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Original Article

# A mobile-based telepathology system for a low resource setting in Ethiopia

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ABSTRACT

In most developing countries like Ethiopia, blood count of a microscopic image is done manually which is tedious, time consuming and error-prone. Recent advances in technology have introduced the use image processing software especially mobile technology. This research designed a low-cost smart phone microscope adapter, and developed a decision support system for automatic blood cell count and malaria. The image acquisition and processing applying the adapter and the software was tested in two clinics. The result, compared to the manual way of diagnosing microscopic images, is simple for diagnostic process and provides better decision support for malaria and blood cell counting, as well as speed up the diagnosis process. For blood cell counting and malaria detection, it takes about 30 s to 1 min using this system, but using a manual system it takes around 10–20 min. The preliminary result indicates that the developed system is cost-effective for higher and medium clinics in rural and urban clinic setup. This reduces the initial, running and maintenance cost of the laboratory equipment and also improves the quality of services.



## 1. Introduction

Blood cell counting gives important information about the type and number of cells in the blood, especially red blood cells, white blood cells and platelets. The information obtained from the count can be used to identify symptoms such as weakness, fatigue, bruising, anemia, infection, and many other disorders [11]. There are two means of counting blood cells, automatic and manual ([9], January). The automatic means of blood cell counting uses complete blood count machine Hematology analyzer) or flow cytometry. However, in most developing countries like Ethiopia, blood count of a microscopic image is done by manual way, which is tedious, time taking and error-prone ([11,9], January). These errors lead to wrong diagnosis and treatment. The existing automatic blood cell counting devices are expensive and do not show the structure of the blood cells, and are limited in the diagnosis of common blood disease like, malaria, leukemia, sickle cell disease. However, in recent times, blood cell counting is possible from microscopic blood images using image processing software either by computer or mobile phone. This image processing provides both the structural and count information, but the basic challenge is image acquisition step.

One of the major advantages of automated systems is the reduction of time consumed by manual systems and cost effectiveness. These days' computer systems are replacing human being in most area which needs expertise. Since computer systems map the expertise knowledge, the errors due to less experience will be reduced. In this system, the time for image processing is very minimal. For blood cell counting it take about 30 s. to 1 min. but using a manual system it takes around 10–15 min. There are automated machines to count blood cells, hematology analyzer machine, which are expensive for low resource setting areas. Not only the cost of the machine there chemical reagent is also expensive and not available in the market. They provide the count for RBC, WBC, Hemoglobin and platelets, but they didn't provide the structural information for the diagnosis of blood diseases like malaria and leukemia. Malaria is one of the major killer blood diseases in

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most developing countries like Ethiopia, thus providing the structural information and helping the diagnosis of malaria will have great contribution.

Historically, microscopic images can be acquired using a permanently mounted camera unit on a microscope, two main types of camera sensors are attached to the microscope; charge coupled device CCD) and complementary metal oxide semiconductor CMOS) [7]. In the past, CCD cameras were used for highest quality images. However, CMOS cameras have narrowed the difference in quality [7]. Presently, both camera sensors are used to capture more pixels than required for optimal photomicrographs with each generation of smartphones, there has been a significant improvement in their hardware and software specification [8,3,10]. Recent advances in smartphones include integrated camera utilizing CMOS sensors. We capitalize on the availability of smart phone with high quality digital camera to design a low-cost smartphone microscope adapter and develop an application to acquire and process microscopic images to support automatic blood cell count, medical diagnosis and e-consultation.

### 1.1. Review of related works

Hartman et al. [5] developed an iPhone application to facilitate rapid diagnostic pathology teleconsultation utilizing a smartphone. The mobile application developed is only used for sending acquired microscopic image for teleconsultation. The developed mobile application has no image processing steps (for decision support system) to facilitate diagnosis for less experienced personnel. Fontelo et al. [4] in their work, also presented the advancement of mobile networks and smartphones in developing countries. The paper explains 3-D printed mobile adapters for capturing microscopic images. Nine pathologists worldwide evaluated the images for quality, adequacy for telepathology consultation, and confidence rendering a diagnosis based on the images viewed on the web. The system lacked microscopic image processing for decision support. The system only discussed the quality of the image acquired from microscope using smartphone camera.

