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| **Abstract:** | Malaria is one of the largest endemic diseases in the Sub Saharan Africa. In Low developed countries (LDCs), the scourge is further buttressed by the lack of enough skilled lab technologists in health centers to diagnose the disease using the widely accepted gold standard Microscopy method of diagnosis. Thus the need for reliable diagnosis.  This explains the birth of Automated malaria diagnosis using Artificial Intelligence. The aim is to harness AI through supervised machine learning to automate the detection of malaria parasites/pathogens in a case study dataset. This method provides fast, accurate and reliable diagnosis solutions.  With authorization from the Ministry of Health (MoH), coupled with collaboration of our research Microscopists in Mulago referral Hospital in Uganda, we were able to access datasets of microscopic thick blood smear images with expert labels representing pathogens within an image. |

# Overview

Despite malaria being one of the major diseases causing death in the sub Saharan Africa according to WHO report, the most popular gold standard microscopy method of diagnosis is not a match to the big volume cases of malaria in developing countries.

The challenges associated with the use of this method have many times resulted into poor diagnosis at the laboratory level leading to misdiagnosis of the disease as well as drug resistance. This has immensely contributed to the endemicity of malaria in developing countries. This method is labour intensive and sandwiched with the lack of enough skilled lab technologists in most health facilities has equally hampered efforts to curb malaria. This traditional conventional microscopy method is prone to results that are subjective and often vary significantly by the different Microscopists hence the need for timely and more accurate diagnostic interventions.

In the AI-based detection of Malaria, we focus on use of artificial intelligence techniques to detect plasmodium pathogens in blood smear images in a timely and more accurate manner. Machine learning methodologies learn good representations of data directly from the pixel data providing a more reliable, fast and accuracy levels good enough to provide confidence of a diagnosis to the lab technicians. Currently, labelled datasets are available from which an AI model can infer a diagnosis.

# Relevance

Malaria is one of the top 10 causes of death in the sub Saharan Africa. According to the World Health Organisation report of 2016 of the 438,000 malaria deaths registered, an estimated 92% of all malaria cases resulted in deaths, two thirds of which occurred among children under five years of age. Referring also to earlier records from the WHO report of 2012, an estimated 3.2 billion people in 95 countries are at risk of being infected with malaria and developing disease, and 1.2 billion are at high risk of getting malaria in a year. In 2015 malaria accounted for 480,000 deaths, 90% of which were from Africa, 7% from S.E Asia and 2% from Eastern Mediterranean region. In Uganda, Malaria has been reported as the leading cause of death accounting for over 27% of lives of Ugandans thus of major concern to public health.

Conventional light microscopy remains the standard method of diagnosis of malaria. Microscopy is particularly well adapted to low-resource, high disease burden areas, being both simple and versatile. In contrast to alternatives such as rapid diagnostic tests, however, microscopy-based diagnosis does depend on the availability of skilled technicians, of which there is a critical shortage. As a result, diagnoses are often made on the basis of clinical signs and symptoms alone, which are error-prone and lead to higher mortality, drug resistance, and the economic burden of buying unnecessary drugs causing wastage as many developing countries are seen dumping expired drugs despite disease burdens. There is therefore need for alternatives which help to provide the access to fast and quality diagnosis.

AI-based Detection of malaria comes in timely, through helping laboratory staff to achieve accuracy and consistency in diagnosis, and by focusing concentration on parts of the images likely to contain pathogens. This ideally helps to relieve operator fatigue and improve output rates especially in the developing countries.

# Impact

AI based detection of Malaria aims to reduce the need for many human Microscopists by providing a consistent and accurate diagnosis with minimum human intervention. This is because AI algorithms can accurately learn a good representation of data directly from the annotated datasets. Automation presents a significant advantage over a human Microscopists by potentially increasing the speed and accuracy for blood film analysis, reducing the turnaround time, and significantly improving diagnostic performance.

