Pigmented Network Structure Detection Using Semi-Smart Adaptive Filters

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Abstract — **This paper demonstrates a method for detecting pigment based dermatoscopic structure called pigment network. This structure is used in dermatoscopy as one of the criteria in clinical evaluation of pigmented skin lesions and can indicate if a lesion is of malignant nature. For detection process we have developed an adaptive filter, inspired by Swarm Intelligence (SI) optimization algorithms. The introduced filtering method is applied in a non-linear manner, to processed dermatoscopic image of a skin lesion. The non-linear approach derives from SI algorithms, and allows selective image filtering. In the beginning of filtration process, the filters (agents) are randomly applied to sections of the image, where each of them adapts its output based on the neighborhood surrounding it. Agents share its information with other agents that are located in immediate vicinity. This is a new approach to the problem of dermatoscopic structure detection, and it is highly flexible, as it can be applied to images without the need of previous pre-processing stage. This feature is highly desirable, mainly due to the fact that in most cases of computer aided diagnostic, input images need to be pre-processed (e.g.: brightness normalization, histogram equation, contrast enhancement, color normalization) and results of this can introduce unwanted artifacts, so this step need to be verified by human. Results of applying the introduced method can be used as one of the differential structures criteria for calculating the Total Dermatoscopy Score (TDS) of the ABCD rule.**

***Keywords*—component; Pigment Network Detection, Pattern Recognition, Swarm Intelligence, Image Processing**

I. INTRODUCTION

Modern society suffers from the fast development of disease that is skin cancer, reaching nearly 20% increase in diagnosed cases each year. The incidence is different for each region of earth. Lowes examined incidence (6-10 per 100,000) is in Southern Europe and the highest incidence is in Australia (50-60 per 100,000). So far the primary and the most commonly used method of non-invasive diagnostics of skin cancer is dermatoscopy, although to make correct diagnosis great deal of experience is required. This means that only experts have 90% sensitivity and 59% specificity in skin lesions diagnosis, as shown in table 1 [1].

TABLE I. SENSITIVITY AND SPECIFICITY OF PHYSICIANS

Physician	Sensitivity	Specificity
Experts	90%	59%
Dermatologists	81%	60%
Trainees	85%	36%
General practitioners	62%	63%

We believe that using computerized image processing, feature extraction and classification methods, it is possible to improve diagnosis process and assist the physician in making the correct decision.

The computer aided diagnostic is possible due to fact that there are several standardized approaches for analysis and diagnosis of cutaneous lesions [2]. One of those methods is ABCD rule and it is using linear equation (1) called TDS (Total Dermoscopy Score) to grade skin lesions depending on the degree of their malignancy [3].

$$TDS = A * 1{,}3 + B * 0{,}1 + C * 0{,}5 + D * 0{,}5 \qquad (1)$$

In the ABCD rule each variable of TDS score correspond to different feature of assessed lesion:

- A – asymmetry,
- B – border,
- C – colors (red, blue-gray, brown, black, white),
- D – dermoscopic structures

So far numerous methods for automatic calculation of variables A, B and C have been developed and successfully applied [4][5]. On the other hand research on automatic recognition of dermoscopic structures is relatively new topic and it is not an easy task.

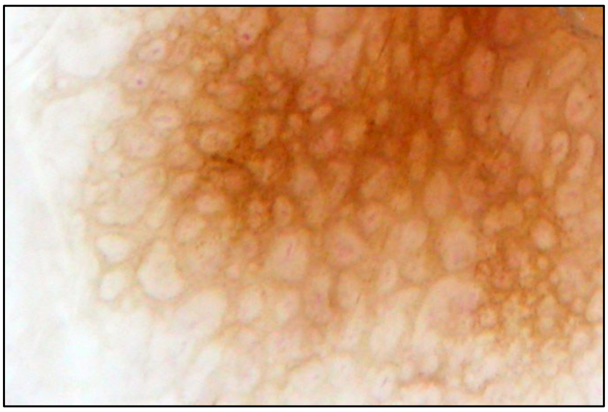

Figure 1.Example image of pigmentation network.

One very distinctive structure present in most pigmented lesions is pigmentation network (Fig.1). Pigmented network has been defined as: “Network of brownish interconnected lines over a background of tan diffuse pigmentation” [6].

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II. PIGMENTED NETWORK AND EXTRACTION PROBLEM

The pigmented network that can be observed in the images of melanocytic skin lesions comes from higher concentration of melanin (brown pigment) in the epidermis (outermost layer of the skin). The pattern is formed when melanocytes produce excessive amounts of melanin.

