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Real-time Supervised Detection of Pink Areas in Dermoscopic Images of Melanoma: Importance of Color Shades, Texture and Location

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Abstract

Background/Purpose—Early detection of malignant melanoma is an important public health challenge. In the USA, dermatologists are seeing more melanomas at an early stage, before classic melanoma features have become apparent. Pink color is a feature of these early melanomas. If rapid and accurate automatic detection of pink color in these melanomas could be accomplished, there could be significant public health benefits.

Methods—Detection of three shades of pink (light pink, dark pink, and orange pink) was accomplished using color analysis techniques in five color planes (red, green, blue, hue and saturation). Color shade analysis was performed using a logistic regression model trained with an image set of 60 dermoscopic images of melanoma that contained pink areas. Detected pink shade areas were further analyzed with regard to the location within the lesion, average color parameters over the detected areas, and histogram texture features.

Results—Logistic regression analysis of a separate set of 128 melanomas and 128 benign images resulted in up to 87.9% accuracy in discriminating melanoma from benign lesions measured using area under the receiver operating characteristic curve. The accuracy in this model decreased when parameters for individual shades, texture, or shade location within the lesion were omitted.

Conclusion—Texture, color, and lesion location analysis applied to multiple shades of pink can assist in melanoma detection. When any of these three details: color location, shade analysis, or texture analysis were omitted from the model, accuracy in separating melanoma from benign lesions was lowered. Separation of colors into shades and further details that enhance the characterization of these color shades are needed for optimal discrimination of melanoma from benign lesions.

Keywords

Machine vision; color analysis; color shade detection; dermoscopy; pink area; image analysis; melanoma; computer-aided diagnosis

I. INTRODUCTION

Malignant melanoma is responsible for up to 49,100 deaths worldwide annually [1]. Yet when melanoma is detected at the earliest stage, there is no change in life expectancy [2]. Thus early detection of malignant melanoma is an important public health challenge. In the USA, dermatologists are seeing more melanomas at an early stage, before classic melanoma features have become apparent. In one study, 21% of in-situ melanomas were smaller than 6mm in greatest diameter [3]. Thus, if automated assistance for early malignant melanoma detection can be implemented, it could have lifesaving effects.

Dermoscopy is a non-invasive imaging technique that employs magnification while reducing skin surface reflections. Dermoscopy improves sensitivity, specificity and accuracy in melanoma detection [4-7], by enhancing visualization of many features, including shades of pink [7-10]. Pink has not been adequately addressed in either clinical or image analysis studies of dermoscopic images of melanoma. Pink coloration has long been described as a component of variegated coloring [11]. It is a critical feature of nodular melanoma [9]; more than one shade of pink was a critical feature in detecting amelanotic melanoma [10]. Pink is also present in benign scalp nevi, often throughout the entire lesion [12]. Pink throughout the entire lesion was found in the majority of both melanoma and benign lesions [13]; while pink at the rim of the lesion (pink rim sign) was described as a useful feature in detecting melanoma [13].

In a previous study [13], we analyzed 1290 lesions, 296 melanomas (170 *in situ* lesions; 126 invasive lesions), and 994 benign lesions, with regard to three general locations of pink:

peripheral only (pink in the outer part of the lesion but not in the central part), central only (pink in the central part of the lesion but not in the outer part), and pink throughout the lesion (present in both the outer and the central part of the lesion) as shown in Figure 1. Data presented in Figure 1 show that, although pink present throughout the lesion is the most common pattern, pink found in the periphery of the lesion is more discriminatory for melanoma, yielding an odds ratio of 2.51 [13].

In this article, we present a real-time method that segments melanoma images for three shades of pink to implement melanoma discrimination from benign lesions using color, texture, and shade location features. The order of the remaining sections of the article is as follows: Section II describes the methodology, including image sets, manual spot determination, thresholding procedure, quintile overlays, and feature determination; Section III provides the results; Section IV presents the discussion; and Section V examines limitations for this study and future work in pink area segmentation.

