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Fuzzy logic color detection: Blue areas in melanoma dermoscopy images

Mounika Lingala[a,1], R. Joe Stanley[b,2], Ryan K. Rader[c,3], Jason Hagerty[c,3], Harold S. Rabinovitz[d,4], Margaret Oliviero[d,4], Iqra Choudhry[c,3], William V. Stoecker[c,*]

[a] Department of Electrical and Computer Engineering, Missouri University of Science and Technology, G20 Emerson Electric Company Hall, 301 West 16th Street, Rolla, MO 65409-0040, United States
[b] Department of Electrical and Computer Engineering, Missouri University of Science and Technology, 127 Emerson Electric Company Hall, 301 West 16th Street, Rolla, MO 65409-0040, United States
[c] Stoecker & Associates, LLC 10101 Stoltz Drive Rolla, MO 65401-7714, United States
[d] Skin & Cancer Associates, 201 NW 82nd Avenue, Suite 501, Plantation, FL 33324, United States

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ABSTRACT

Fuzzy logic image analysis techniques were used to analyze three shades of blue (lavender blue, light blue, and dark blue) in dermoscopic images for melanoma detection. A logistic regression model provided up to 82.7% accuracy for melanoma discrimination for 866 images. With a support vector machines (SVM) classifier, lower accuracy was obtained for individual shades (79.9–80.1%) compared with up to 81.4% accuracy with multiple shades. All fuzzy blue logic alpha cuts scored higher than the crisp case. Fuzzy logic techniques applied to multiple shades of blue can assist in melanoma detection. These vector-based fuzzy logic techniques can be extended to other image analysis problems involving multiple colors or color shades.

1. Introduction

Of all skin cancers, invasive malignant melanoma exacts the highest total mortality with an estimated incidence of 76,250 and an estimated total of 9180 deaths in the United States in 2012 alone [1]. The incidence rate for melanoma has risen tenfold over the past 60 years [2]. Earlier detection of melanoma is crucial, as diagnosis at the earliest *in situ* stage does not alter life expectancy [3]. Dermoscopy is a non-invasive imaging technique that employs magnification in combination with reduction of skin surface reflections. Dermoscopy improves sensitivity, specificity and accuracy in melanoma detection [4–7], by enhancing visualization of many features, including shades of blue [7–10].

Blue coloration is present within several dermoscopic features: homogeneous blue pigmentation; blue-white veil, and blue-black color. Homogeneous blue pigmentation is a first-step criterion in the 2-step procedure for examining pigmented skin lesions [8]. Blue-white veils are defined as irregular structureless areas of confluent blue pigmentation with an overlying white "ground-glass" appearance [9]. These structures allow semi-automatic discrimination of melanoma from benign lesions with an accuracy of 82.9% on a more advanced lesion set with blue that is easier to detect [10]. In clinical studies, a blue color is one of the positive criteria within the 7-point checklist for suspicious melanocytic skin lesions [8] and a blue-black color rule has been suggested as an indicator of pigmented nodular melanoma [11]. We analyzed 195 melanoma images and noted 22 with prominent blue pigmentation. In contrast to earlier studies [9,10], few lesions within the image set presented in the clinic with fully developed blue veils or blue-black areas. We therefore focused on shades of blue found in melanomas now seen in clinics at an early stage, often at the pre-invasive (*in situ*) stage [12–14].

Three shades of blue were chosen for analysis: light blue, dark blue, and lavender blue (Fig. 1). Melanoma classification has been previously studied using color-derived features [15–18]. We are not aware of any previous analysis of specific color

* Corresponding author. Tel.: +1 573 364 0122; fax: +1 573 364 0129.
E-mail addresses: ml427@mst.edu (M. Lingala), stanleyj@mst.edu (R. Joe Stanley), rkrc5b@health.missouri.edu (R.K. Rader), hagerty.jason@gmail.com (J. Hagerty), harold@admcorp.com (H.S. Rabinovitz), maggie@admcorp.com (M. Oliviero), iqrachowder@live.com (I. Choudhry), wvs@mst.edu (W.V. Stoecker).
[1] Tel.: +1 573 341 4518; fax: +1 573 341 4532.
[2] Tel.: +1 573 341 6896; fax: +1 573 341 4532.
[3] Tel.: +1 573 364 0122; fax: +1 573 364 0129.
[4] Tel.: +1 954 473 6750; fax: +1 954 424 7093.