The brown color of the network makes it easy to distinguish from normal skin as Fig.1 illustrates. Although when the pigment accumulates deeper in the skin the brown color can be obscured by blue-white veil as shown on Fig.2.

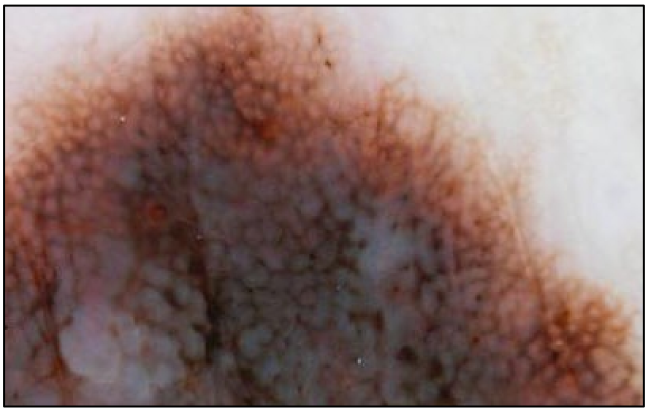

Figure 2.Example image of pigmentation network obscured by blue-white veil.

Our approach on detecting pigmentation network is based on the idea used in Swarm Intelligence (SI) algorithms. The standard application of SI is to solve global optimization problems and in its core, this method does not require any knowledge about the character of the search space. Only the method of calculating local solution is needed. This makes it possible to find the solution to the problem using a swarm of agents that are searching the solution space in a semi-random manner. A number of agents are able to search large solution space and find one or more desired result. In most optimization problems the agents calculate the local solution (fitness) using a simple formula. Every each iteration of the algorithm the fitness value of agents is calculated and the position of agent can change according to a set of rules that are specific to the type of SI algorithm used. The rule set that agents use, define the type of the SI algorithm, and those can be: Particle Swarm Optimization (PSO), Ant Colony, Glow Swarm Optimization (GSO) etc. Nearly all of those algorithms are based on real life swarm behavior [7]. Although SI algorithms have been proven effective while solving large optimization problems, they do not guarantee giving the optimal result. In addition the given results can be different each time if the starting conditions are randomized.

Applying SI algorithm to the problem of pigmented network pattern detection is not as straightforward as it is in case of optimization problem, as we are not looking for one best solution. The goal here is to find a set of mid-way solutions that gathered together will compose desired output, which in this case will be a mask of pigmented network.

In our approach the swarm of agents works as localized filters preforming operations on input image. These agents communicate between themselves and share knowledge about processed image. Each of agents in the swarm takes independent decision as if to apply filter to certain region of the processed image or not. Shared knowledge allows the swarm to adapt to each processed image separately. This makes the method insensitive to varying lesion illumination. Fig.3 represents result of running pigmented network detection algorithm.

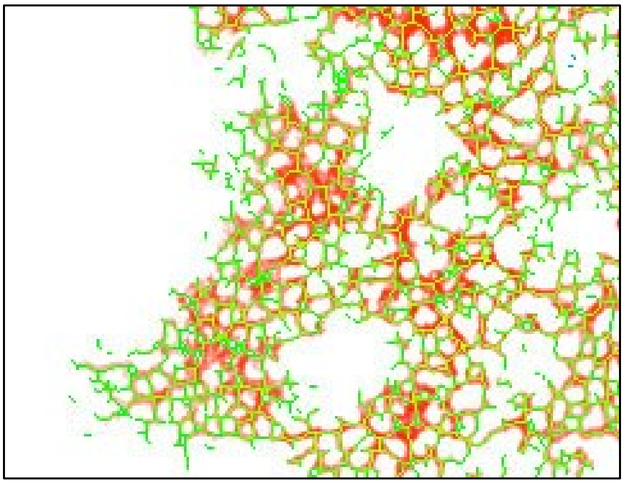

Figure 3. Detected pigment network (in green) on segmented lesion image.

Detecting pigmented network is crucial step in calculating TDS as it is for computer-aided diagnostic of skin lesions.

III. STATE OF THE ART

A. Swarm Intelligence

Several approaches of modeling swarm behavior are available currently. Those can be: Ant Colony Optimization (ACO), Stochastic Diffusion Search (SDS) or Particle Swarm Optimization (PSO). Fig.4 illustrates clusters of particles that are concentrated near the maxima of the two-dimensional search space. This is the result of running the example Partice Swarm algorithm, the objective of which was to find maximal values on the search surface.

