DETERMINATION OF OPTIMAL AXES FOR SKIN LESION ASYMMETRY QUANTIFICATION

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ABSTRACT

Malignant melanoma is a skin tumour typified by high mortality rates when not diagnosed and excised in its earliest stages. Preoperative diagnostic accuracy may be improved through the development of computerised systems which accurately quantify features indicative of this cancer. One such feature is boundary contour asymmetry, which is typically measured across a skin lesion's major and minor axes of symmetry. In this paper techniques for detection of skin lesion asymmetry are discussed, and the viability of integrating Fourier descriptors into a shape asymmetry quantifier is investigated. It is concluded that Fourier descriptors facilitate accurate isolation and ranking of a lesion's symmetry axes and provide an approach which could easily be integrated into new or existing diagnostic procedures.

Index Terms— Melanoma, Asymmetry, Dermoscopy, Fourier Descriptors

1. INTRODUCTION

Malignant melanoma is the third most frequently occurring skin cancer amongst Caucasian populations. Accountable for 90% of all skin cancer related mortalities, the speed with which this disease is diagnosed directly relates to expected prognosis [1]. Prompt identification and diagnosis of suspicious lesions improves survival rates considerably as patients with thinner tumours have a reduced risk of metastatic disease. When diagnosed during stage I of development, melanomas can be surgically excised with a good prognosis (5 year survival rates approaching 95%) [2]. The prompt identification of malignant tumours is therefore of overriding importance.

A popular method for clinical diagnosis of melanoma is the ABCD rule of dermoscopy [1], which defines an algorithmic approach to lesion feature evaluation and subsequent malignancy quantification. The asymmetry, border (variegation and irregularity), colour (number and homogeneity of colours), diameter (greater or less than 0.6cm) of a lesion are considered. A possible criticism of the ABCD rule is that feature evaluation is susceptible to subjectivity, resulting in reduced diagnostic sensitivity and specificity. Therefore computerised systems have been developed which assist diagnosis [3-5]. Such systems automate feature quantification, ensure more precise feature definition, and diminish variability of feature analysis.

This paper focuses on skin lesion boundary asymmetry, specifically on the viability of integrating Fourier descriptors into a shape asymmetry quantifier. Section 2 summarises existing approaches for automated skin lesion asymmetry measurement. Section 3 outlines our methodology and describes its development. Results and conclusions are provided in Sections 4 and 5 respectively.

2. ASYMMETRY QUANTIFICATION

The degree of asymmetry of a pigmented lesion is significant when evaluating its malignant potential [5], and is frequently quantified within automated melanoma classification tools. Biaxial asymmetry is more indicative of melanoma than single-axis asymmetry. Using the ABCD approach, asymmetry evaluation separates a lesion into four sectors using orthogonal axes which pass through the lesion centroid and are aligned so that minimum asymmetry is obtained [1]. The effectiveness of the ABCD method is clearly dependent on first isolating a lesion's primary or principal axis of symmetry. Figure 1 illustrates an asymmetrical malignant tumour.

Many automated algorithms mimic the ABCD rule and evaluate asymmetry across axes within the lesion. Seidenari et al. [4] segment a lesion across 128 axes and exploit area differences between sectors to generate an asymmetry measure ranging between 0 (symmetrical) and 10 (asymmetrical). Similarly, Andreassi et al. [5] evaluate contour symmetry based on the variance of area differences between 360 lesion segments. However, depending on how the lesion is segmented and how axis locations are determined, such approaches may not be invariant to rotation.

Stoecker et al. [3] assume a contour's major chord to be the principal axis of symmetry and reflect the image across this axis and its orthogonal counterpart (minor chord). Area differences calculated across each axis determine asymmetry of shape as

$$Asymmetry = \frac{\Delta A_{min}}{A} \bullet 100\%$$

where ΔA_{min} is the smallest absolute area difference and A is the lesion area. This "folding" or "reflection" operation has been replicated in [6, 7] and [8]. Similarly, Ganster et al. [9] calculate asymmetry across four quadrants (defined by the major and minor chords) using

$$R_i = \frac{Q_i}{\sum_{j \neq i} Q_j}$$

where Q_i represents a feature value (specifically, the area, form-factor or perimeter) of quadrant i. The assumption that a contour's major chord is a close representation of a non-symmetrical object's best axis of symmetry underlies numerous other automated asymmetry quantifiers found within the literature [10, 11]. However, the use of such an assumption when aiming to develop a standardised approach to feature extraction is undesirable.

