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MALARIA DIAGNOSIS IN MICROSCOPIC BLOOD SMEARS IMAGES: A BRIEF SURVEY

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Abstract: Malaria has been responsible for the deaths of millions of people all across the world. As of the year 2021, the World Health Organization (WHO) reported that the disease was responsible for 6,19,000 deaths worldwide. On account of the fact that plasmodia parasites are transmitted to people through the bites of mosquitoes, the high death rate that occurs in cases of malaria is a cause of worry. The sickness is characterized by a high fever that causes shivering, chills, and headaches, all of which demand a significant amount of effort from the human body. The death rate is particularly high among youngsters and the elderly. The presence of parasites in human blood, which can only be discovered seven days after a person has been bitten by a malaria parasite, is one of the contributing factors that contributes to the high fatality rate. The administration of antimalarial treatment is not permitted unless it has been established that parasites are present. This delay in therapy occasionally proves to be fatal for the patient. Historically, the detection was carried out through the use of the blood smear test, which involved the examination of a sample of blood through the lens of my microscope. Computer-aided techniques have been successful in detecting the presence of parasites, which has resulted in a reduction in the number of errors that are caused by human intervention.

Index Terms—Malaria Detection, Computer Aided Detection, Plasmodium parasites, Machine Learning, etc.

1. INTRODUCTION

Malaria continues to be one of the leading causes of death around the world, despite the fact that there have been considerable breakthroughs in the prevention and treatment of the disease. These potentially fatal illnesses are caused by parasites belonging to the genus Plasmodium, which are transmitted to humans by the bites of mosquitoes. Malaria is a serious public health epidemic that has a catastrophic impact on the health and economics of poor countries. It is responsible for the deaths of more than one million people each year, making it a severe public health crisis. Because it is the main cause of death in a number of countries all over the world, malaria has emerged as a serious worry for the health of people all over the world. The protozoan parasite that is responsible for this potentially fatal infection can be treated, despite the fact that it might be fatal. According to the most recent information regarding the global situation of malaria that was provided by the

World Health Organization (WHO), it is anticipated that there will be 247 million cases of malaria and 619000 casualties caused by malaria in the year 2021. In Africa, more than ninety percent of these fatalities occurred, followed by more than six percent in the South East Asia Region, four percent in the Eastern Mediterranean, and four percent in the Western Pacific. It is anticipated that there will be 241 million cases of malaria and 627,000 deaths that are a direct result of malaria in the year 2020. There were 229 million confirmed cases of malaria in 2019, and it is projected that 409 thousand people died from the disease. There were 228 million instances of malaria that were identified in 2018, and the number of casualties reached 411,000 (WHO, 2022). There were around 1.09 million instances of malaria reported in India in 2016, while roughly 0.84 million cases were documented in 2017. The majority of these cases were caused by the species of P. falciparum, according to the Incidence of Malaria in India research report from 2020. Figure 1 illustrates the number of deaths and cases of malaria that occurred over the world from 2015 to 2021.

In the year 1897, Dr. Ronald Ross made the initial discovery that mosquitoes were responsible for transmitting malaria from body to body (Cox, 2010) [1]. An organism that is a protozoan parasite is the primary cause of malaria. It is the plasmodium genus that is responsible for the infection of the human body's red blood cells (RBC), which is the cause of malaria (May et al., 2013) [2]. Humans and female Anopheles mosquitoes are the two primary hosts that are infected by the parasite. In general, the parasite is transmitted to humans. When female Anopheles mosquitoes seek to foster their eggs, they bite and draw blood from the human body. If that person is infected with a parasite, then the same parasite that is infected with that person's blood will be found in the mosquito, and the parasite will reproduce and develop inside the body of the mosquito.

Figure 1: Worldwide malaria cases and deaths

The salivary gland-containing parasites enter the targeted person's circulation when an infected mosquito bites them (World Health Organization, 2020). The parasites that cause malaria multiply incredibly quickly in the liver and red blood cells of the afflicted individual after being carried into the human body by the mosquito. Malaria symptoms will show up after a week or two. The main symptoms that appear are headaches, nausea, vomiting, fever, and chills. Malaria can seriously

harm a person's body if it is not treated quickly and effectively [3]. Gilles (1991) Kidney failure, low blood sugar, respiratory discomfort, spleen enlargement, and other illnesses of a similar nature may be caused by it. Malaria can kill a person by destroying their red blood cells. Malaria during pregnancy is a very dangerous illness and one of the reasons why women decide to have abortions, according to Murphy and Breman (2001) [4].