II. METHODS

A. Overview

Figure 2 provides an overview of the experimental workflow. The analysis was conducted in two phases: first, manually marked oval spots within pink areas of 60 melanomas were analyzed to determine the color ranges within multiple color spaces for each of three pink shades: light pink, dark pink and orange pink. Next, for each color shade, optimal shade color thresholds were determined empirically using the relative color method [14,15]. The original nine color planes used was reduced to five. Using five-color-plane techniques, computer segmentation of the three pink shades was performed in real-time. Quintile overlays were added to the lesion, analogous to the decile overlay technique of Dalal *et al.* [16]. From the segmented and quintile-overlaid areas, blob features, color features and histogram features were extracted. Finally, classification was performed using a logistic regression model.

B. Experimental data sets

Training and testing data sets were acquired in the course of the study NIH CA101639-02A2. The training data set, used to train the logistic regression model, consisted of 60 malignant melanomas containing visible pink areas within the lesion in which each of three pink color shades was manually marked (Figure 3). Of the 60 melanomas in the training set, 25 were invasive with a median depth of 0.40mm and 35 were *in situ* melanomas. A separate testing set consisted of 132 lesions with significant pink coloration (54 melanomas and 78 benign dysplastic and congenital nevi). Out of the 54-lesion melanoma test set, 30 were at the *in situ* stage and 24 were at the invasive stage with a median thickness of 0.4mm, giving a ratio of in-situ to invasive malignant melanomas of 1.25 for the test set. The training and test set were comparable: the median depth of the invasive melanomas was 0.4mm for both sets; the in-situ to invasive ratio was 1.40 for the training set, similar to the ratio of 1.25 for the test set. Melanomas *in situ* are more difficult to discriminate from benign nevi than invasive melanoma, and melanomas in this study are representative of melanomas found in private practice dermatology clinics in the USA [3].

All melanomas were verified by histopathologic examination by a dermatopathologist. All benign lesions were evaluated with dermoscopy; any lesions with concern by either patient or physician were either biopsied or were followed in the clinic and found to be benign. All images had 1024×768 resolution and were contact non-polarized dermoscopy images acquired using 3Gen DermLite Fluid Dermatoscope (3Gen Inc., Dana Point, CA) with a Sony DSC-W70 7.2 megapixel digital camera. This research was approved by The Phelps County Regional Medical Center Institutional Review Board, Rolla, Missouri, USA, according to the Helsinki Declaration. Informed consent was obtained from all participants.

C. Manual pink area marking

For each training image, three small, uniform-sized roughly elliptical areas were selected for analysis by a dermatologist (W.V.S.). A second-order best-fit B-spline curve was used to connect the border points selected by the dermatologist, as in a previous study [17]. Examples of these selections are shown in the images on the left in Figure 3. Since melanoma images could have any shade or shades of pink, and it was not known *a priori* how to precisely define which shades were present, the widest possible range of pink shading was marked. Figure 3 shows the small areas selected and the areas selected automatically, after determination of color thresholds. The procedure noted above to mark the pink areas (manual determination of lesion areas followed by a second-order best-fit B-spline curve) was also used to mark the lesion borders.

D. Color spaces used in shade detection

Three color spaces were examined as candidates for these shade limits: the RGB (red, green and blue) color space, directly obtained from image pixel values, the relative RGB color space as outlined below, and the IHS (intensity, hue and saturation) color space. The supervised algorithm was designed to be adaptable, finding pink shades over varying skin colors and lighting techniques. Accordingly, the relative color technique was used [14,15] to create the relative RGB color space. This technique reassigns pixel values with the lesion to a new relative value. For each pixel at location (x,y) value in the image, the red value $r(x,y)$ is transformed $r(x,y) \rightarrow r_{rel}(x,y)$ by the equation $r_{rel}(x,y) = r(x,y) - r_{background_average}$, where the background red average is the average of the red value outside the lesion and within a distance $= 0.2 * \sqrt{A}$, where A is the area of the lesion. Rules for relative green and blue are similar.

