Preliminary Studies for Incoming Web-based Melanoma Diagnostic System

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***Abstract*— In this paper, we report the current status of incoming web-based melanoma diagnostic system and mainly focus on the new tumor area extraction algorithm. Appropriate tumor area extraction from dermoscopy images is sometimes difficult, but the diagnostic accuracy highly depends on the result of this process. The proposed algorithm performs conventional threholding and segmentation process and introduces the region-growing approach that refers to the manually extracted results of dermatologists. 319 dermoscopy images were used and average of manually extracted results of five dermatologists was used as a gold standard. The proposed algorithm showed superior extraction performance (precision=93.2%, recall=95.1%) than conventional algorithms and average of manually extracted results of non-expert people. This efficient algorithm will be mounted on the next diagnostic system soon.**

***Index Terms*— dermoscopy, remote diagnosis, melanoma, region-growing, tumor extraction**

I. Introduction

The incidence of malignant melanoma patients has increased dramatically in most parts of the world over the past few decades. In Australia the incidence is now approaching 50 cases per 100,000 population [1]. Although advanced malignant melanomas are often intractable, early-stage melanomas are curable in many cases if resected and not associated with metastasis. In particular, patients with melanomas equal or less than 0.75 mm thick have good prognosis and the five-year survival rate is reported to be more than 93% [2]-[5]. Therefore, early detection and correct diagnosis of early-stage melanoma is the most important issue in reducing melanoma-related mortality rate.

Discrimination between early-stage melanomas and Clark nevi is often difficult with naked eyes even by expert dermatologists, especially when these lesions are still small. Dermoscopy or epiluminescence light microscopy (ELM) was recently developed to help establish a correct diagnosis of pigmented skin lesions (PSLs) [6]. However, dermoscopy is often subjective and is therefore associated with low reproducibility and potential errors in the diagnosis of PSLs. Computer analyses of PSLs could overcome the subjectivity of dermoscopy. Several groups have already developed automated analysis software in order to solve these problems and reported the high sensitivity and specificity of their algorithms [7]-[11].

Nevertheless, we think that there are still the following problems in software-based analysis reported in the above studies. (1) The results of these studies are not comparable, because different images are used in each study and there is no image standardization. Although the authors sometimes defined their images as equivocal nevi or dysplastic nevi, the meanings of the terms are different among dermatologists. (2) The number of dermoscopic images subjected to digital analyses in the above reports was not sufficient for proper statistical analysis, and the images were usually collected in one or a few institutions. The more number of images is used in a study, the more accurate and the more reliable the study certainly becomes. (3) These systems are personal computer-based analysis programs. Although such applications are useful on a single desktop computer, they are developed without considering to be in public or used by many users. Therefore, installation and upgrade of such programs are often troublesome.

In such backgrounds, we developed a web-based screening system [12]. When the server receives the clinical image, it performs tumor area extraction, characteristic calculation, diagnosis execution and then sends back the results based on linear discriminant analysis. This system achieved sensitivity of 87.0% and specificity of 93.1% on preliminary study of 188 Clark nevi and 59 melanomas.

Since we opened this server in public, we have been investigating to improve system accuracy and generality; more concretely we focused on (1) Develop more accurate tumor area extraction, (2) Use more incidents, find more efficient characteristics and analytical algorithm and (3) Shortening the turn-around time.

In this paper, we report the current status of building the next generation web-based melanoma diagnostic system and mainly focus on the new tumor area extraction algorithm. Tumor area extraction is the first step and one of the most important tasks for diagnosing melanoma. In section II, we will explain the web-based diagnostic system consists of the digital analysis of images. In section III, the current status and foremost tasks are shown. In section IV, the improved tumor area extraction algorithm is mentioned and the results are discussed in section V.

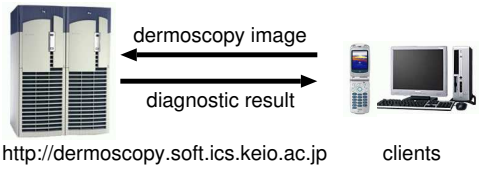


Fig. 1. System overview.