TABLE I: LIST OF ABBREVIATIONS

Abbreviation	Description	Abbreviation	Description
WHO	World Health Organization	PCR	Polymerase Chain Reaction
SVM	Support Vector Machine	UWB	Ultra-wideband
GLCM	Gray Level Co-Occurrence Matrix	DNA	Deoxy-Ribo-Nucleic Acid
OFS-Z	Optimal Feature Selection by Z-Score	RNA	Ribonucleic Acid
DTBC	Decision Tree-based Binary Classifier	RSD	Relative Standard Deviation
PPV	Positive-Predictive-Value	RT	Room Temperature
TNR	True Negative Rate	RT-PCR	Real Time Polymerase Chain Reaction
RBC	Red Blood Cells	SAM	Self-Assembled Monolayer
NPV	Negative-Predictive-Value	IFA	ImmunoFluorescent Antibody
RDT	Rapid Diagnostic Test	OFS-Z	Optimal Selection of Feature through ZScore

Global knowledge and the availability of efficient interventions, such gene drives and pharmaceutical treatments, are necessary for the control and eradication of malaria. Building a malaria-free world involves a number of challenges for effective and timely malaria extinction, and the potential oversight of the WHO 3 T (Test, Treat, and Track) strategy may be a rollercoaster ride (WHO, 2020). To encourage successful implementation, antimalarial drugs, cutting-edge insecticides, powerful vaccines, long-term domestic and international funding, and global awareness campaigns were developed. Although these efforts were initially successful, there was a growing obstacle to the eradication of malaria due to the slow changes in the unusual climate patterns, the emergence of vaccine resistance, and the delayed delivery of massive amounts of medications and medical personnel (Sachs & Malaney, 2002). [5]. Surveys show that in 41 high-burden countries, funding per person at risk for malaria is less than $2 (WHO, 2022). Malaria is a chronic illness that mainly strikes the impoverished. It is closely linked to poverty and has a substantial negative impact on the economy, society, and people's health. This made it more difficult to diagnose malaria early and treat it quickly, which was essential to preventing patients from acting as global parasite reservoirs.

2. A BRIEF HISTORY OF MALARIA

For thousands of years, people have been afflicted with the parasite disease malaria. The term "malaria" comes from the Italian word "mal'aria," which means "bad air," and it was formerly believed that the illness was caused by breathing in foul air. The English word "malaria" originates from this. In China, a malaria outbreak was first documented in 2700 BC [1]. Hippocrates, a Greek physician, wrote about the illness's symptoms in the fifth century BC. Celsus, a Roman writer, also made reference to it in the first century AD. The illness was a leading cause of death throughout history and was common in Asia, Europe, and Africa. British physician Ronald Ross was the first

to identify the link between mosquitoes and malaria transmission in the 19th century. He found the parasite that causes malaria in a mosquito's stomach and demonstrated how an infected mosquito's bite may spread the infection to humans and other birds and mammals. A Russian researcher named Romanowsky developed a technique in 1891 for detecting malarial parasites in blood films. Between 1886 and 1890, three distinct types of malaria parasites were known to infect humans: P. malaria, P. falciparum, and P. vivax. The four distinct species of P. ovale were identified in 1922. Ronald Ross identified the stages of parasite growth in mosquito bites in the Indian city of Secunderabad in 1897. He found that mosquitoes may transmit malaria to humans [1]. A protozoan parasite is the primary cause of malaria. Malaria is caused by the plasmodium genus, which infects the human body's red blood cells (RBC) [2]. The pathway of disease transmission was described as a result of this research. Laveran and Ross both received Nobel Prizes for their contributions to the study of malaria. Insecticide sprays and mosquito nets were developed as a result of this discovery, which helped lower the prevalence of malaria. The development of antimalarial medications like quinine and chloroquine in the 20th century considerably lessened the disease's effects. The World Health Organization launched a global campaign to eradicate malaria in the 1950s. The United States was one of the nations that succeeded in doing so. (WHO, 2022). Despite this, the disease still poses a serious threat to public health in many parts of the world, especially in sub-Saharan Africa, where the great majority of malaria infections and deaths occur. Resistance to insecticides and antimalarial medications has grown significantly in recent years, prompting the creation of new medications and disease-control measures. There are also ongoing efforts to create a malaria vaccine, and a number of intriguing candidates are presently undergoing clinical testing.