E. Automatic thresholding for three shades of pink

The goal was to find a range of colors for each shade that included all target areas for the training set. These ranges can then be used to set upper and lower limits allowable for each shade, as shown in Figure 3b. The following procedure was used to develop empirical rules to detect areas for each shade within a lesion, using the manually marked areas in the 60-melanoma set to train the algorithm. First, we found the minimal range in each color space to include each shade sample. We compared results among all nine planes: RGB, relative RGB, and IHS planes. Only five color planes were needed for optimum individual shade detection: relative RGB, hue, and saturation. These detected areas, shown in Figure 3c, were subsequently used for further color, blob and texture processing.

Equations 1-3 show the 5-part rule for color detection using intersection of areas found within each of 5 color planes:

$$\cap_{i=1}^5 \left\{ \text{color}(i)_{\text{light_pink_minimum}} < \text{color}(i)_{\text{light_pink}} < \text{color}(i)_{\text{light_pink_maximum}} \right\} \quad (1)$$

$$\cap_{i=1}^5 \left\{ \text{color}(i)_{\text{dark_pink_minimum}} < \text{color}(i)_{\text{dark_pink}} < \text{color}(i)_{\text{dark_pink_maximum}} \right\} \quad (2)$$

$$\cap_{i=1}^5 \left\{ \text{color}(i)_{\text{orange_pink_minimum}} < \text{color}(i)_{\text{orange_pink}} < \text{color}(i)_{\text{orange_pink_maximum}} \right\} \quad (3)$$

where:

Color(1)=RGB relative red component

Color(2)=RGB relative green component

Color(3)=RGB relative blue component

Color(4)=IHS H (hue) component

Color(5)=IHS S (saturation) component

All color determinations in the rule are made pixel-by-pixel and implemented in real time in the C++ programming language.

F. Quintile Overlays

To allow for the determination of central versus peripheral location of pink areas, the lesion areas were segregated by quintiles, as calculated by the Euclidean distance transform from the lesion boundary (e.g. the outer fifth of all pixels closest to the lesion boundary are the first quintile, the next fifth of all pixels comprise the second quintile, proceeding until the inner fifth of all pixels, closest to the center). This is modified from the study of Dalal *et al.* that used deciles to analyze white areas within melanoma dermoscopy images [16]. An example image with quintile overlay and three shades of automatically detected pink can be seen in Figure 4.

G. Feature extraction

Key discriminating features were identified within the total area for each pink shade to characterize lesions for lesion discrimination analysis. Various blob features, color features and texture features listed in the following section were extracted for the analysis. For each of the five quintiles, the area occupied by each pink shade was determined, yielding a total of 15 areas detected, each with a specific shade and a specific location, as in Figure 4. A total of 150 features were derived, 50 for each of the three color shades. Equations for these features are found in the appendix.

G.1 Blob Features (5 per shade)

- Eccentricity of the largest blob: calculate Euclidean distance between the centroid of the largest blob and the centroid of the lesion, then normalize by the square root of the lesion area
- Relative size of all blobs: sum of all blob areas normalized by the area of the lesion
- Relative size of largest blob: measures ratio of the largest blob area to the area of the lesion
- Absolute size of largest blob: Area of largest blob within the lesion
- Number of blobs in the lesion

G.2 Color Features for each pink shade over entire lesion (15 per shade) (note: these are different from the features used for color detection)

- Average red, green and blue (RGB) values
- Maximum and minimum RGB values
- Standard deviation of each of RGB values in pink areas
- Average red, green and blue chromaticity of each pink area

G.3 Texture Features Derived from Lesion Histogram (24 per shade)

- Mean measures of average color-image intensity (brightness) in each color plane: RGB and intensity plane where intensity is defined as $(R+G+B)/3$.
- Variance measures the average contrast of pink areas in all four color planes (the three RGB planes and the intensity plane).
- Smoothness measures the smoothness of pink areas in all four color planes; its value is near zero for very smooth areas and near one for very rough regions.
- Skewness measures the asymmetry of pink area histograms in all four color planes. It returns a value of zero for histograms symmetric about the mean, a positive value for right-skewed histograms, and a negative value for left skewed histograms.
- Uniformity returns a maximum value when all gray levels or red, green and blue values are equal in all the pink areas in all four color planes.
- Entropy measures the randomness or uncertainty of values over pink areas in all four color planes.

