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Automated Skin Lesion Assessment using Mobile Technologies and Cloud Platforms

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Abstract— **This paper presents a smart phone based system for storing digital images of skin areas depicting regions of interest (lesions) and performing self-assessment of these skin lesions within these areas. The system consists of a mobile application that can acquire and identify moles in skin images and classify them according their severity into melanoma, nevus and benign lesions. The proposed system includes also a cloud infrastructure exploiting computational and storage resources. This cloud-based architecture provides interoperability and support of various mobile environments as well as flexibility in enhancing the classification model. Initial evaluation results are quite promising and indicate that the application can be used for the task of skin lesions initial assessment.**

I. Introduction

Skin cancer is among the most frequent types of cancer and one of the most malignant tumors. Its incidence has increased faster than that of almost all other cancers and the annual rates have increased on the order of 3–7% in fair-skinned populations in recent decades [1]. Currently, between 2 and 3 million non-melanoma skin cancers and 132000 melanoma skin cancers occur globally each year. One in every three cancers diagnosed is a skin cancer and, according to Skin Cancer Foundation Statistics, one in every five Americans will develop skin cancer in their lifetime [2]. The cutaneous melanoma, which is the most common type of skin cancer, is still incurable. However when it is diagnosed at early stages it can be treated and cured without complications.

The differentiation of early melanoma from other pigmented skin lesions (e.g., benign neoplasms that simulate melanoma) is not trivial even for experienced dermatologists; in several cases primary care physicians seems to underestimate melanoma in its early stage [3]. The latter has attracted the interest of many researchers, who have developed systems for automated detection of malignancies in skin lesions. Such systems require the acquisition of the skin lesion image using techniques like epiluminence microscopy (ELM or dermoscopy), transmission electron microscopy (TEM) and image acquisition using still or video cameras [4]. The latter systems consist of expensive hardware equipment that is installed in dermatological assessment/treatment centers and require an on-site visit from the patient. Mobile teledermoscopy systems can be utilized as an efficient, low cost and early diagnosis method of skin cancer [11].

This work presents an automated skin lesion assessment system based on mobile technologies that can be used by patients for an early characterization of lesions and estimation for further assessment. The system can be integrated into any mobile environment (Android, iOS, etc.). A Cloud infrastructure provides the essential data processing components for pattern recognition and effective melanoma detection. The rest of the paper is organized as follows: Section II presents important information about skin lesion characterization and discusses related work. Section III presents the materials and methods utilized for developing and deploying the system. Section IV presents results of the initial evaluation and finally, Section V concludes the paper.

II. Related Work & Background Information

Pigmented skin lesions appear as patches of darker color on the skin. In most cases the cause is excessive melanin concentration in the skin. In benign lesions (e.g. common nevi) melanin deposits are normally found in the epidermis. In malignant lesions (i.e. melanoma), the melanocytes reproduce melanin at a high, abnormal rate (see Figure 1). Dysplastic nevi are skin lesions that have high risk of becoming melanomas since the temporal deformation of melanin is a major indication of melanoma [1]. In the conventional procedure, the following diagnosis methods are mainly used [8]: (i) ABCD rule of dermoscopy (ii) Pattern Analysis; (iii) Menzies method; (iv) 7-Point Checklist; and (v) Texture Analysis. An ordinary automated-assessment process involves the segmentation of the skin lesion, the feature extraction based on the aforementioned diagnosis methods and finally the classification phase. The latter is based on the generation of train models based on an initial manually annotated image dataset. In the literature various classifiers have been utilized for the diagnosis of melanoma. In [4] we have presented a detailed comparison between the most common methods and research works.

(a) (b) (c)

Figure 1. Illustration of (a) typical melanoma, (b) dysplastic nevus and (c) non-dysplastic (common) nevus.

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Regarding automated assessment of skin lesions using mobile systems there are only a few works presented in the literature. Authors in [5], [6] present 'SkinScan', a portable library for melanoma detection. Image processing, feature extraction and classification are performed on an iOS device. The system utilizes texture features for classification and accuracy in detecting melanoma versus benign lesions can reach up to 81% according to the authors. Processing time can reaches 5 seconds on an iPhone 4 mobile device. The training model resides within the device. In [7] another mobile implementation is presented. An OpenCV library has been utilized for the essential image processing on the device. Color and shape features have been used for the melanoma characterization among with a kNN classifier. The system runs on an Android mobile device achieving an accuracy of 66.7% in melanoma detection.