Currently malaria diagnosis in highly malaria endemic Countries is by use of symptoms and signs, Rapid Diagnostic Tests (RDTs) and conventional microscopy which methods are prone to human error, slow and lack specificity details and thus accuracy is based on human judgment which is usually biased. Therefore, the need to benchmark AI algorithms for malaria diagnosis.

Automated AI based microscopy for malaria diagnosis maintains the benefits of manual microscopy (gold standard) by incorporating them in a machine vision platform which helps to provide the access to fast and quality diagnosis that is currently routinely unavailable. The added advantage is that the solution can be applied to any microscopical assessment.

# Existing work

Our earlier work on mobile microscopy has confronted automated microscopy through exploiting recent technological advances in 3D printing to enable development of a low-cost 3D printed adapter. This has provided attachment to a wide range of Smartphones on a microscope. Further more, we have deployed both traditional machine learning (with hand engineering of features) and deep learning algorithms (do not require feature engineering) for pathogen detection in blood smear samples to produce effective hardware and software respectively. The diagnostic challenge our prototype has focused on is malaria parasites in thick blood smear samples. We have also extended this to other related microscopy diagnosis challenges for example in the detection of tuberculosis and intestinal parasites.

# Feasibility

Basing on the diagnosis challenges in malaria endemic areas where there is lack of enough skilled technicians, the AI based detection of Malaria comes in handy to improve microscopic diagnosis in a fast, timely and accurate manner. This is possible because current state of the art AI methodologies have been significantly advanced to the extent that object recognition tasks can be automated with accuracy of image analysis surpassing human capability. Such methods can learn effective representations of input images automatically

Our use-case has applied the AI methodologies based on supervised learning to detect malaria pathogens in thick blood smear images. With the available dataset used, a confident proof of concept for the AI based diagnosis of Malaria has been realized.

# Data availability

The available data contains 1,182 images of thick blood smear images captured by a smart phone and 2,703 images captured by a Motic camera (with pixel dimensions) all mounted on an eye piece of a microscope and these were collected adhocly from Mulago Referral Hospital with whom we have a working collaboration. The dataset is inclusive of labels indicating malaria pathogens and these are annotations in a PASCAL VOC format and stored in an XML file. However, information about the environment under which the images were captured are not available.

We have already contributed to an open dataset by availing some data through our website. With legal and ethical approval from regulatory authorities, we intend to contribute more.

# Data quality

The source of data is from Mulago referral hospital which registers a variety of Malaria referral cases across the Country.

This data is collected and annotated by skilled Lab technicians who have an ethical mandate and correct judgment of how to capture data under a microscope. The expert lab technicians handle the whole process from when the blood is got from the patients, through the staining process to capturing the images. We have confidence that the data we get from the lab technicians is a true representation of quality data since it is from experts.

# Annotation/label quality

Just like the image dataset, the annotation process is also handled by the trained lab technicians who through use of an annotation tool, draw bounding boxes around the malaria pathogens and these are labelled as “malaria” basing on their judgment as experts to what a malaria pathogen is (color and shape characteristics).

# Data provenance

Through an ethical approval by the Ministry of Health in Uganda, the images are from Mulago referral Hospital, captured and annotated by the skilled lab technicians (Microscopists) who have authority and correct judgment of what the malaria pathogens are. The same data reaches us as pixel data (images) which does not reveal the details of the patients and thus highly anonymized. Pilot tests are also carried out by the same lab technicians.

# Benchmarking

Our use-case solution has utilized traditional machine learning techniques like Random Extra tree approach. We have also used deep learning methods like Convolutional Neural Networks.

The algorithm evaluation mechanism should include metrics like ROC accuracy, precision, recall basing on the algorithm used.

# Organizer

The Artificial Intelligence laboratory (AI lab) in Makerere University has focus on improving microscopy diagnosis through the use of Artificial Intelligence. To this end, a proof of concept has been achieved in which data collection pipeline has been established and an AI based Malaria pathogen detection model that uses the collected data has been developed.

As we seek to improve malaria diagnosis through the use of Artificial intelligence, similar datasets from a variety of sources across highly malaria endemic Countries and tests are needed for a generalized AI based diagnosis solution.

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