It is difficult to gauge the accuracy of algorithms developed for quantifying skin lesion asymmetry as the majority of approaches are integrated into fully operational systems which automate the measurement of multiple features (for example asymmetry and colour heterogeneity). Within the literature, the maximum reported diagnostic accuracy of fully replicable systems quantifying asymmetry (amongst other parameters) was 86.6% [12].

3. METHODS

The concept of how contour symmetry, specifically rotational symmetry, is displayed within Fourier descriptors was first introduced by Granlund [13]. Rotational and axial symmetry, as represented in Fourier space, have also been discussed by Zahn & Roskies [14]. In [14] descriptors are generated using a revised transform which considers the angular direction of boundary points. Our approach, which extends work outlined in [15], is a preliminary stage in the development of a fully automated melanoma classification system. We utilise Fourier descriptors to accurately isolate a contour's principal axis of symmetry (Principal Fourier axis) and have developed our algorithm through a combination of theoretical and empirical research into how symmetry properties are characterised in the Fourier domain.

Our test set comprises 30 digital dermoscopic images of pigmented skin lesions with varying degrees of asymmetry. All patients gave consent for inclusion of their images, and the project has Ethics Committee approval. Lesion boundary samples were obtained manually, resulting in 64 boundary points per lesion. Lesions were assessed blindly by two dermatologists to determine the location of the principal axis of symmetry in each case. A folding algorithm similar to that proposed by [3] was applied to estimate the minimum percentage asymmetry (A_{min}) of each lesion: the mean difference between A_{min} and percentage asymmetry obtained using the principal Fourier axis was calculated.

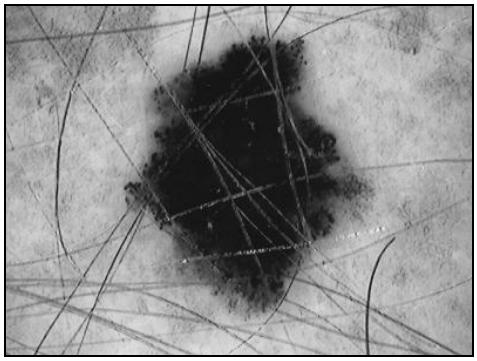

Figure 1. Asymmetric Malignant Melanoma.

3.1. Fourier theory

Fourier descriptors are a popular application of discrete Fourier analysis. They exploit a linear transfer to map spatial functions into the frequency domain, thereby generating contour based shape descriptors. Fundamental to Fourier descriptor theory is the concept that any continuous wave shape may be approximated via a summation of complex exponential functions.

Consider a closed contour, comprised of N boundary points (represented in 2-dimensional Cartesian space), and defined as the sequence $s(k) = [x(k),y(k)]$ for $k = 0,1,\ldots,N\text{-}1$ with start point $s(0) = [x(0),y(0)]$. Each boundary point may be expressed in complex form such that $s(k) = [x(k)+iy(k)]$ for $k=0,1,2,\ldots,N\text{-}1$. This complex sequence may in turn be utilised to generate a series of Fourier descriptors (complex coefficients) using:

$$a(u) = \frac{1}{N} \sum_{k=0}^{N-1} s(k) e^{-i 2\pi u k / N}$$

for frequencies $u = 0,1,2,\ldots,N\text{-}1$. Each resultant frequency coefficient corresponds to a sinusoid or basis function, and represents a specific element of contour shape. Lower frequencies capture the general properties or essence of shape; higher frequencies characterise finer details.

