Detection and Classification of Leukocytes from Blood Smear using Mobile Cloud

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***Abstract*—Smart cities are a future reality for municipalities around the world. Healthcare services play a vital role in the transformation of traditional cities into smart cities. In this work, we present a ubiquitous and quality computer aided blood analysis service for the detection and counting of white blood cells in blood samples. WBCs also called leukocytes or leucocytes, are the cells of the immune system that are involved in protecting the body against both infectious disease and foreign invaders. Analysis of leukocytes provides valuable information to medical specialists, helping them in diagnosing different important hematic diseases such as AIDS and blood cancer. However, this task is prone to errors and can be time consuming. A mobile-cloud assisted detection and classification of leukocytes from blood smear images can enhance accuracy and speed up the detection of WBCs. In this research, we propose a smartphone based cloud-assisted resource aware framework for localization of WBCs within microscopic blood smear images using a trained multi-class ensemble classification mechanism in the cloud. In the proposed framework, nucleus is first segmented, followed by extraction of texture, statistical, and wavelet features. Finally, the detected WBCs are categorized into five classes: basophil, eosinophil, neutrophil, lymphocyte, and monocyte. Experimental results on numerous benchmark databases validate the effectiveness and efficiency of the proposed system in comparison to other state-of-the-art schemes.**

I. INTRODUCTION

A smart city transforms traditional health care services into centralized and online services, providing patients ubiquitous access to standard diagnostic services. Moreover, smarter health care management translates health-related data into medical and professional intuitions. Researchers are also working to provide resource-aware e- Health frameworks for data sharing and diagnostically relevant information extraction using mobile-cloud architectures. This empowers the medical specialists to improve the productivity of services provided at the underlying smart environments. In this context, the field of mobile computing has been significantly focused by carrying out extensive research, reducing computational complexity. These mobile-cloud computing frameworks specifically reduce the computation burden in terms of system performance by offloading various tasks to the cloud server from smart phones

[1]. Information and communication technologies, particularly mobile-cloud computing, have experienced rapid development, positively impacting our lives in several ways [3]. Mobile- cloud based health telematics is an emerging research area that brings a major improvement with regard to patient subsists, especially in remote areas for the elderly, disabled, and chronic patients. Therefore, rapid development in mobile technology and smartphone based healthcare systems are increasingly becoming useful to deliver health services easily. In smart cities, mobile-cloud plays an important role to facilitate the doctors/hematologists to monitor patients remotely in a very cost effective manner

[2]. Similarly, mobile-cloud based leukocytes classification systems can provide Health solutions and address hematic diseases including hematic problems such as AIDs and blood cancer (Leukemia) by reducing the existing high costs of national healthcare to cheaper health care solutions. The current demand of this modern technological age is to facilitate the doctors / hematologist in diagnosing hematic related problems remotely and facilitate patients by providing easy access to health facilities in smart cities regardless of time and place. In this context, we present a resource-aware mobile-cloud based framework for leukocytes classification and segmentation in microscopic blood smear images. Leukocytes classification and segmentation provides valuable information to specialists and hematologists in medical diagnostic modalities. Mobile-cloud based medical imaging can allow us to detect and recognize different types of blood cells, soft tissues, and bones from medical images

[3]. It has been observed in the medical field that the majority of diseases in the body can be identified by analyzing blood samples. This is evident from different medical imaging software's, which automatically diagnose various types of diseases by analyzing leukocytes.

[4] The processing of microscopic blood smear images also helps us to detect RBCs/platelets, count the number of cells, calculate their sizes, and normal percentages in human blood. Leukocytes consist of five sub-categories known as monocyte, lymphocytes, basophile, eosinophil, and neutrophil. In order to diagnose and correctly detect leukocyte and its underlying sub-class, a multi-class classification is considered as the best option, which can be used to efficiently classify each category. To accomplish this task, we first need to detect WBCs in microscopic blood smear images. There are two possible methods to detect WBCs in blood smear images: manual segmentation and automatic segmentation. Manual segmentation of nucleus from WBCs and their classification is based on a pre-defined procedure, which is inherently difficult, prone to errors, and time consuming due to the involvement of human labor. Furthermore, the instruments used by experts for manual segmentation and classification of WBCs are not affordable by all hospitals and clinics, especially in remote areas. Image classification is based on different image features like

histogram of gradients (HOG), edges, geometric, texture, and statistical features