Species of Malaria Parasites

The illness known as malaria is brought on by parasites that are members of the species Plasmodium. Many different types of malaria parasites can affect people, and each type of malaria parasite has a unique effect on human health. There are five different protozoan parasite species, which are the main cause of malaria in the human body. These are *Plasmodium falciparum* (*P. falciparum*), *Plasmodium vivax* (*P. vivax*), *Plasmodium ovale* (*P. ovale*), *Plasmodium malaria* (*P. malaria*) and *Plasmodium knowlesi* (*P. knowlesi*). Among all five species, the first four are the most common species, which occur in the human body. The fifth species is *P. knowlesi* mostly occurs in monkeys that live in South - East Asia forests. But, in past years, some cases of *P. knowlesi* malaria occurred in the human body. The most common species found in the human body is *P. vivax* but the most dangerous species is *P. falciparum* [6]. Figure 2 shows the images of the different types of malaria found in human peripheral blood smears.

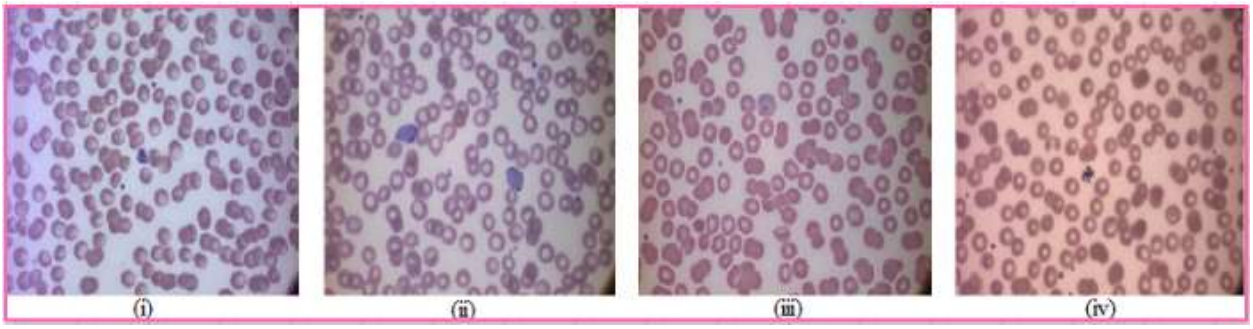

Figure 2: Different types of malaria peripheral blood smear images (i) P. falciparum (ii) P. vivax (iii) P. ovale (iv) P. malaria

A. Plasmodium falciparum

The majority of malaria-related deaths worldwide are caused by this most dangerous strain of the parasite. It is common throughout sub-Saharan Africa and is recognized as the cause of severe forms of malaria, including cerebral malaria and severe anemia. P. falciparum, the malaria bug, is one of numerous species that can infect humans. The female Anopheles mosquito spreads the parasite from person to person. Once inside the human body, it multiplies and invades red blood cells, resulting in malaria symptoms as fever, headache, lethargy, and muscle soreness. P. falciparum can quickly develop into severe forms of the illness and cause potentially fatal side effects such organ failure and brain damage if treatment is not received. Given the seriousness of the P. falciparum-caused illness, anyone who feels they may have contracted it should get medical help right away.

B. Plasmodium vivax

Plasmodium vivax is a species of malaria parasite that can cause the disease in humans. One of the five different varieties of Plasmodium that are capable of infecting people is this one and is less severe than P. falciparum, the most dangerous species of the malaria parasite. P. vivax is found in most countries with tropical or subtropical climates, including Latin America, Asia, and the Middle East. P. vivax is transmitted from person to person by the female Anopheles mosquito. Once inside the human body, the parasite infects red blood cells and multiplies, causing symptoms of malaria, such as fever, headache, muscle pain, and fatigue. In some cases, P. vivax can also cause severe complications, including anemia and low blood sugar levels. One of the unique features of P. vivax is its ability to form hypnozoites, which are inactive phases of the parasite that can survive in the liver for extended amounts of time even though they are not actively reproducing there. This means that P. vivax infections can recur months or even years after the initial infection, even if the person has been treated with antimalarial drugs. Diagnosis and treatment of P. vivax infections are important to prevent complications and reduce the risk of transmission to others.