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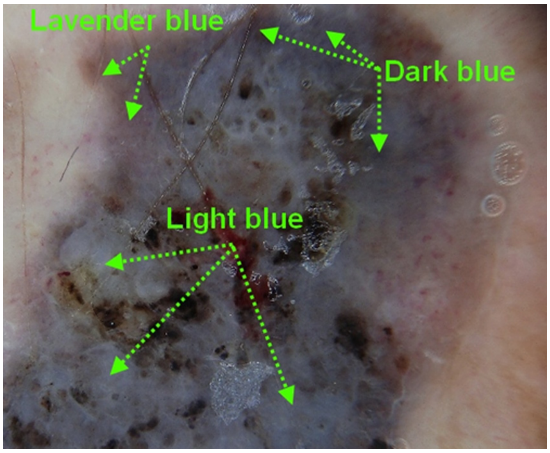

Fig. 1. Dermoscopy image of invasive melanoma illustrating three shades of blue indicative of pigmented nodular melanoma. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

shades in a machine learning approach for melanoma discrimination.

There have been numerous studies exploring fuzzy logic techniques for color analysis and segmentation in medical applications. Some of the fuzzy logic methods investigated in previous research for color and skin analysis include color histogram analysis for color labeling and skin lesion discrimination [19], blotch size estimation for skin lesion discrimination [20], blotch detection in skin lesions using fuzzy clustering and texture segmentation [21], fuzzy clustering for adaptively removing background skin color for skin color region segmentation [22], fuzzy c-means clustering for skin lesion segmentation [23], adaptive fuzzy c-means using local spatial continuity for cluster prototype estimation [24], and skin region segmentation using fuzzy decision tree modeling [25].

In this article, we present a fuzzy set representation to segment blue areas in melanoma images for discrimination from benign lesions using red, green, and blue chromaticity, relative RGB color, value (from the HSV color space) and the blue:green ratio. The order of the remaining sections of the article is as follows: Section 2 describes the image set, absolute thresholding procedure, fuzzy set characterization, blue shade segmentation, feature extraction techniques and classification method; Section 3 provides the results; Section 4 pertains to the discussion; Section 5 elaborates on potential future work in blue area segmentation and Section 6 presents conclusions.

2. Methods

Fig. 2 provides an overview of the experimental workflow including supervised blue shade segmentation and lesion discrimination using a training set to determine the membership function parameters. Detection of blue area was performed in two stages using the training set in the former stage and the test set in the latter: (1) manual blue area marking, determination of absolute threshold parameters, and fuzzy set implementation; and (2) automatic blue area mask generation, feature extraction, and classification.

2.1. Description of experimental data set

A test dataset of 866 contact, non-polarized dermoscopic images (173 melanoma and 693 benign acquired dysplastic and congenital nevi) were acquired in the course of the study NIH CA101639-02A2. All melanomas were verified by histopathological examination by a dermatopathologist. All benign lesions were evaluated with dermoscopy. All lesions with any concern by either patient or physician were either biopsied or were followed in the clinic and found to be reliably benign. For fuzzy set development for the different blue area color shades, a training set of 22 additional melanoma images with blue areas was examined. In total, there were 888 images, with 195 melanomas in the training and test set. Of the melanomas, 110 were at the *in situ* stage and 85 were at the invasive stage, giving a ratio of *in situ* to invasive malignant melanomas = MIS:MM = 1.29. 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 and a dermoscopic adapter. This research was approved by Phelps County Regional Medical Center Institutional Review Board, Rolla, MO, USA, according to the Helsinki Declaration. Informed consent was obtained from all participants.

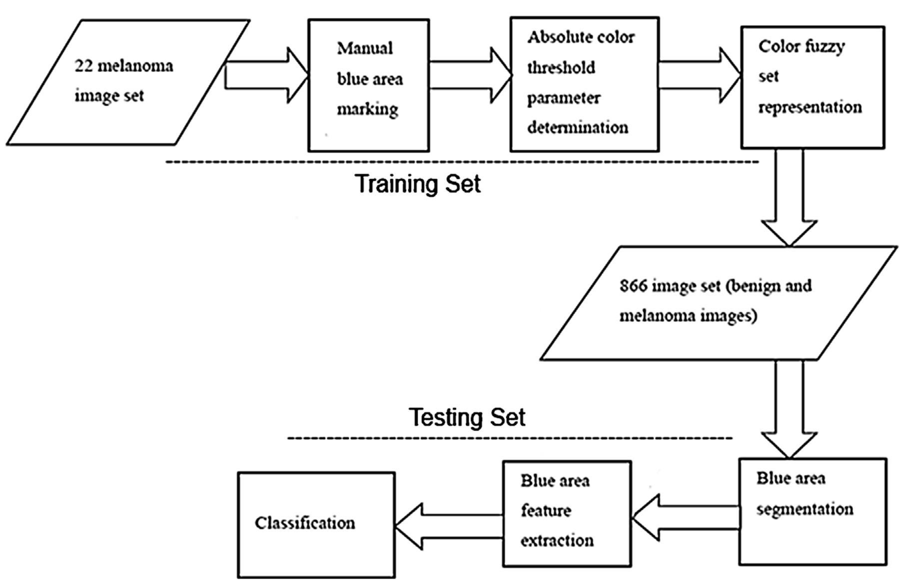

Fig. 2. Blue area workflow overview.