3.2 Symmetry representation in Fourier descriptors

For a contour (containing N sampled boundary points) with perfect symmetry around a vertical axis and start point on that axis, the sampled boundary points satisfy

$$(x(k),y(k) = (-x(N\text{-}k),y(N\text{-}k))$$

The k'th and $(N\text{-}k)$'th terms, $a_k(u)$ and $a_{N-k}(u)$, of the Fourier descriptor $a(u)$ are given by

$$a_k(u) = (x(k) + iy(k))e^{-2\pi uk/N}$$

and

$$a_{N-k}(u) = (x(k) + iy(k))e^{-2\pi u(N-k)/N}$$

and consequently the sum $a_k(u) + a_{N-k}(u)$ equals

$$2i(-x(n)\sin(2\pi un/N) + y(n)\cos(2\pi un/N))$$

Hence $a(u)$ is purely imaginary. Given a perfectly symmetrical contour for which the symmetry axis is vertical and start point lies on that axis, the real part of each Fourier descriptor (from $a(1)$ onwards) is zero. Similarly, when the symmetry axis and start point lie horizontally, the imaginary part of each Fourier coefficient equals zero. Furthermore, where reflectional symmetry exists across two axes, all Fourier descriptors with indices which are multiples of two are equal to zero.

Based on the properties identified in perfectly symmetrical contours, we use the proximity to zero of the real parts of Fourier coefficients to locate the best symmetry axis in the case of an asymmetric boundary. As a measure of symmetry we consider the sum of the real parts of the Fourier descriptors. Given a set of descriptors $a(u)$, corresponding to a non-symmetrical boundary contour with arbitrary symmetry axis inclination and start point, we can implement start point and rotation normalisation respectively, as $a_p(u) = a(u)^{e\text{-}j2ku/N}$ for $k = 0,1,\ldots,N\text{-}1$ and $a_r(u) = a_p(u)^{ej\theta}$ for values of θ between 0 and π corresponding to angular increments of 0.5º. This will align each sampled boundary point with the start point and facilitate a search for the angle which aligns that point with the vertical axis. The minimum sum of absolute real values ($AR_{\min}$) across all normalisations subsequently pinpoints the location of the principal symmetry axis and its inclination, θ, from the vertical axis.

This approach may be used to rank potential axes of symmetry, as minimum asymmetry will correspond to minimum values of the absolute sum of real coefficients. Figure 2 illustrates the results of our Fourier search for a near-symmetrical ellipse with its major symmetry axis aligned 65º clockwise from the vertical axis. It can clearly be seen from figure 2 that four minima, corresponding to two orthogonal axes of symmetry, are identified. Correspondingly, points of minimum symmetry may be identified as maxima in the sum of absolute real values.

Such an exhaustive search over both start point and angle of rotation is unnecessary, as start point and angle of rotation are not independent. A more efficient approach is to only normalise our initial set of descriptors for rotations that will align each new sample point (or potential symmetry axis) with the vertical axis. This approach to symmetry axis determination forms the basis of our methodology. Figure 3 illustrates this methodology for a near symmetrical ellipse

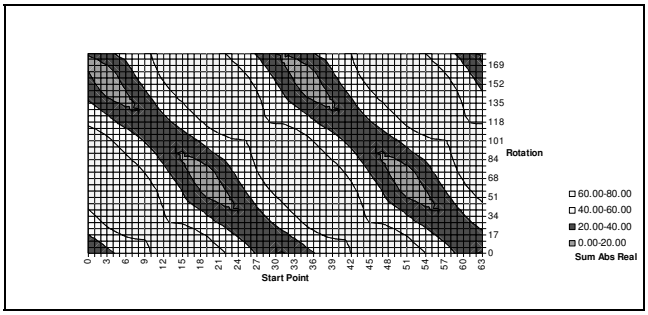

Figure 2. Contour Map Illustrating Symmetry Axis Isolation

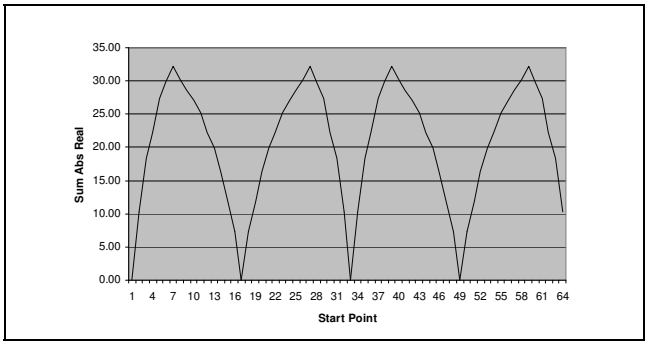

Figure 3. Revised Approach to Symmetry Axis Computation.

with symmetry axes at 0º and 90º, measured clockwise from the vertical axis.