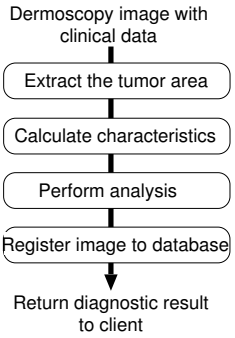


Fig. 2. Transaction of the system.

II. Current web-based melanoma diagnostic system

We developed a web-based melanoma diagnostic system at our university [12]. The complete URL of the site is http://dermoscopy.soft.ics.keio.ac.jp/index_eng.html. Figures 1 and 2 show the overview of the system. The server system consists of apache web server, tomcat application server and mySQL database server. The server is designed so that any visitor can upload the digital dermoscopic images and register the clinical and pathological data. After the server machine accepts the image(s), the program automatically starts to extract the PSL image from the surrounding skin, and calculates several parameters from both the entire lesion and the 10% periphery of the lesion. The lesion is evaluated as a melanoma or Clark nevus using the above parameters and the result are sent back (melanoma or Clark nevus) to the client.

In this research, all cases were biopsied or excised and diagnosed histopathologically. The digital images were selected if they fulfilled the following three conditions. (1) The images contained no hair that interrupts the segmentation of pigmented lesion from the surrounding skin. (2) Acral and mucosal lesions were excluded. (3) The whole image of the pigmented lesion was included inside the frame.

A total of 59 cases of early-stage melanomas, including 23 cases of melanomas in situ and 36 cases of thin invasive melanomas with tumor thickness of 0.75 mm or less, and 188 cases of Clark nevi, fulfilled the above criteria, total 247 tumors, were used in this study.

As evaluation criteria, "sensitivity" and "specificity", the common measure in this field, were used. The sensitivity (SE) indicates the rate that the system discriminates the malignant melanoma for such as. The specificity (SP) denotes the rate that the system discriminates the benign for such as. The SE and the SP are incompatible values. From the view of clinical purpose, it is much important to keep the SE in high level.

Each function is explained briefly in the following sections.

A. Register images to the database

When the server receives the dermoscopy image, it requests the clinical information such as age, sex, tumor location, size, duration and the like. Sent image and clinical information are registered to the database, first and the diagnostic results are also registered to the database at the last. The objective of this database can be summarized in two: (1) To collect tumor clinical data, especially early stage of melanoma. (2) To make standard tumor dataset; every research group uses their own dataset and they aren't comparable. We're planning to disclose those collected data accordingly.

B. Tumor area extraction

In order to calculate characteristics of dermoscopic image, it is required to extract tumor area properly. Current system applied the algorithm based on automatic threshold decision [13] with Gaussian and Laplacian filter. This algorithm can extract tumor area in most cases, however it isn't versatile because the selection of proper tumor area sometimes highly depends on the experience of dermatologists. Appropriate tumor area extraction is one of the important on going research themes and recent improvements are mentioned in section IV.

C. Characteristic calculation

After tumor area is extracted, characteristics of the tumor are calculated. At first we calculated over 300 parameters from tumor, and then we selected 62 from those ones based on the results of principal component analysis (PCA).

The mathematical properties of the PSL were determined with respect to color, texture, asymmetry and circularity. Color descriptors included the minimum values, maximum values and mean values of red, green and blue channels, of both the entire lesion and peripheral lesion.

With regard to the color-related minimum values, three parameters were computed: (1) the intact minimum value, (2) the minimum value relative to the mean value of surrounding skin, and (3) the minimum value of the area that occupied more than 0.05% of the total area. Furthermore, we also estimated the percentages of the areas with color intensity equal to or less than 100 (max: 255), both in the whole lesion and the peripheral lesion. Texture descriptors included standard deviation, skewness, entropy and energy of red, green and blue values for both of the entire lesion and peripheral lesion. The values of the asymmetrical points, including the major and minor axes, were determined from the red, green, blue and binary images. Two orthogonal axes (major and minor axes) were used to evaluate asymmetry. The circularity c was defined as $c = P^2/4\pi A$, where P is the perimeter and A is the area of the lesion. Large c value denoted a more elongated and complex-shaped lesion.

