Invasive and Non-Invasive Rapid Detection of Malaria Using Magneto-Optical Technique

Ibraheem Al-Ghoidi (1,*)
Ahmed Al-Kumaim 1
Hamdi Ghazi 1

1 Department of Biomedical Engineering, Faculty of Engineering, University of Science and Technology, Sana'a, Yemen

* Corresponding author: ibraheem5ali7@gmail.com

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Abstract:

Due to the widespread presence of malaria in our country and the increasing number of deaths caused by it, especially in remote areas, along with the challenges of laboratory tests that require time and incur high costs, we have developed a device for detecting malaria in the body. This device relies on the detection of hemozoin particles through a strong magnetic field, taking advantage of the nature of hemozoin particles formed in the blood. The magnetic field is applied in two scenarios: the first case involves directing infrared rays at the sample or finger in the absence of a magnetic field, and the second case involves the presence of a magnetic field. Subsequently, the results are transmitted, and the difference between the two cases is calculated. This device has the capability to scan for malaria in short time, in any environment and anywhere. It is user-friendly, making it accessible to anyone. This device represents the first steps toward finally eliminating this deadly disease through early and rapid detection.

Keywords: invasive, noninvasive, malaria, hemozoins, magnetic field, infrared, rapid detection, Beer–Lambert law, Triclinic structure, photodetector.

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الكشف السريع لطفيلي الملاريا بالطريقة الوخزية وغير الوخزية باستخدام التقنية المغناطيسية الضوئية

الملخص:

نظرًا للانتشــار الكبير لمرض الملاريا في بلدان افريقيا وشــرق اســيا وزيادة عدد الوفيات الناجمة عنه، خاصة في المناطق النائية، بالإضافة إلى صعوبة الاختبارات المخبرية التي تســتغرق وقتًا وكلفة مرتفعة، فقد تم تطوير جهاز لكشــف الملاريا في الجســم، يعتمد على خاصية الكشــف عن جزيئات الهيموزاين من خلال مجال مغناطيســي قوي، نظرًا لطبيعة جزيئات الهيموزاين المتكونة في الدم. حيث يتم تطبيق مجال مغناطيسي في حالتين: الحالة الأولى عندما يتم توجيه الأشعة تحت الحمراء إلى العينة أو الإصبع في غياب المجال المغناطيسي، ثم في وجود المجال المغناطيسي. بعد ذلك، يتم إرســال النتائج إلى المتحكم وحســاب الفرق بين الحالتين ثم تظهر النتيجة الدالة علــى وجود المرض مــن عدمه. يتميز هذا الجهاز بالقدرة على الكشــف عن الملاريا في وقت قليل، وفي أية بيئة وأي مكان. ويمكن لأي شــخص اســتخدامه، ويمثل هذا الجهاز الخطوات الأولى نحو القضاء النهائي على هذه المرض القاتل من خلال الكشف المبكر والسريع عن وجوده.

الكلمات المفتاحية : الوخزية، غير الوخزية، الملاريا، الهيموزوينات، المجال المغناطيسي، الأشعة تحت الحمراء، الكشف السريع، قانون بير-لامبيرت، البنية ثلاثية الميل، كاشف الضوء.

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1. Introduction

Malaria is a life-threatening disease spread to humans by some types of mosquitoes. It is mostly found in tropical countries. It is preventable and curable [1]. According to the latest World malaria report, there were 263 million cases of malaria in 2023 compared to 252 million cases in 2022. The estimated number of malaria deaths stood at 597 000 in 2023 compared to 600 000 in 2022[1]. Table 1 shows the Estimated malaria burden by WHO region in the world. More than 21 million people in Yemen are estimated to live in areas at risk of malaria, with more than 1 million malaria cases estimated to occur every year [2]. Malaria is considered one of the major health problems in the Republic of Yemen, where 60% of the population lives in areas with endemic malaria, the WHO estimates until the beginning of this century about 2-3 million cases of malaria annually and mortality rates were about 1% of this number annually [1]. The importance of combating malaria is evident:

- Malaria can lead to severe illness, causing serious health complications, especially in children and pregnant women.
- Malaria weakens the immune system and increases the risk of contracting other diseases.

From an economic perspective, malaria costs countries billions of dollars annually due to treatment expenses and loss of productivity. It negatively impacts economic growth and development in affected countries. Effective malaria treatment heavily relies on accurate and confirmed laboratory diagnosis [1]. Figure 1 shows the Current distribution of malaria in the world based on the tata reported in 2020.