4. RESULTS

Fourier descriptors were generated for each of the 30 images in our test set, and the proximity to zero methodology was applied to identify each lesion's principal axis of symmetry. Dermatologist opinion regarding principal axis inclination was consistent for 60% of test images, within a tolerancemargin of ±15°. Of the 12 instances where disagreement existed regarding symmetry axis inclination, the axes chosen
by experts were orthogonal to each other in 42% of cases (±15°). The mean difference between angle inclination, as identified by expert 1 and expert 2, was 33°.

When applied to our test set the Fourier search for symmetry axis isolation matched expert dermatologist opinion in 68% of cases (±15°). The individual accuracy rates obtained were 60% and 76.6% for experts 1 and 2 respectively.

If accuracy rates are amended to allow cases where dermatologists have identified an axis orthogonal to the Fourier axis, the percentage correlation between expert opinion and Fourier axis location increases to 80% (±10°) and 92% (±15°). This rationale is deemed acceptable as it compliments the ABCD clinical method of skin lesion asymmetry measurement. Additionally, if we consider the

best 4 Fourier axes, in every case they are either closely aligned to the best axis or approximately orthogonal to it.

When the Fourier approach is used to rank a lesion's potential axes of symmetry (Figure 4), the best 2 unique axes (±15°) derived matched those identified by dermatologists in 92% of cases. The individual accuracy rates obtained were 93.3% and 90% by experts 1 and 2 correspondingly. In 77% of cases, the best two unique axes identified by our Fourier approach were orthogonal to each other (±15°).

In order to evaluate the effectiveness of our methodology, an overlap measure was calculated via a folding algorithm which rotated each lesion boundary at 0.5° intervals and calculated the total percentage asymmetry between lesion halves at each rotation via an exclusive or (XOR) function [3]. The minimum percentage mismatch between lesion halves (A_{min}), found across all rotations, may be considered an estimator of a lesion's minimum percentage asymmetry. For our test set of images, the mean difference between A_{min} and percentage asymmetry calculated via the same XOR function across the principal Fourier axis was 1.5% with a standard deviation of 1.1%

5. CONCLUSION

The feasibility of integrating Fourier descriptors into new or existing methods for skin lesion asymmetry quantification has been investigated. A new method for identifying and ranking a closed contour's principal axes of symmetry has been proposed and applied. The algorithm developed is grounded within a sound mathematical framework and can be implemented without excessive use of computational resources.

Experimental results indicate that the Fourier approach to symmetry axis isolation is not only accurate and robust; it correlates strongly with the manner in which clinical diagnosis is accomplished. Using the top two unique axes identified via our algorithm, a match was achieved between our method and dermatologist opinion in 92% of cases. As the location of a lesion's principal axis of symmetry is fundamental to the accuracy with which asymmetry can be measured, future work will focus on integrating the Fourier technique into an asymmetry classification algorithm that can be incorporated into a fully automated tool for assisting melanoma diagnosis.

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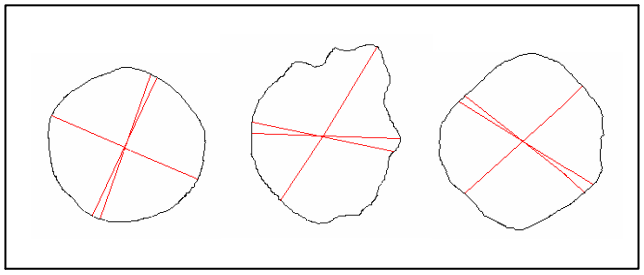

Figure 4. Examples of Best Symmetry Axes

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