D. Linear discriminant analysis

We applied multivariate stepwise discriminant analysis for analytical algorithm of the web system. This procedure selected 14 parameters from 62 and achieved the sensitivity of

93.1% and the specificity of 87.0% on the dataset by "leave-one-out" cross validation. After the server made diagnostic result, the server registers the result on the database and returns it to the user.

E. Advantages of the web-based screening system

The use of this internet-based program offers certain advantages. (1) Our system could easily create a large library of images. The uploaded images are stored on the server and can be offered for viewing to other dermatologists. The user could use the library images and select the images to use for their analyses. The use of the same images could allow comparison of the analytical power of different digital discrimination analyses. (2) The client may not necessary be a personal computer. A portable digital assistant (PDA) or a mobile phone, with a digital camera and polarized filters, could be used in the future. (3) The web site is available 24 hrs to anyone with access to the Internet. (4) Following the release of the updated version, the latest version of the program is always available all the time for all users. Users do not have to worry about problems related to the operating system, installation or updating.

III. Current status and foremost tasks

The web-based screening system has already started its services. We already noticed that there were some drawbacks in our system. At this point, we do not have a program that could be applied to other PSLs except melanoma and Clark nevus. Our program cannot be applied to mucous or acral lesions. As described earlier, digital extraction of the lesion from the surrounding skin is the most difficult task. Lesion acquisition could fail when the image is not completely within the frame or the lesion contains some hairs. However, we continue to improve our program to overcome these weak points and hope to create an auto-screening system for all types of PSLs in the near future.

We're currently investigating to reduce current limitation and improve system accuracy and generality. More concretely, we are coping with following topics; (1) Develop more accurate tumor area extraction algorithm, (2) Use more incidents, find more efficient characteristics and analytical algorithm and (3) Shorten the turn-around time. In the following section, we will briefly mention in each of these topics.

A. New tumor extraction algorithm

Appropriate tumor area extraction is one of the most important processes to realize automatic diagnostic systems. It can be said that the diagnostic accuracy highly depends on the results of this process. In this paper, we focus on this topic and detailed explanations are mentioned in section IV.

B. Data, characteritics and analytical algorithm

The current web-based diagnostic system is composed of the analytical results from 247 tumor images mentioned before. For improving diagnostic accuracy and generality, we subjoin additional dermoscopy image of 56 Reed nevi and 16 advanced melanomas; total 319 dermoscopy images are currently used. Although we used 62 characteristics and linear discriminant analysis for classification, we have confirmed other textual information such as tumor size and duration are effective parameters in other experiments. Selection of efficient characteristics for the diagnosis is very important and it has a significant impact on the diagnostic accuracy. However it varies depends on the given tumor set and the results of tumor area extraction. We keep searching to find better combination of parameters.

On the other hand, artificial neural networks have superior learning ability and are able to approximate non-linear relationship between input-output data. In dermatological research fields, several researches use artificial neural networks in their analysis [7]-[11]. We also confirmed artificial neural network showed superior classification ability than the current linear discriminant analysis on stand-alone tests. We're now trying to find other efficient input elements and examining the advantages. After this, we will mount those new diagnostic techniques on our web server.

C. Shortening the turn-around time

The proposed web system is composed of server side Java program because it has high degree of compatibility with web-server and database system. However, the calculation cost of tumor area extraction and characteristics calculation is large, so that an each transaction needs long calculation time. In fact, the current system consumes around 15 seconds per transaction. This will become a critical problem when the number of transaction becomes larger. In response to this problem, we introduce Java native interface (JNI) and re-write the time consuming Java program code into faster C program code. This modification has effect so much and reduces wait time to a few seconds even the new server introduces more complicated tumor extraction algorithm and artificial neural networks.