Apart from the aforementioned research work there are several commercial (or free) mobile application available for Android and iOS devices. Android applications like 'ABCDEs of Melanoma', 'DoctorMole', 'MelApp' and 'SpotMole' provide features like detection of moles in skin lesion images, segmentation and extraction of border asymmetry features. Some of them also provide referral images of melanoma to users for performing self-assessment or allow users to track temporal progress in mole asymmetry. Similarly, iOS applications like 'Melanoma Visual Risk Calculator', 'Mole Checker' and 'Skin Cancer' check the progress of a mole and can provide options like automatically sending user skin images to dermatologists for manual assessment.

The presented system can perform the feature classification both on the phone and on the Cloud, depending on the network availability. The mobile application can be implemented on both Android and iOS devices. Local classification should be performed when Internet connection is not available. However, the Cloud platform provides better results in terms of assessment speed and allows experts to continuously build a better training model. In addition it offers on-line storage capabilities. The following section presents technical details about the implementation of the system.

III. MATERIALS AND METHODS

Figure 2 presents an overview of the system's architecture. The system is divided into two parts: the mobile part that acquires the skin lesion image from the user and performs the basic image processing steps and the Cloud part that contains the classification model and performs the classification task for a new image.

A. The mobile application

The mobile application provides all the essential functionality for acquiring the image (either from a storage media device like an SD card or through the mobile's camera). It is also responsible for segmenting the pigmented skin lesion and extracting the essential features. It also allows users to add contextual information (like age, inheritance factor in melanoma, exposure to UV radiation) and information about the assessed skin lesion (like multiplicity factor, age estimation of the lesion, etc.).

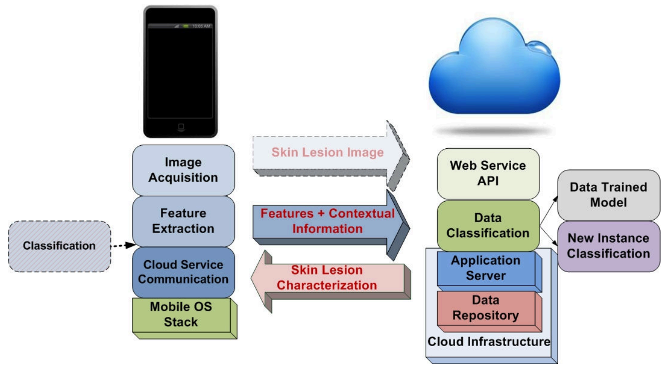

Figure 2. An overview of the system's architecture.

The image segmentation and feature extraction is performed on the mobile device using a method presented in [9]. The method does not require the usage of specific image processing libraries and thus can be implemented on every mobile platform. Initially the skin lesion region is segmented and then texture (like ASM and GMSM), size (like area, perimeter), asymmetry index and color features are generated. More information on the features utilized can also be found in [4]. The features along with the contextual information are then encrypted using AES symmetrical encryption with a 128bit length key stored within the mobile device. Once encrypted the data can be uploaded to the Cloud service for the characterization process. The communication with the service is performed through a HTTP POST request using the REST Web Service API provided by the service. The response of the REST API call is the skin type estimation (melanoma, dysplastic nevus or benign nevus).

For evaluation purposes we have also ported the classification module (based on the WEKA Engine as discussed in the following section) to the mobile application allowing the whole image processing, feature extraction and characterization to be performed on the mobile device.

B. The Cloud Part

The Cloud part consists of a Java EE application that provides both the management graphical interface and the interfaces for the communication with the sensors. As a Cloud infrastructure the Jelastic platform has been selected. The Jelastic [12] is a Platform as a Service (PaaS) type Cloud provider that allows users to deploy Java-based applications providing all the essential components (application server instances, databases, load balancers, etc.) and all the appropriate scalability. Jelastic provides full access to the application server runtime environment, which enables the deployment of additional Java extensions like encryption and authentication libraries.