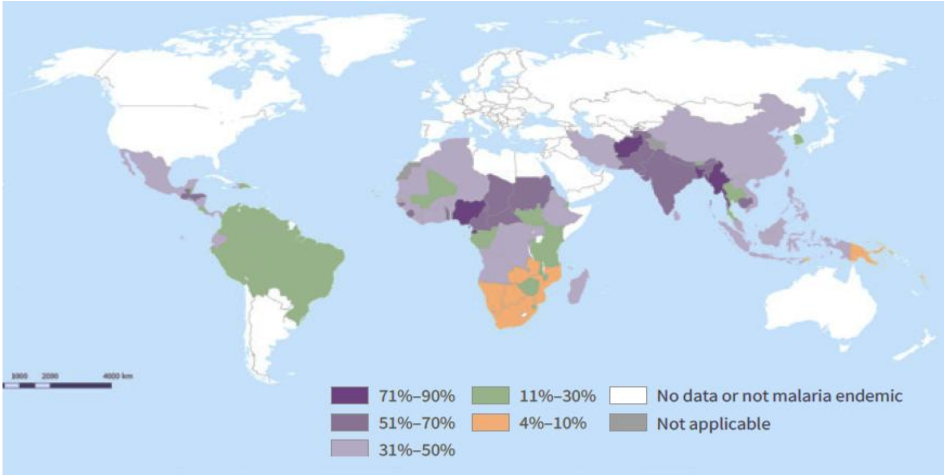

Figure 1: Current distribution of malaria 2020 [1]

Table 1: Estimated malaria burden by WHO region in 2016 [1]

WHO Region	Malaria cases	Malaria deaths
African	194 million	407 000
Americas	875 000	650
Eastern Mediterranean	4.3 million	8200
South-East Asia	14.6 million	27 000
Western Pacific	1.6 million	3300
World	216 million	445 000

Initiation of malaria treatment largely depends on good, laboratory confirmed diagnosis. This project focuses on quantify the type of malaria parasite (hemozoin) presented in blood stream by measuring the property of light interaction with hemozoin crystal absorption of laser beam when interacting with hemozoin particles on application of a magnetic field in a non-invasive way.

2. Problem Statement

Malaria is recognized as one of the most critical global health challenges, with 263 million cases reported in 2023, an increase from 252 million cases in 2022. The estimated number of deaths attributed to malaria was 597,000 in 2023, a slight decrease from 600,000 in the previous year [1]. This disease poses a significant health threat in Yemen, where conventional diagnostic methods for malaria require considerable long time (20 minutes or more) and exhibit limitations in their capacity to accurately identify the infection. The reliability of these methods is heavily dependent on the expertise of laboratory technicians, making them time-intensive and not universally applicable across different settings.

Particularly vulnerable populations, such as children and pregnant women, face heightened risks due to their compromised immune systems [1] and the challenges associated with obtaining samples from young children. In response to these issues, we have developed a device for malaria detection that incorporates both invasive and non-invasive techniques.

3. Objectives

The project aims to design and develop a portable device capable of detecting the malaria-causing parasite and providing quantitative diagnosis in a very short time and at a low cost. These objectives are achieved through several key steps:

- Designing the hardware of system.
- Simulating the device circuit design.
- Designing the software of system.
- Testing the efficiency and functionality of the device.

The system consists of two parts software and hardware parts as shown in Figure 2.

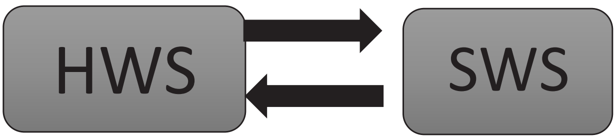

Figure 2: The integration of software and hardware

4. Malaria and Hemozoin

Parasites target the red blood cells as their hosts. Once inside, the parasite digests the hemoglobin and breaks it down into proteins and hems, protein structures with iron cores that are used by the blood to carry oxygen throughout the body. The parasite then sequesters the iron cores into carbon containers and connects them together with hydrogen bonds. The containers tend to line up such that they form a needle structure within the parasite. Once the parasite moves on to a new blood cell, it leaves the previous cell's needles,

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now called homozine, in the bloodstream, where they can be detected. There is much more to homozine, however, the main points are that malaria creates it and it tends to form into crystals that have a preferred axis. [5,8] method.

Figure 3 shows the structure and morphology of homozine crystals (a) Triclinic structure of hemozoin with two-unit cells displayed using structural. The main crystallographic axes a, b and c are also indicated. (b) The local symmetry of five-fold coordinated iron in hemozoin nearly preserves a four-fold rotation axis, C4v. The angle spanned by this C4v axis (hard axis of the magnetization) and the crystallographic c-axis (fore-axis of the elongated crystals) is d < 60u, where the c-axis points out of the plane of the figure. (c) Transmission electron micrographs of typical hemozoin crystallites dried from suspensions. [5]