IV. Improved tumor area extraction

As a tumor area extraction algorithm from dermoscopic images, threshold processing algorithms have been often used [14][15]. Because the algorithm [13] can decide statistically ideal threshold very fast, it has been applied for many applications. However, the results of them provide a lot of unexpected noises and missing areas with the results that they require some posterior treatments.

On the other hand, because the region-based object extraction algorithms utilize a segmented each region as a processing unit, they can handle efficient characteristics and their results are easy to modify or maintain [16]-[20].

While the benefits of using these algorithms may seem obvious to some, their results depends on the parameters and initial state. Also they need a lot of calculation cost in many cases. In such backgrounds, the proposed extraction algorithm combines both merits of pixel-based and region-based methods and introduces region adjustment approach that aims for bringing the results closer to those of dermatologists.

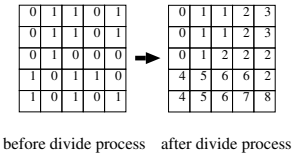


Fig. 3. Relabeling separated regions.

The proposed tumor area extraction algorithm consists of following four phases.

- Initial tumor area decision phase
- Segmentation phase
- Tumor area selection phase
- Region adjustment phase

These concepts enable us to (1) low parameter dependency, (2) fast and (3) easy to adopt the philosophy of dermatologists.

A. Initial tumor area decision phase

In the initial tumor area decision phase, the proposed algorithm decides the tumor area from dermoscopic image tentatively by statistical pixel-based thresholding operation [13]. This method decides threshold very fast in such a way that maximize the inter-group variance of pre-defined property, such as intensity, red, green or blue so as to it separates the given image into two groups. The given dermoscopy image is processed by Gaussian filter to eliminate noises. Then Laplacian filter is applied and the pixels belong to top 20% of the result are only used for calculating threshold. This method has effect to reduce undesired noises at the thresholding operation. Threshold decision is performed by means of blue information and the darker area is regarded as tumor area here.

B. Segmentation phase

In the segmentation phase, two local operations are performed to divide the given image into several regions. First, we give unique region number for each locally separated area. Figure 3 shows the notion of the first operation of this phase. 0 and 1 in the left image indicate the initial region number those are obatained by previous thresholding operation. Next, regions whose size is smaller than $\xi_{small}\%$ of whole image size, are combined with the most adjoining region if the target region is smaller than the neighbor. This process is performed until total number of regions stays constant and it makes possible to handle the image as assembly of regions.

C. Tumor area selection phase

In the tumor area selection phase, tumor areas are decided by selecting proper areas from segmented regions reflects on dermatologists' knowledge. The region fulfills the conditions shown in Figure 4 is regarded as the tumor area and extracted. Note that this algorithm assumes whole tumor area is in the view.

In the figure, "region L" , "region N" and "region V" indicates the largest size region, the most contact region with

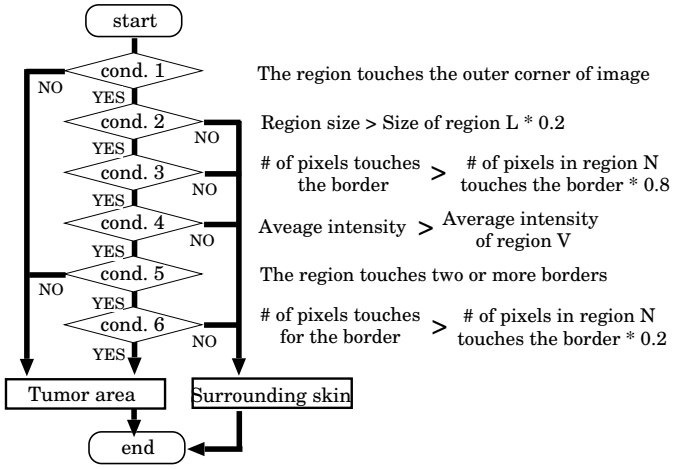


Fig. 4. Selection of tumor regions.

the border of the picture and the highest intensity (V) region, respectively.