For the specific application the Tomcat application server among with a MySQL database have been utilized. Data decryption has been achieved using the java cryptographic extension implementing a symmetric (AES) mechanism using the same encryption key with the mobile application. Communication with the mobile application is performed through a REST Web Service API. REST Web Services is a very lightweight communication protocol suitable for Cloud application interacting with mobile devices [13]. Once the data has been received from the mobile device and decrypted, the contextual data is stored into the database for future usage. The features are then processed by the data classification module for characterizing the skin lesion. The module utilizes the WEKA classification engine [14]. The classification engine uses train models that have been previously created using the WEKA tool. Several models can be used to achieve the best accuracy; a train model can be initially validate a new feature set for discriminating the corresponding image between 3 classes: melanoma, dysplastic nevus and benign nevus. In case a melanoma or a benign nevus is estimated, a second model can be utilized that characterizes features to melanoma or nevus providing this way best accuracy to the user. The train models can be updated with more data or advanced classification techniques and parameters at any time without affecting the use of the mobile application and without the need for an update. The Cloud application has been designed to enable also the management and storage of skin lesion images on the Cloud. Users are provided with the option to (anonymously) upload images for further manual assessment by experts and enhancement of the training models or as an image repository for their own usage. Storage resources and data maintenance (e.g., backups, recovery in case of system failure and redundancy, etc.) is provided automatically by the Jelastic Cloud platform.

The next section presents and discusses an initial evaluation of the system based on Android mobile device.

IV. Initial Evaluation

A. Description of the System Implementation

For the initial evaluation of the proposed system's mobile part, an Android application has been developed and deployed on an Android Samsung Galaxy S Plus phone (Android OS v2.3, 1.4GHz CPU, 512MB RAM). User initially enters the contextual information like age, UV exposure, estimated skin lesion age, etc. (see Figure 3). Then the skin lesion image is provided, either through browsing the image file on a local storage media (e.g., an SD memory card) or by capturing it using the mobile's camera. The lesion is segmented, features are extracted and the segmented image presented to the user (see Figure 3). The extracted features are encrypted among with the contextual information and transmitted to the Cloud service. The response contains the lesion estimation that is presented to the user.

On the Cloud part, a Web Service application developed as described in Section III has been deployed on the Jelastic Service.

B. Initial Evaluation Results

For the initial evaluation of the system a dataset consisting of over 3000 skin lesion image sets of manually classified images has been utilized. The dataset contained about 800 images with melanoma, 600 with dysplastic nevus and the rest 1600 images with benign nevi. A subset of them, e.g., 80% of the images is used as learning set and the other 20% of the samples are used for testing using the trained classifier. The images in both learning and test subsets are exchanged for all possible combinations to avoid bias in the solution.

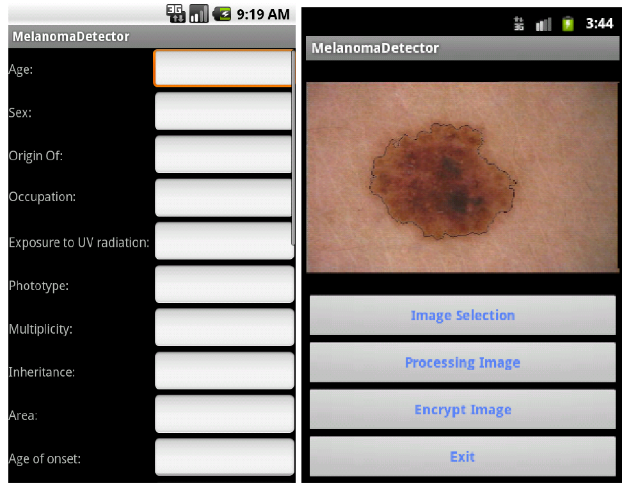

Figure 3. Screenshots of the Android mobile application. On the left: The initial screen for entering contextual data. On the right: A skin lesion image segmented by the mobile application.

We have evaluated a number of different classification algorithms provided by the WEKA tool. Accuracy (%) in correctly classifying instances, Root Mean Square Error (RMS), True Positive Rates (TPR), False Positive Rates (FPR) and Area under ROC Curve (AUC) have been also utilized as evaluation metrics. The first experiment involves the evaluation of the algorithms in characterizing melanoma versus dysplastic and non-dysplastic (i.e. benign) skin lesions. The corresponding results are presented in Table I.