C. Plasmodium ovale

The parasite that causes malaria in humans belongs to this species. It is one of the five species of Plasmodium that may infect people and is comparable to P. vivax in its influence on human health, but less prevalent. The female Anopheles mosquito, which is primarily found in West Africa, is

the carrier of P. ovale and spreads it from person to person. Once inside the body, P. ovale multiplies and infects red blood cells, resulting in malaria symptoms like fever, headache, muscle pain, and fatigue. In some cases, P. ovale can also cause severe complications, including anaemia and low blood sugar levels. P. ovale, like P. vivax, can produce hypnozoites, which are the parasite's dormant stages that can live for a very long time in the liver. This means that even if a person has received antimalarial medication, P. ovale infections might return months or even years after the first illness. It's critical to identify and treat P. ovale infections early to avoid complications and lower the risk of spreading the infection to others.

D. Plasmodium malariae

This specific species of the malaria parasite, which accounts for a small portion of all cases of the disease, is believed to be the source of the persistent form of malaria. This particular species of malaria parasite is capable of infecting people. It is less severe than P. falciparum, the most serious form of the malaria parasite, but it is nonetheless one of the five types of Plasmodium that can infect humans. P. malaria is primarily found in South Asia and sub-Saharan Africa, and it is spread by female Anopheles mosquitoes. Once within the human body, P. malariae grows and infects red blood cells, resulting in symptoms like fever, headache, lethargy, and muscle soreness. Anemia and low blood sugar are two serious consequences that P. malariae can occasionally induce. The lengthy incubation period of P. malariae, which can last anywhere from 10 to 60 days, is one of its distinctive characteristics. This makes it challenging to diagnose the illness because symptoms could not show up for weeks after the initial infection. To avoid problems and lower the potential of transmission to others, P. malariae infections must be diagnosed and treated.

E. Plasmodium knowlesi

It is a malaria parasite that can cause the disease in humans and non-human primates, such as monkeys and apes. It is mainly found in Southeast Asia and is transmitted from person to person by the female Anopheles mosquito. P. knowlesi is one of the five species of Plasmodium that can infect humans and is a growing public health concern in Southeast Asia. Unlike other species of malaria, P. knowlesi has a rapid replication cycle in the human body, which can result in rapid progression of the disease and severe symptoms. Symptoms of P. knowlesi infection are similar to other types of malaria and can include fever, headache, muscle pain, and fatigue. In some cases, P. knowlesi can also cause severe complications, such as anemia, low blood sugar levels, and organ failure. Diagnosis of P. knowlesi infection can be challenging because the symptoms are similar to other types of malaria. Laboratory tests, such as microscopic examination of blood samples, are needed to confirm the diagnosis.

3. LITERATURE REVIEW

To apply computer vision image processing and machine learning for malaria detection, digital photographs of blood smear samples—both thick and thin—from each individual are needed. Although research on thick digital blood smear images has been conducted, most computer-assisted detection investigations concentrate on thin digital blood smear images [7]. A substantial collection of high-quality photos is necessary to develop an accurate and dependable computer-aided diagnostic (CAD) system for malaria identification. Malaria is a severe disease that affects

millions of people worldwide. An efficient CAD system could significantly increase the speed and accuracy of malaria detection, leading to more efficient and timely patient treatment. Ultimately, this would help reduce the mortality rate from malaria. Therefore, it is essential to continue developing and improving CAD systems for malaria identification while utilizing the latest developments in machine learning and computer vision.

Deep learning techniques are also beneficial in image segmentation. Researchers for image segmentation have proposed many deep-learning techniques. For image segmentation, a fully convolutional neural network-based deep learning technique has been proposed by Long and Wang [8, 9]. A completely CNN encoder and decoder deep learning segmentation technique (SegNet) has been used by Badrinarayanan [10]. The U-Net was proposed by Ronneberger et al. to segment biomedical microscopic images [11]. Dai et al. created a multifunction network, for instance, segmentation that includes three networks for separating instances, computing masks, and labeling objects. These networks must share their convolutional characteristics and form a cascaded structure [12]. Visin et al. has used ReSeg, an RNN-based deep learning approach for semantic segmentation of the images. This approach is primarily based on the image classification model ResNet [13].