At this moment generic area of tumor is extracted. However, blue-white or white areas often seen in malignant lesion in dermoscopy called "whitish-blue veil" or "regression" are difficult to extract by conventional general algorithm because the features of them are not identical. Although the diagnosis of these areas is very difficult and even dermatologists often give results in a different way, it is important feature to diagnose melanoma [21]-[23]. Following the diagnostic theory the tumor that has these features generally has complex shape and peripheral so that it is high possibility that such tumors are divided in several regions in the previous segmentation phase. Note that the shape of benign is generally round shape and the tumor area is represented by one region. Consequently, we assume that when several regions are selected as tumor area, whitish-blue veil or regression areas should be in the lesion. In such a case, hold the current selected tumor area and start the extraction process from the beginning again. In the "second" initial tumor area decision phase, blue information is also used at threshold decision, but this time brighter areas are selected as additional tumor area. Following segmentation phase is as same as the "first" operation and the additional terms of tumor areas are followings: All additional regions except ones which lie next to the outer border of dermoscopy image with more than 1% of sum of outer border size are regarded as tumor.

D. Region adjustment phase

From the results of comparative experiments with several dermatologists, conventional method could not extract a part of tumor area, especially its peripheral. This trend is just as valid for almost all tested images and the extracted area by dermatologists are generally larger than that of computer methods. Hence in this phase, the extracted area is adjusted by region growing approach to bring it closer to dermatologists.

Figure 5 shows the concept of this task. Assume the pixel on the border of tumor area (black dot in the figure) and the $S \times S$ pixel window with the target pixel in its center. For every border pixel, the average intensity of inside and outside tumor

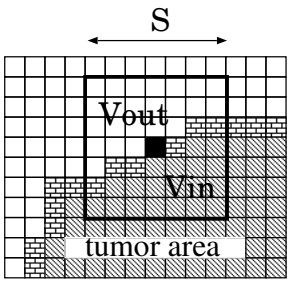


Fig. 5. Region adjustment phase.

area, V_{in} and V_{out} are calculated. If the following equation is true; we regard this $S \times S$ area as also tumor area and continue this process until the tumor area becomes stable.

$$V_{in} \times \xi_{\min} \leq V_{out} < V_{in} \times \xi_{\max}. \quad (1)$$

V. Experiments and Results

We conducted tumor extraction experiment from dermoscopy images under following conditions to validate the efficiency.

A. Experimental Conditions

Dermoscopy images of 188 Clark nevi, 59 Reed nevi and 75 melanomas (including 23 in situ) from Graz, Naples and Florence University were used. A tumor area was extracted manually by five dermatologists (Average years of experience is 11), and we assume average of them as a gold standard. Hand-operated extraction was performed by following the outline of tumor image on the tablet computer. We evaluate the extraction results using following evaluation indexes, $precision$ and $recall$.

$$precision = \frac{correct\ extracted\ area}{extracted\ area}. \quad (2)$$

$$recall = \frac{correct\ extracted\ area}{tumor\ area}. \quad (3)$$

Note that tumor area is defined from the average results of dermatologists. So the average extraction results of dermatologists is set to precision=recall=100%.

Since Joel et al, used 25 tumor images and mentioned in their researches [19][20] that the extraction results by dermatologists are not reproducible and not considered as a gold standard, we prepared a great number of manual extraction results (319 images $\times$ 5 dermatologists) for responding this assignment. Indeed, we have no better index than the results of dermatologists this time. We compare the extraction results with

- Conventional thresholding method
- Region-based thresholding method (threholding+K-mean algorithm)
- 10 non-expert people

Here parameters of the proposed method are followings: S=7, ξ_{small}=1.0, $\xi_{\min}$=1.02, $\xi_{\max}$=1.07.