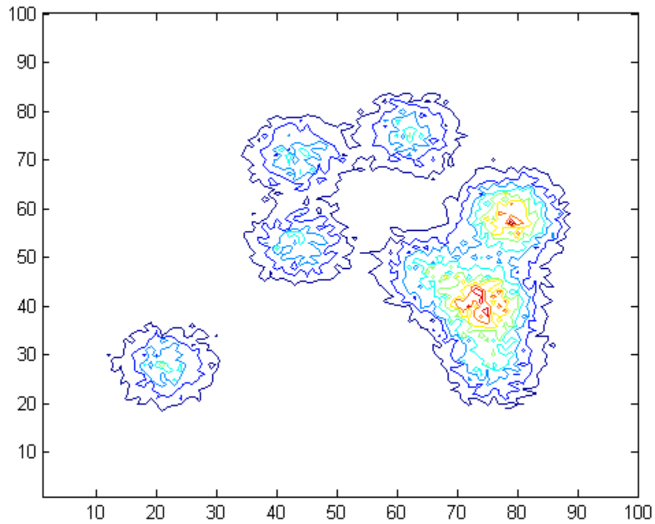

Figure 4. Maxima search results given by Particle Swarm algorithm. Clusters of particles indicate maximal values localized on the two dimensional space.

The Ant Colony Optimization algorithm is inspired by real-life insects; ants that collaborate with each other to find best

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possible route to the food source. Agents used in ACO algorithms use stigmergic communication just like natural ants; they leave trails of “pheromone” which are signals to other agents. Examples applications of this model are in swarm robotics, traffic management and graph coloring. ACO method is also successfully applied in the task of contour matching in 2D [8].

Another example is the Stochastic Diffusion Search algorithm. It uses independent agents that examine certain space searching for the best possible solution according to the previously assigned problem model. Every agent is equipped with methods allowing it to find the solution for the given part of the problem. After obtaining information the agent shares it with other agents that meets neighborhood condition. Example of successful application of this algorithm is text searching and object recognition [9].

Particle Swarm Optimization is a different approach than those presented so far. In PSO agents are setup randomly on search space, from where they start searching for better solution then the one they found so far. Their behavior can be influenced by the information sent by other agents.

B. Pigment Network Detection

Knowing that pigmented networks is strictly connected with melanin (brown color), the calculations using standard image segmentation was done and results of this segmentation can be observed on Fig.5. Each point in the scatter plot illustrates one color specific region of a skin lesion image (Fig.7). The plot was generated using multiple types of skin lesions and it shows how difficult it is to find threshold between network color and other colors present on lesion images. Fig.6 represents the same regions color classification but in different color spaces than RGB. As can be observed on corresponding plots, the HSV color space gives the best options for segmentation and color thresholding.

Detecting pigmented network is relatively new subject and only few attempts to approach it have been made so far. Most recent approach involves using Laplacian of Gaussian (LoG) filter to detect pigmented network edges and later, represent it as graph and submit it to process of classification and differentiation [10].

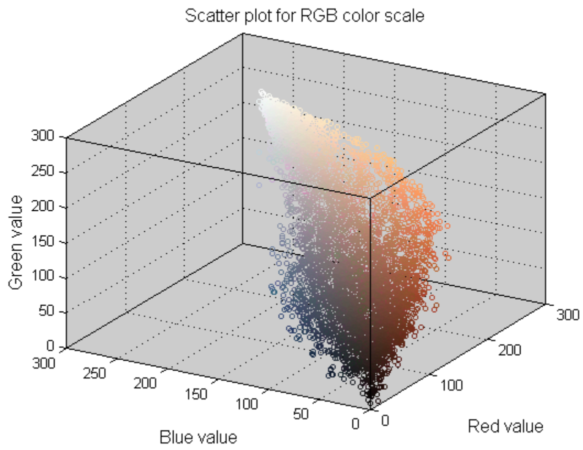

Figure 5. RGB color scatter plot of regions segmented from multiple skin lesion images.

Process proposed in this paper consists of number of steps:

- Pre-processing (manual lesion segmentation, image enhancement).
- Calculating luminance color component of the image
- Edge detection using Laplacian of Gaussian filter.
- Loophole detection and conversion to graph representation.

This method relies strongly on pre-processing, although if the network pattern is correctly filtered the classification process produces excellent results.