To extract the features of haralick textures mean, entropy, roughness, homogeneity, and standard deviation Das et al. suggested a grey-level co-occurrence matrix [14]. To extract the intensity-based features Chayadevi et al. used a color channel intensity algorithm [15]. Rajaraman et al. has given a pre-trained model for feature extraction and detection of malaria parasites [16]. In this, a pre-trained convolutional neural network including AlexNet, VGG-16, Xception, ResNet-50, and Densenet-121 are used for extracting features from infected and uninfected 27558 cell images. The developed model for feature extraction and malaria parasite detection took more than 24 hours for training and produced 95.9% accuracy for malaria parasite detection in thin blood smear images. To identify the texture features from a blood smear image to detect malaria parasites, Chavan et al. used a histogram-based feature extraction method [17]. The color histogram features extraction technique is used by Malihi [18] for identifying infected erythrocytes from blood smear images. Seman extracted features of RBC size and shape, RBC texture, and parasite shape from the thin blood smear images and used these features to classify malaria parasite species [19]. For extracting the features from digital microscopic images based on morphology, Malihi used a granulometry algorithm.

Anggraini et al. has classified the different stages of malaria parasites using a Bayesian classifier on 110 thin blood smear images and obtained 93.3% accuracy [23]. A minimum distance classifier technique has been given by Ghate et al. for detecting the presence of malaria parasites using 80 blood smear images and got 83.75% accuracy [24]. Savkare et al. presented Otsu thresholding, watershed transform, and SVM binary classifier to classify normal and parasite-infected cells. Das et al. has presented the bayesian approach for the automated screening of malaria parasite from microscopic images [14].

4. TECHNIQUES FOR MALARIA DIAGNOSIS

Malaria is a disease in which symptoms appear after 7 to 15 days. Primary symptoms are headache, vomiting, fever, pain, chills, etc. These symptoms could be an indication of malaria. Although, many diseases have the same symptoms. Hence, some techniques are needed that can diagnose malaria correctly. For malaria diagnosis, different techniques have been developed such as microscopy blood smear examination, cytometry, rapid diagnostic test (RDT), polymerase chain reaction, fluorescent microscopy, etc. Still, for diagnosing malaria, the primarily used techniques are:

- Microscopic thick and thin blood smears examination
- Rapid Diagnosis Test in medical science (NCBI, 2020).
- Rapid Diagnosis Test (RDT)
- Quantitative Buffy Coat Method (QBC)
- Serological Tests

4. COMPUTER ASSISTED DIAGNOSIS (CAD) TECHNIQUE FOR MALARIA DETECTION

The field of medical science has undergone a revolution thanks to computers, especially in the area of disease automation diagnosis. Ultrasound, magnetic resonance, X-ray, and computed tomography images are just a few examples of computerized imaging techniques that have been successful in identifying different human anatomy disorders. Computer-assisted detection of malaria is based on microscopic examination using computer vision and machine learning methods. This method uses digital pictures of thin and thick blood smears to automatically identify malaria parasites. This method highlights the potential advantages of computer-assisted diagnosis in the area of medical science by enabling a more precise and effective diagnosis of malaria. This technology helps doctors diagnose malaria accurately through the study of medical images, cutting down on costs and the chance of misdiagnosis while speeding up and improving diagnosis [25].

CAD for malaria detection works by using digital images of blood samples to identify the presence of the malaria parasite. The system starts by capturing high resolution images of blood samples using a microscope or other imaging device. These images are then analyzed using computer algorithms that are designed to detect the distinctive features of the malaria parasite [26]. One of the key advantages of CAD for malaria detection is that it can provide a more accurate diagnosis than traditional diagnostic methods, such as manual blood smears. The system can detect even small amounts of the parasite in the blood, which can be missed by manual methods. This can lead to a more accurate diagnosis and a faster treatment for the patient.

5. CONCLUSION

The sickness that is currently diagnosed in the largest number of patients is malaria. Even so, the illness is treatable if detected early. Using 27558 blood smear microscopy images of the malaria parasite that were downloaded from the National Institutes of Health (NIH) website, a strategy utilizing three distinct computer-assisted methodologies is proposed in this paper.

In tropical areas with little resources in Sub-Saharan Africa, epidemic malaria is extremely common. It remains a worldwide health concern that requires effective mosquito control measures, prompt and precise diagnosis, and appropriate treatment. Therefore, in order to eradicate the

disease and lower mortality in areas where it is endemic, diagnosis is essential. However, the ongoing issues with traditional microscopic examination in these settings due to a lack of resources and skilled microscopists, as well as the growing failure of RDTs primarily because of gene mutations, highlight the need to create new, accessible, and reasonably priced diagnostic techniques for Plasmodium infection.

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