In Yang & Zhan [13], the integration of a Quantitative Phase Imaging QPI) method onto a smartphone platform and the application of imaging red blood cells was demonstrated. The adopted QPI method solves the Intensity Transport Equation ITE) from two defocused pupil images taken in one shot by the smartphone camera. This system uses smart phone microscope for image capturing, and has no image processing steps for diagnosis and decision support system. The system presented in this paper uses ordinary microscope and smartphone for image capturing and uses image processing for malaria detection and blood cell counting for decision support system. According to Auguste & Palsana [2], The Open Mobile Telepathology System (OMT) is a combination of two components, the Pocket Electronic Health Record (pEHR) and the Mobile Whole Slide Imaging (mWSI) app. This system is more about image acquisition and transportation over the internet using mobile applications. The system has no image processing and decision support system for blood cell counting and malaria diagnosis.

In Reni [6], Malaria, a deadly disease which according to the World Health Organization (WHO) is responsible for the fatal illness in 200 million people around the world in 2010, is diagnosed using peripheral blood examination. This work developed an automated system for malaria detection which is comparable to manual diagnosis of malaria. The work uses Annular Ring Ratio transform for blood component identification. But the system lacks how to acquire microscopic image using smartphone and has no mobile application developed for decision support [14]. This paper demonstrates a compact and cost-effective imaging cytometry platform installed on a cell-phone for the measurement of the density of red and white blood cells as well as hemoglobin concentration in human blood samples. Fluorescent and bright-field images of blood samples are captured using separate optical attachments to the cell-phone and are rapidly processed through a custom-developed smart application running on the phone for counting of blood cells and determining hemoglobin density. This system requires additional optical hardware components for microscopic image acquisition. In a point-of-care POC) setting, it is critically important to reliably count the number of specific cells in a blood sample [1]. Software-based cell counting, which is faster than manual counting, while much cheaper than hardware-based counting, has emerged as an attractive solution potentially applicable to mobile POC testing. This system explains how software-based blood cell counting is faster and cheaper than hardware based systems. However, the system has no microscopic image acquisition and processing steps for blood cell counting and malaria detection. Image processing steps were employed for blood cell counting to identify Leukemia [12]. Leukemia is diagnosed with complete blood counts which is done by calculating all blood cells and compare with the number of white blood cells (White Blood Cells/WBC) and red blood cells (Red Blood Cells/RBC). The system uses image processing algorithms such as thresholding, canny edge detection and color identification filters. This system lacks microscopic image acquisition steps using smartphone camera.

## 2. Design architecture

The system design is a five step process involving image acquisition, image pre-processing, image segmentation, image post-processing, and blood cell classification as shown in Fig. 1. The graphical user interface was developed after the image processing steps.

**Image acquisition** is the first step of the system. Digitized images of the samples on the slides are acquired with a smartphone camera which is mounted upon the microscope. High resolution images will better for detection of blood cell. The minimum image resolution accepted by laboratory professional was acquired by 4mpx mobile camera with the support of developed image processing application; therefore the application could be deployed in the low resource setting environment. The image acquisition is based on the mathematical expression:

$$f(x,y) = i(x,y).r(x,y) \tag{1}$$

Where $f(x,y)$ : Intensity at the point (x, y),
$i(x,y)$: Illumination at the point (x, y),
(The amount of source illumination incident on the scene).
$r(x,y)$: Reflectance/transmissivity at the point (x, y),
(The amount of illumination reflected or transmitted by the object)
$0 < i(x,y) < \infty$ and $0 < r(x,y) < \infty$

However, microscopic image acquisition using smartphone camera needs an interface or adapter to create a stable system between the microscope eyepiece and the mobile phone. One of the challenges encountered while trying to capture microscopic images using a smartphone at the clinics is stability and focusing. This was resolved by designing a smartphone microscope adapter with no optical component using solid work software. The microscope eyepiece length and diameter are measured and used in the adapter to get focus point between the smartphone camera and eyepiece lens. Since the eyepiece is cylindrical, a radius of 1.5 cm and height of 4–5 cm was used. The adapter is flexible to cover all smart phones for microscopic image acquisition. Since the Smartphone camera is not always at the center, thus the adapter should have a movable holder for the phone from each side and