One of early methods for detection of pigmented network uses standard image processing tools [11]. This approach is based on combining threshold of difference between skin lesion image and its corresponding median filter output and image processed in the Fourier domain by high-pass filter. This method is reported to have 50% sensitivity.

Another approach is based on methods used in typical texture recognition problem. Using the fact that presence of pigmented network is highly color dependent, methods like: co-occurrence matrices, statistic classification and Markov random fields allowed to determine if pigmented network is present on the skin lesion image [12][13].

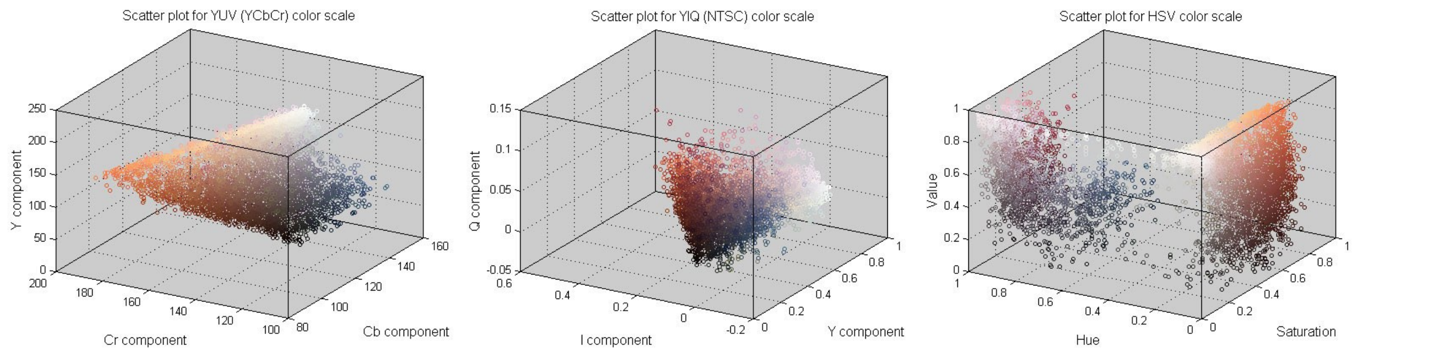

Figure 6. Scatter plots for segmented skin lesions represented in other color spaces (YUV, YIQ and HSV)

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IV. ADAPTIVE FILTERS IN PIGMENT NETWORK DETECTION

The algorithm we used to detect pigmented network pattern is strongly inspired by concept behind particle swarm optimization algorithms. The idea was to use a group of agents equipped with certain knowledge to search solution space. In this case the sear space is two dimensional three color image. The agents operate in similar way as typical image filters (e.g. median filter), each agent analyzes surrounding (neighborhood) and decides to process fragment of the image or not. Additionally agents constantly share statistical image information as: minimal, average, maximal image lamination, median value of each color components, and size of the neighborhood being analyzed. Finally agents can share their local image information with other agents that are in the vicinity.

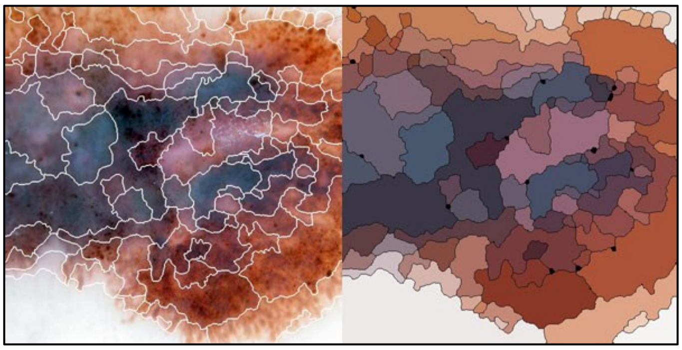

Figure 7. Example segmentation of skin lesion based on dominant color values. Left side illustrate segmented lesion. Right side shows region dominant color.

A. Data Set Used For Testing

To test adaptability of the algorithm, images of various sizes and sources were used. Images varied in resolution, skin lesion magnification and general lightning condition. Smallest image used was 256x256px and the largest was 800x600px. Images larger than 800x600px ware scaled down to decrease image processing time. In general 64 skin lesions images containing pigmented network ware used. Except of scaling down, images were not normalized in any way.

