 11 presents the results of the colour segmentation.

Figure 12. Colour segmentation with the k-means clustering.

To determine the colour parameters the skin regions after colour segmentation are divided into four parts with the major and minor axis. The colours occurring in the adjoining parts are compared (area, location, distance). we have to keep in mind that in a strict sense ‘nothing in nature is completely symmetric’ so we are looking only for significant differences.

4. Results

The proposed and implemented algorithm for the diagnosis of asymmetry of the pigmented skin lesion has been tested on a database containing over 100 images from two university hospitals (University of Naples, Italy and University of Graz, Austria) that were stored on a CD-ROM in JPEG format [1]. Documentation of the dermoscopic images was performed using a Dermaphot apparatus (Heine, Optotechnik, Herrsching, Germany) or
a photo camera (Nikon F3) mounted on a stereomicroscope (Wild M650, Heerbrugg AG, Switzerland) [1]. All of the cases were based on histopathological examination of the biopsy material. The original database consisted of 252 melanoma cases. For this study we have chosen images that fitted entirely in the image and did not contain any (or too much) hair in the examined lesion. The database included 34 images containing hair and 143 lesions lying partly in the image. To verify the proposed algorithm 30 challenging cases were chosen. Testing of correct implementation was carried out on a database containing 70 benign and 30 malignant images with different resolutions, ranging from 0.033 to 0.5 mm/pixel [1]. All of the images were assessed manually by dermoscopic experts with extensive clinical experience. The asymmetry in the ABCD rule criteria can take the value of:

- 2 (no symmetry on two axes) - 30 images,
- 1 (symmetry on one axis) - 50 images,
- 0 (symmetry on both axes) - 20 images.

For the evaluation of correct border detection with the active contour method we use the Border Error (BE) measure, which is also called XOR measure. This method was firstly introduced by Hance et al. [18] in dermatoscopy and is is more important for skin lesion detection researchers than precision and recall [18]. It quantifies the percentage border detection error as

\[
BE = \frac{\text{AREA}(AB \oplus MB)}{MB} \cdot 100\%
\]  

(6)

where AB and MB are the pixels of binary images obtained by filling the automatic and manual borders, \(\oplus\) is the XOR operation, and Area denotes the number of pixels in the binary image. The aim of method is to measure the pixels for which AB and MB disagree (fig. 6). The border error for 91 medical images was less than 5% and the error rate did not affect the further research. Only in one image with regression structures (white area) the border error was over 20% and affected the feature extraction process.

For evaluating the performance of the asymmetry sensitivity and specificity were calculated.

Sensitivity relates to the test’s ability to identify positive results [5, 8].

\[
\text{Sensitivity} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative}}
\]

(7)

Specificity relates to the ability of the test to identify negative results [5, 8].

\[
\text{Specificity} = \frac{\text{True Negative}}{\text{True Negative} + \text{False Positive}}
\]

(8)

TP is “number of true positives”, FP is “number of false positives”, TN is “the number of true negatives”, and FN is “the number of false negatives”.

<table>
<thead>
<tr>
<th></th>
<th>Symmetry</th>
<th>Asymmetry(1+2)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test positive</td>
<td>28 (TP)</td>
<td>5 (FP)</td>
<td>33</td>
</tr>
<tr>
<td>Test negative</td>
<td>2 (FN)</td>
<td>65 (TN)</td>
<td>67</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>30</td>
<td>70</td>
<td>100</td>
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Asymmetry assessment algorithm gave 93% of sensitivity and 93% specificity. In four cases that were marked as false positive the error occurred only in one axis. Error occurred on both axes in the image with the high (over 20%) border error. In different papers the sensitivity ranges between 85-91% and the specificity between 75-90% [3, 16, 19].

5. Conclusion

Achieved results indicate that the proposed algorithm can be used for the diagnosis of asymmetry of skin lesion. We observed an increase of the correct detection of asymmetry from 86.6% [21] to 93%.

The proposed algorithm can be a part of a whole ABCD melanoma diagnostic system that will be used not only by young inexperienced dermatologist but first and foremost by family physicians. This is an opportunity for people that live in remote and rural areas outside the regional centre and are faced with the usual difficulties of making an appointment with a dermatologist.

It is very important to diagnose melanomas in the early stage because it will reduce the melanoma-related mortality rate.

Despite the fact, that the results are satisfactory, the proposed algorithm will by still developed. Firstly, the border detection algorithm has to be improved to detect also regression structures. Secondly, more test have to be carried out to improve the asymmetry determination.

In conclusion the implemented algorithm meets the expectations and satisfies. The results of the preliminary tests show that computer-based image processing has the potential of better evaluation of changes [10].

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References