[5]. First step in image classification, is pre-processing, which includes image sharpening, contrast adjustment, and noise removal. Different techniques are used for the enhancement of microscopic images. The enhanced image is further processed for segmentation of WBCs using different segmentation techniques such as manual thresholding

[6], OTSU binarization, fuzzy c-means (FCM)

[7], and active contours

[8]. Active contours are well-known segmentation algorithms and are widely used in various applications such as medical image analysis and computer vision. Active contour models segment the objects from an image using curves, which start around the object and move toward its inner normal. When it reaches the boundary of the segmented object, it stops moving. From the stopping point, shape of the object is detected

[9]. FCM is unsupervised clustering technique which is frequently used in image segmentation, allowing a chunk of data belong to two or more clusters

II. LITERATURE REVIEW

This section provides review of related current state-of- the-art schemes for leukocytes segmentation and classification. In recent years, various medical applications such as mobile healthcare, remote patient monitoring, and tele-endoscopy services have been developed in smart cities, utilizing mobile-cloud resource rich framework [11]. The gradual advancements of techniques for leukocytes segmentation and classification have been accessible to explore their role in medical filed, because leukocytes segmentation and classification plays a dynamic role in medical hematology to diagnose different hematic pathologies.

A. Computer-Assisted Leukocytes Segmentation and Classification Applications

Authors in [3] have used thresholding and mathematical morphology for segmentation of cell nucleus. Morphology is a mathematical operation that applies addition/subtraction on blood smear images to separate WBCs, RBCs, and platelets. Threshold segmentation was done to partition the image into background and foreground and the optimal threshold value for the segmentation of WBCs was then selected. Geometrical features were extracted and SVM classifier was used for classification of leukocytes. In another study [16], self- dual multi-scale morphological toggle method was used to segment the nucleus and cytoplasm of WBCs. Watershed transform and level set methods were used to identify the cytoplasm regions. For identification of cytoplasm, there are two different techniques based on granulometric analysis and morphological transformations. This method extracted geometrical features such as area, solidity, eccentricity, perimeter area of convex part of the nucleus, ellipse, and its major axis length. Authors used KNN classifier for the classification of WBCs.

In [17], different segmentation techniques have been used such as global thresholding and FCM, calculating the blue channel of blood smear images for segmenting WBCs. Next, stain colour analysis is performed to get the feature vector of a particular region of interest. Finally, leukocytes are classified as infected or non-infected according to the set threshold value of the dataset. Bikhet et al. [17] enhanced the input image by removing noise and subtracted the foreground. Next, different features such as area of the cell, area of the cytoplasm, area of the nucleus and average colour of the cell were extracted for classification.

B. Mobile-Cloud Computing In Medical Applications

In recent years, mobile-cloud computing has become a valuable area for researchers [2, 20], mainly focusing to minimize the computational burden on smart devices by offloading computational tasks to cloud server, extending lifespan of smart devices. Guet et al. [21] have done extensive trace-driven assessments that presented efficient offloading extrapolation machines that can effectively reduce resource limitations of smartphone devices to minimize computational burden than other common schemes. In [22], authors showed a resource-aware offloading scheme for a resource constrained smartphone devices. They focused the overall resources of the system including computational power, storage, and communication cost. Main purpose of the system was to save valuable resources up to greater extent. Miettinen and Nurminen [23] described energy consumption as a secondary source for smartphones. In [24], authors have given an extensive review of mobile-cloud computing in the field of mobile-cloud based healthcare. They aided various state-of-the-art methods dictating the constraints of the currently developed approaches. Utilization of cloud computing is mandatory, because most of the image processing techniques required high computational power, storage space, and network bandwidth. In [25], authors presented an adaptive resource discovery based energy-efficient technique for mobile cloud computing which works independently with different network environments.

III. METHODOLOGY

Mobile-cloud based leukocytes segmentation and classification is an advanced technology and through this, system specialists and haematologists can easily diagnose different haematic's locally and remotely. Mobile-cloud based leukocytes classification and segmentation can be performed either on local devices or at cloud. The proposed system will help doctors and haematologists to access blood microscopic images from the database for processing, sharing, and analysis. However, the implementation of such type of framework on mobile device is challenging task due to its limited resources in terms of computational power and storage. Therefore, we combine mobile and cloud computing because it provides better computational speed, storage, and communication services in a scalable way at low cost. The proposed framework is the extended version of our previous work overview of the proposed resource-aware framework is shown in Fig 1.