B. Image Processing Stages

Each image was processed according to the following steps:

- Generation of the agents groups is the stage where each agent is placed on random position in the image. The number of agents varies depending on the image size. The number is calculated according to ratio 1 agent per 1000 pixels of the processed image.
- Execution of rules for every agent is done in each iteration of the algorithm. The algorithm requires from 300 to 1000 iterations to produce satisfactory results. Assuming that the agent can change its position by 1 pixel per cycle, the number of iterations defines the longest network fragment a single agent can find.
- Calculation of the image variables available to all agents is done after first iteration of the algorithm. Median and mean values of color components are calculated.
- The final step is to combine results of every agent and produce output image. At this stage it is possible to determine if the output is binary or grayscale.

C. Particle Behavior Rules

The behavior of the agents assumes that the objective of each agent is to move through the search space along route that is a “ridge” according to height map presented on Fig.8. To do this agents moving in selected direction try to follow highest pixel value in the neighborhood. Defined rule-set determines what pixel is chosen as the one with the highest value. If conditions of the rule-set are meet the agent produces its own output image that is a map of his route.

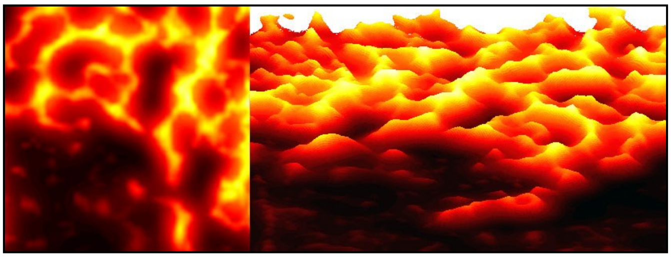

Figure 8. Height map representation of pigmented network. Brighter color represents higher values. On left - 2D image. On right - 3D visualization.

To determine the behavior of agents a data structure describing each of them was used:

- Position of the particle composed of X and Y component.
- Direction of movement. With 8 possible directions South, South-East, East, and so on.
- Median value of the neighborhood color components.

In addition to the data structure, each agent is equipped with a set of decision rules that influenced their behavior. These rules included:

- The agent can change direction of movement by 45 degrees (e.g. moving south, particle can turn to south-east or south-west). This rule prevents early “looping”.
- The agent calculates three possible paths (turn left, go straight, turn right) two steps ahead. Then according to highest luminance value the best path is selected. This
- If all possible paths have the same value, the path remains unchanged.
- The output is generated if path pixel color have values that correspond to color brown (H<90 or H>280 in HSV color space was used to represent brown color). Other condition is that the path pixel must be of higher value than the mean of medians calculated by the nearby (within 50px range) agents. If the considered path pixel value is lower than half of global median luminance, than the agent gives no output.

These rules allow input image to be processed regardless of the lightning conditions and hue of the pigmented network. Fig.9 illustrates example results of detection process.

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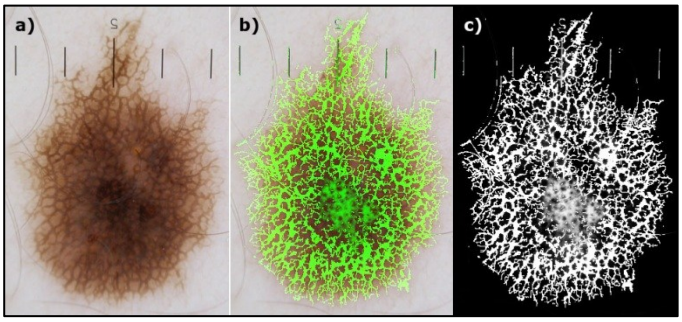

Figure 9. Results of pigmented network detection. a) original image; b) original image with detected network overlaying mask; c) filtered image;

V. DISCUSSION

Presented method proved to be highly adaptive and gave expected results in case of all images containing pigmented network. It works well with skin lesion images containing globules (clusters of melanin), pseudo network and streaks (discontinued network) detecting any melanin clusters. However the method proved to have problems with .jpg images of higher compression value resulting in compression artifact detection.

Unfortunately the method inherited high computation complexity of the optimization problems and this makes it very difficult to develop and fine tune, as processing one image can take up to 5 minutes depending on the agents count, iterations and image size.

VI. CONCLUSION

Proposed approach of semi-smart filtering proved to be complex subject and could be developed further in other image processing aspects. Recognition of textures of more regular character would be possible simply by modifying rules used by agents.

Natural next step for further research in dermoscopic structures detection would be to classify results given by proposed method in regard to other pigment based structures and attempt to differentiate them. For this graph based representation could be used [10].

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