G.4 Location Features (6 per shade)

- Individual area for each of five quintiles.
- Total area for that shade (sum of all five quintiles)

H. Classification

Multivariate analysis using linear regression was performed using the Proc Logistic function in the SAS statistical analysis software (SAS Institute, Cary, NC). Four experiments were

performed: the first used all calculated features, the second omitted color location features, the third omitted pink shade features, and the fourth omitted texture features.

III. RESULTS

Figure 5 shows the results of diagnosing melanoma by applying SAS to a test set distinct from the training set. The pink shade segmentation algorithm was performed on each image in real time, producing lesion segmentations similar to that shown in Figure 3.

Table 1 lists and ranks (by χ^2 Pearson) the most important features in each model. We required $p = 0.18$ for entry (slentry) and retention (slstay) in each of the models. In Figure 5, the four ROC curves from four experiments are shown, along with c , the estimate for the area under the ROC curve. The four different experiments are: 1) utilizing all features, 2) omitting location features, 3) omitting color shade features, and 4) omitting texture features. The area $c = 0.879$, indicates that the best accuracy is obtained using the model that includes all features.

IV. DISCUSSION

This study analyzed the effectiveness of melanoma and benign lesion identification using features extracted from lesion pink areas. After automatic segmentation, features within the areas of three shades of pink were analyzed with respect to pink shade location, color, and texture. Accuracies measured up to 87.9% were obtained when all features were used, using the SAS parameter which estimates the area under the ROC curve. Diagnostic accuracy decreased to values 82.2 – 84.6% using the three other models, obtained by omitting parameters for shades, texture, or shade location within the lesion. To our knowledge, this work is the first to exploit the presence of multiple critical shades of pink to enable automatic detection of early melanoma.

There are clinical correlates for the most important features found by logistic regression. For example, the significance of red color represented in the top three features in the logistic regression model is that red correlates with blood vessel expansion, which in turn corresponds to inflammation within melanomas. When this blood vessel expansion is patchy or irregular, variance (or standard deviation) increases. This may explain why the top two features in this model are statistical measures of variation within two of the pink shades. All of the four features are texture features found within specific shades.

This study extends the observation made by Menzies and colleagues [10] that multiple shades of pink are associated with amelanotic melanoma. Here, we extend that research to the detection of multiple pink shades for *all* melanomas, including early melanomas, adding texture and location analysis to the color characterization. Programming directly in C++ makes the proposed algorithm potentially useful in practice.

V. LIMITATIONS AND FUTURE WORK

The empirical nature of the observed color-shade definitions is a drawback in this study. The study is an ‘anthropomorphic’ modeling of color representation, insofar as the color shades

marked in the training set were visually determined by the dermatologist. This method, although entailing the drawbacks of empirical diagnostic modeling, can help elucidate the diagnostic process. Other limitations in the study include the relatively small set of lesions analyzed, which did not allow an additional test set to further validate the model. Yet, the use of all features converged to a final model yielding a better accuracy than any model omitting any of those features. A good model fit was found using SAS analysis, as the model utilized only ten predictors, resulting in Akaike's information criterion (AIC) = 134.5 [18]. Testing on a larger set with separate training and test sets and automatic lesion borders is planned for future studies. Additional texture features can be included to improve the accuracy, as the texture model in this study included only first-order histogram texture features. *CVIPtools*, an online image processing system [19], includes second-order features derived from the gray-level correlation matrix, including the key features originally described by Haralick [20].