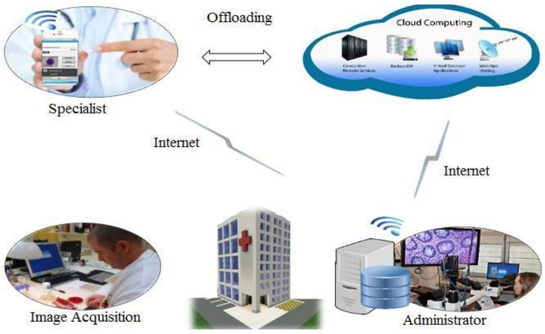


Fig. 1 Proposed mobile-cloud assisted leukocytes segmentation and classification framework

Input blood smear image is first processed to segment nuclei and then different features are extracted from the segmented nuclei for the purpose of training multi-class classifier in the cloud. Trained classifier is used for WBCs classification. This will facilitate the doctors and haematologists to remotely perform haematics related tests anytime without carrying heavy instruments. Features are extracted locally from the microscopic blood smear images, and offloaded to cloud server for further analysis.

A. *Mobile-Cloud Based Leukocytes Classification*

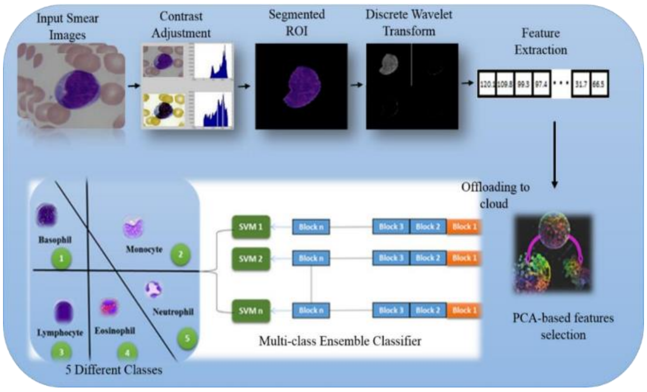
Current mobiles have limited potential and are not applicable to process complex tasks. Thus, the leukocytes classification and segmentation from microscopic blood smear images is a computationally challenging task and such kind of tasks can be transferred to cloud server for processing. For offloading, a virtual machine (VM) based learning technique is used that can ensure the ability by transferring computationally heavy tasks partially or entirely from a mobile to more prevailing servers such as cloud server [27]. For leukocytes classification and segmentation, a multi-class classifier is trained in the cloud.

B. *Offloading-Based Learning Automata*

Learning automata in context of mobile-cloud offloading is an adaptive decision making model, which interacts with surrounding environments in discrete time instants. At each time instant, the proposed automata chooses a suitable threshold value for partitioning data and its processing tasks into local and cloud server. Data collected from environment works as an input for the learning automata and therefore it is known as response from the environment. In the underlying scenario, automata gets responses from surrounding environment, i.e., computational power, storage, bandwidth, and battery strength of a mobile phone, and then it shows special reaction (threshold calculation) in that specific situation. The process of threshold selection based on environment parameters is called reinforcement. The variation in the performance of the mobile-cloud adaptive loading framework is termed as "learning", and, therefore, the learning system enhances the performance with respect to time in the process of achieving ultimate goal i.e., ideal threshold value selection. There are various internal and external environmental conditions that can increase or decrease the performance of the proposed learning technique. The proposed learning automata can be represented as LE = {A, B, C}, where A is input set, B is output set and C represents the environment

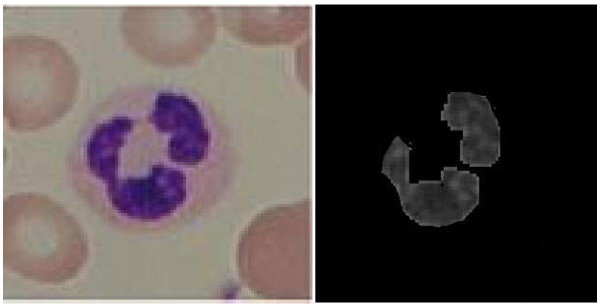
IV. MOBILE-CLOUD ASSISTED LEUKOCYTE ANALYSIS

In this section, the proposed resource aware framework for leukocytes classification and segmentation is explained. The framework consists of three steps: 1) WBC's nuclei