(a) Dermoscopy image (clark nevus)

(b) Conventional. precision=99.5 recall=81.5

(c) Proposed. precision=94.1 recall=95.0

Fig. 6. Example of tumor area extraction 1

(a) Dermoscopy image (melanoma)

(b) Conventional. precision=96.4 recall=70.8

(c) Proposed. precision=86.4 recall=98.8

Fig. 7. Example of tumor area extraction 2

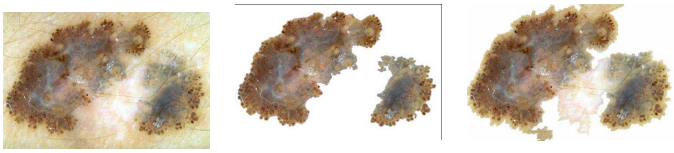
B. Results and Discussion

Figures 6 and 7 show the sample extraction results. Table I shows the summary of the results.

The conventional thresholding method, method A, performs thresholding operation [13] with Gaussian and Laplacian filtering as a pre-processing. The method A is same as the first phase of the proposed method and achieves very high precision (99%). However it can only extract narrow area than necessary and recall remains at low level. The region-based threholding method, method B and C, combines thresholding operation and K-means algorithm, the commonly used clustering technique. K-means or FCM (Fuzzy c-means), also used in tumor extraction method [19][20], algorithm needs to decide appropriate initial cluster condition, such as its number and shape and the final segmentation results are highly depends on them. Besides they require enough number of their initial clusters in order to achieve certain accuracy; however they consume calculation time a lot. From results of preliminary experiments, processing XGA size (800*600) dermoscopy image by K-mean algorithm which utilizes RGB color base and 6*6 rectangle initial cluster requires around 30 sec. (Pentium4 2.4GHz) This time consuming procedure does not acceptable for web-based diagnostic system, in addition these techniques

TABLE I
Comparison of the extraction results

method	precision (%)	recall (%)
A) Thresholding	99.2	82.8
B) Thresholding + K-mean (YCrCb)	98.6	84.6
C) Thresholding + K-mean (HSV)	99.5	78.8
D) Ave. of 10 non-expert people	92.1	90.9
E) Proposed method	93.2	95.1



(a) Dermoscopy image (melanoma)

(b) Conventional. precision=95.9 recall=66.9

(c) Proposed. precision=90.0 recall=88.7

Fig. 8. Example of blue-white areas.

cause another tasks; how to select proper tumor area from many regions. FCM algorithm needs further processing time. With the result that the method B and C use the result of thresholding operation (method A) and set it as the initial cluster of K-mean algorithm. Segmentation is performed by YCrCb color basis (method B) and then tumor area is selected by the same way as the proposed method. Because relatively good initial cluster is given, this process needs to calculate only 2 clusters; this greatly shortens the processing time and can expect good results. However the results of this region-based method showed almost same as method A. That is, these methods also could not extract peripheral part of tumor as well as method A. In addition using another factor such as RGB or HSV and introducing positional factors for calculating distance of each cluster in K-mean algorithm causes deterioration. Although several researches using FCM algorithm for clustering [20], the result of them would show essentially same when they use same characteristics. The proposed algorithm shows superior extraction results and average processing time of tested 319 images is around 3 sec. Figure 8 shows an example result of the extraction which have regression area. We confirmed that the proposed method could extract such areas and improved recall.

VI. Conclusion

Early detection and correct diagnosis of early-stage melanoma is the most important issue in reducing melanoma-related mortality rate. Since we opened automatic melanoma diagnostic system in public, we have been investigating to improve system accuracy and generality.

In this paper, we reported the current status; mainly focused on the new tumor area extraction algorithm. For most tumor images, conventional method could not extract peripheral part of them; the extracted areas by dermatologists were generally larger than that of computer methods. The proposed extraction algorithm combines both merits of pixel-based and region-based methods and introduces region adjustment approach aims for bringing the results closer to those of dermatologists.

The proposed algorithm showed superior extraction performance (precision=93.2%, recall=95.1%) than conventional automatic methods and average of manually extracted results of non-expert people. The proposed extraction extraction algorithm and other improvements will be mounted on the incoming diagnostic system soon.

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