VI. CONCLUSION

In this article, pink areas present in dermoscopic images of skin lesions were used to discriminate melanoma from benign lesions using logistic regression. The method segments three shades of pink in real-time and classifies images based on key color parameters. A logistic regression model provided up to 87.9% accuracy for discriminating melanoma in 132 images. Using this model, lower accuracy was obtained when omitting any of the following features: individual pink shades, texture information, and color location.

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VII. APPENDIX: EQUATIONS FOR CALCULATION OF BLOB, COLOR AND TEXTURE FEATURES

Blob Features

- Eccentricity of the largest blob: (E): $E = \frac{D}{\sqrt{A}}$; D = Euclidean distance between the centroid of the largest blob and the centroid of the lesion; A = lesion area
- Relative size of all blobs (R): $R = \frac{\sum_{i=1}^n B_i}{A}$ sums all blob areas (B_i); n = number of blobs within lesion area A
- Relative size of largest blob (S): $S = \frac{B_{max}}{A}$
- Absolute size of largest blob: $= B_{max}$
- n = Number of blobs in the lesion

Color Features for each pink shade over entire lesion (note: these are different from the features used for color detection)

- Average red, green and blue (RGB) values: $\mu_{\text{red}}, \mu_{\text{green}}, \mu_{\text{blue}}$
- Maximum and Minimum RGB values: Max (Red) $\{all\ pixels \in Image\}$ and Min (Red) $\{all\ pixels\}$, similar for Green and Blue
- Standard Deviation σ for each of RGB values in pink areas
- Average Chromaticity of each pink area: $ChrX = \frac{X}{R+G+B}, X \in R, G, B$

Texture Features Derived from Lesion Histogram

- Mean (μ): $\mu = \sum_{i=0}^{L-1} r_i p(r_i)$ Here, r_i = gray level or intensity of each color plane (R,G,B); $p(r_i)$ is the probability of the occurrence of r_i ; and L is the number of possible gray levels.
- Variance (σ^2): $\sigma^2 = \sum_{i=0}^{L-1} (r_i - \mu)^2 p(r_i)$
- Smoothness (S): $S = 1 - \frac{1}{(1 + \sigma^2)}$
- Skewness (K): $K = \sum_{i=0}^{L-1} (r_i - \mu)^3 p(r_i)$
- Uniformity (U): $U = \sum_{i=0}^{L-1} p^2(r_i)$
- Entropy (e): $e = - \sum_{i=0}^{L-1} p(r_i) \log_2 p(r_i)$

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Figure 1.

Proportion within histopathologic diagnosis of pink color by distribution pattern (n = 1290).

Pink distribution was categorized into three patterns: peripheral-only pink (pink in outer portion of lesion only), central-only pink (pink in center of lesion only), and pink throughout lesion (pink in both outer portion and center of lesion). Note that the majority of lesions have at least some pink color.

Figure 2.
Pink area detection and classification workflow.

Figure 3.

Dermoscopy images of invasive melanomas showing detection of three pink shades.

(Although three sample shade areas were found for each lesion, zoomed images do not show all samples.)

Figure 4. Melanoma having three shades of pink, automatically detected in real time (C++), with quintile Overlays.

Figure 5.

Areas under the Receiver Operating Characteristic Curves resulting from the logistic regression models; c = estimated area under the curve; $c=0.879$, indicates that best accuracy is obtained using model that includes all features.

Table I
Four most significant features

Statistical summary for the four most significant features ($p = 0.05$) in the final model which contained ten features. 150 features were analyzed using logistic regression. The 150 feature values were calculated using all three shades of pink plus all texture and location features.

Feature Description from Section E	Wald Chi-square	p-value
Red Standard Deviation: Light Pink	23.7809	0.0003
Red Variance of Pink: Dark Pink	7.9523	0.0014
Red Smoothness: Light Pink	6.8849	0.0005
Intensity Variance: Orange Pink	2.1921	0.0354