TABLE I. Classification results for the characterization of Melanocytic, Dysplastic and non-Dysplastic skin lesions

	A (%)	RMS	TPR	FPR	AUC
Bayes Networks	68.70	0.4044	0.942	0.011	0.997
NBL	70.58	0.4077	1.0	0.013	0.999
MLR	75.04	0.338	0.986	0.0	1.0
SVM	77.06	0.3911	1.0	0.0	1.0
MultiLayer Perceptron	75.15	0.3536	0.957	0.0	1.0
RBF Network	72.56	0.3561	1.0	0.004	1.0
KStar	67.24	0.4463	0.246	0.0	0.969
LWL	73.20	0.3592	1.0	0.0	1.0
Classification via Regression	74.44	0.3406	0.942	0.0	1.0
NBTree	71.98	0.373	0.681	0.02	0.986
CART	73.50	0.3548	1.0	0.0	1.0

The TPR and FPR refer to the detection of melanocytic class.

As indicated by the conducted experiment SVM performs better in characterizing skin lesions between melanocytic, dysplastic and non-dysplastic with an average accuracy of 77.06%.

The second experiment involves the discrimination between melanoma and benign regions. In this case several classifiers (e.g., SVM, CART, etc.) have managed to identify properly melanocytic skin regions against benign ones with 85-90% accuracy. The results are quite promising and demonstrate the feasibility of utilizing the proposed system as a remote and early diagnosis method for skin cancer.

After having evaluated the aforementioned classifiers and selected the most effective one (e.g., SVM) we have proceeded in evaluating the overall system performance. The training model has been deployed into the Cloud application and various skin lesion images from the untrained dataset have been characterized using the mobile application. The following table presents results regarding the time (in seconds) to perform the analysis using commercial WiFi and 3G networks and the time to perform the image processing and classification on the device. T_R corresponds to the total time it takes to process the image and upload the essential data to the Cloud service and retrieve the classification result. T_{PL} represents the time needed for performing image segmentation and feature extraction on the phone. T_{CL} corresponds to the classification time on the phone and T_L to the processing time on the device ($T_L = T_{CL} + T_{PL}$) when both feature extraction and classification are performed locally.

TABLE II. PERFORMANCE RESULTS (IN SEC) FOR THE MOBILE APPLICATON.

Image Resolution / Network Type	**T_R**	**T_{PL}**	**T_{CL}**	**T_L**
400x300 (WiFi)	3.57	3.1	1.328	4.43
400x300 (3G)	4.08	3.1	1.328	4.43
521x437 (WiFi)	4.13	3.6	1.328	4.93
521x437 (3G)	4.21	3.6	1.328	4.93
640x960 (WiFi)	5.35	4.2	1.328	5.52
640x960 (3G)	5.45	4.2	1.328	5.52

The total response time is not affected considerably by the network type. As expected feature extraction time is affected by the resolution of the image and is slightly slower when performed on the device than when results are retrieved from the Cloud. In general the performance of the system is considered acceptable for a mobile application.

The system has also been evaluated by a small number of users (10) in terms of usability and effectiveness. A Mean Opinion Score (MOS) has been calculated from their responses. The usability of the mobile application (in terms of user interface convenience and application performance) has scored 75% whereas the effectiveness has scored 80%. Users have identified two main issues of the mobile application that need improvement: the contextual data entry and the difficulty in some cases to acquire skin lesion images with proper assessment quality using the mobile camera. Both issues can be resolved by using different mobile equipment (e.g., tablet PC) or better camera device resolution.

V. CONCLUSION

The differentiation of early melanoma from other benign skin lesions is not a trivial task even for experienced dermatologists [3]. On the other hand the early diagnosis of skin cancer is of severe importance for the outcome of the therapeutic procedure and the basis for reducing mortality rates. This paper has presented our work on a mobile system that can be easily used to perform an initial estimation of a skin lesion's severity. The system classifies skin images acquired from a mobile phone into melanoma, dysplastic nevus and common (benign) nevus. The scope is to identify potential early cases of melanoma and urge the users to visit an experienced physician whenever a possible dangerous lesion is detected.

The main advantages of the proposed system are the utilization of a Cloud infrastructure for on-line storage, continuously improving the classification model and providing accurate characterization results in various mobile platforms. In addition it is the first system to collect contextual information from the user that can be later used for a better assessment from an expert and the progress assessment as well.

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