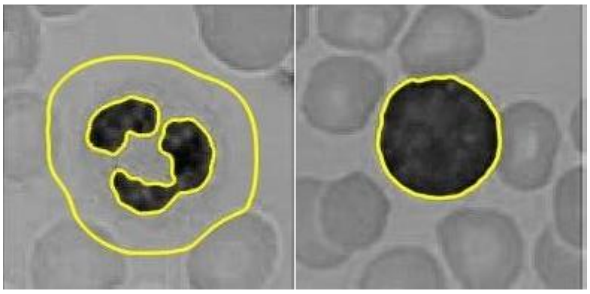


segmentation from microscopic blood smear images, 2) features

extraction from the segmented nuclei, and 3) training of multi-class classifier model on cloud through extracted features for classification of leukocytes into their respective five categories. Segmentation is performed using a colour K-means clustering algorithm. After segmentation, the segmented region is transformed to the frequency domain, where a set of statistical and textural



features are extracted. For effective and resource-class ensemble classification scheme is trained on cloud. The proposed framework has the capability to easily segment and classify WBCs into their corresponding five classes. Fig. 4 describes the schematic representation of the proposed segmentation and cla ssification framework.



Data Acquisition And Pre-Processing

The study consists of 1030 blood smear WBC samples which were collected from Hayatabad Medical Complex (HMC [2]) Peshawar, Pakistan. These blood smears were captured with Head Nikon DS-Fi2 [3]having high-definition color. The digital images were taken with approximately 100× magnification factor. All the images were saved in JPG format of dimension 960 × 1080 pixels.

Each of these energy consumption metrics $\boldsymbol{E}$**no off** and $\boldsymbol{E}$**off**

can be calculated as follows:

$$\text{Eno off} = \left(\frac{Dout}{} * \text{e send}\right) + \left(e_{Mcomp} * I\right)$$

In the latter case, $\boldsymbol{E}$**Total > 0**, shows that energy consumption during program execution on mobile phone is less than executing the same program on cloud. This verifies the feasibility to perform computational tasks locally .

$\boldsymbol{E}$**Total** can have two states: negative or positive. In first case

$\boldsymbol{E}$**Total <0,** means energy consumption during program execution on cloud (training process of our framework) is less than training the same model at local computer. This scenario encourages data offloading processing to cloud.

Herein, $\boldsymbol{E}$**no off** refers to local processing without sending data to cloud. In this scenario, most of the energy is consumed during data processing. On the other hand, $\boldsymbol{E}$**off** refers to mobile-cloud computing framework, in which data is adaptively offloaded to cloud and computationally expensive task are performed at the cloud server.

Performance Analysis Of The Proposed Framework

In this section, several experiments were conducted to evaluate the performance of the proposed classification with other state-of-the-art schemes. The comparison is based on four metrics including accuracy, sensitivity, specificity, and precision as given below:

$$\text{Accuracy} = \frac{(TP+TN)}{TP+TN+FP+FN}$$

$$\text{Sensitivity} = \frac{TP}{TP+FN}$$

$$\text{Specificity} = \frac{TN}{TP+FN}$$

$$\text{Precision} = \frac{TN}{TP+FN}$$

The results based on the given four metrics are shown in during training, 70% of the images from the dataset were used and remaining 30% were incorporated for testing purpose. In testing phase, 98.6% average accuracy is achieved, which is far better than accuracy achieved by Naïve Bayes and linear classifier. The individual sensitivities of each leukocyte subclasses, especially subgroups like basophils, eosinophil's, and monocytes, are found to be far better in the proposed framework than other state-of-the-art methods. Similarly, specificity and precision scores are higher in case of the proposed method, verifying the performance of our work compared to other methods under consideration

IV. CONCLUSION

In this paper, a mobile-cloud assisted framework is presented for segmentation and classification of leukocytes into their corresponding five different classes. Firstly, color k-means algorithm is used to segment WBCs from blood smear images. Next, morphological operations are performed to segment the regions of interests for removing unwanted components. Then, a set of texture, geometrical, and statistical features are extracted from the segmented region. Due to the diverse nature of blood smear images, a single classifier is almost impractical. Therefore, we considered an EMC-SVM for classification of leukocytes. Experimental results confirmed that the proposed method successfully segments WBCs from blood smear images and accurately classifies each of segmented cell into their respective categories which include neutrophil, eosinophil, basophil, lymphocyte, and monocyte. The accuracy of the proposed classifier was found to be higher when compared to linear and naïve Bayes classifiers. The qualitative and quantitative results are encouraging and show that the mobile-cloud assisted framework saves energy consumption and computational time, providing accurate classification and segmentation results.

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