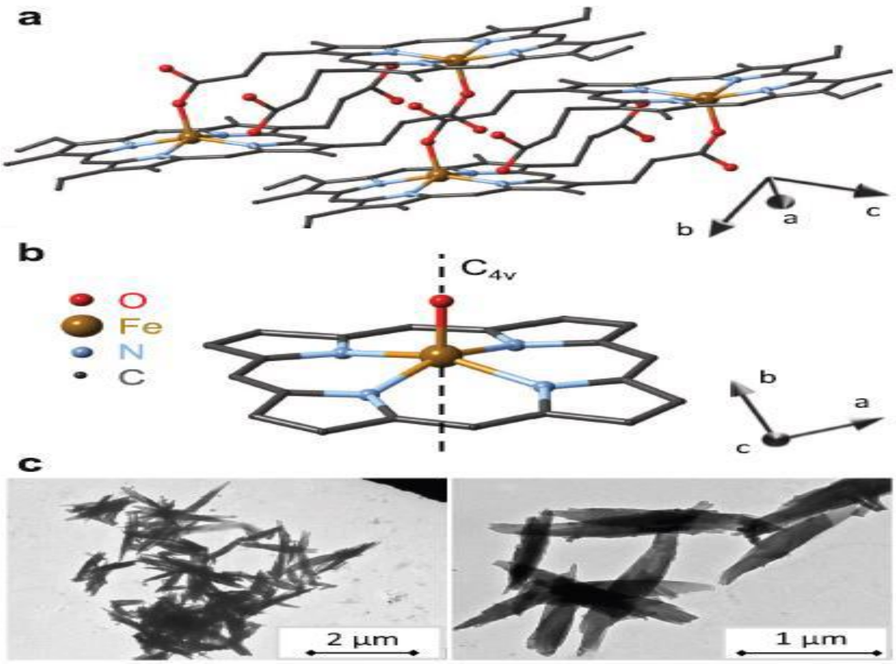

Figure 3: Structure and morphology of homozine crystals

Malaria is a blood-borne parasite carried primarily by mosquitoes. Once infected, the parasite consumes globin from hemoglobin, leaving the heme compound. Heme is toxic to the parasite, so it is further processed into crystalline hemozoin. The hemozoin crystal consists of an iron atom surrounded by a cyclic ring of nitrogen and carbon atoms with an oxygen atom bonded to the iron atom out of plane. These molecules form long needle shaped crystals with a magnetic moment along the iron-oxygen bond these crystals are paramagnetic, dichroic and birefringent. Dichroism and birefringence are properties resulting from an axially- dependent index of refraction for the crystal. The crystal has a preferred optical axis and the attenuation of index of refraction for light passing through the crystal depends on the polarization direction. For a dichroic material, the index of refraction depends on the linear polarization of the incoming light. When linearly polarized light is incident on a dichroic material, the crystal will absorb light differently depending on the orientation of the polarization vector with respect to the materials optical axis. Thus, by measuring the attenuation of light when polarized along the length and width of the crystal, we can measure the net dichroism by the difference between the two signals.

5. Block Diagram

As shown in Figure 4, single light source emit light, which passing through the sample or finger, after that the beam passes through the detector.

The sample is placed between two permanent magnets producing about 0.06 Tesla this magnetic field for ordering the hemozoin, The permanent magnets are connected to a stepper motor that moves them forward and backward in the case of the magnet at the back, the receiver takes several readings from the sample and after two seconds moving the magnet forward using the motor the hemozoin particles –which are already aligned in the direction of magnetic flux where the receiver takes several readings of the sample in the presence of magnets and an infrared circuit is used to set the beginning point of the motor. Finally, the Arduino preform a mathematical and control operation of the deference in the signal with and without the magnetic field .and decided if the blood sample is infected or not through display the result in LCD.

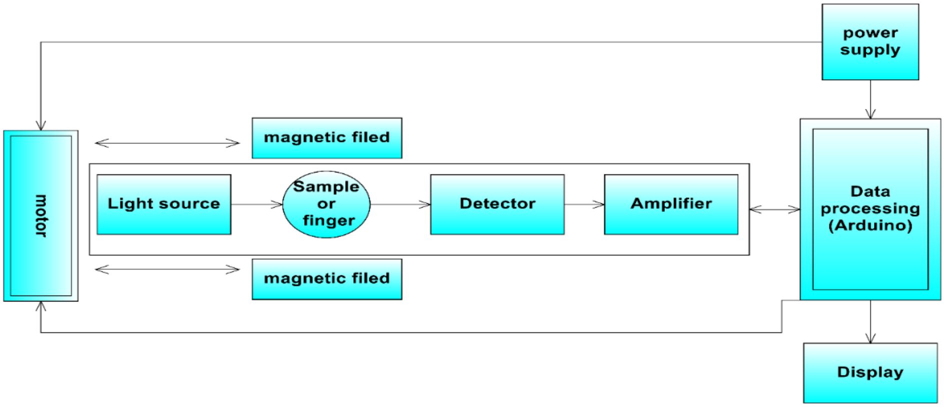

Figure 4: Block Diagram of Invasive & Noninvasive Rapid Detection of Malaria

6. Flow Chart of Invasive & Noninvasive Rapid Detection of Malaria

This flowchart illustrates the working process of a malaria detection device, showcasing the step-by-step procedures from sample collection to diagnosis Follow the flowchart to understand the key stages, including sample preparation, testing, data analysis, and result interpretation, ensuring quick and reliable malaria detection.

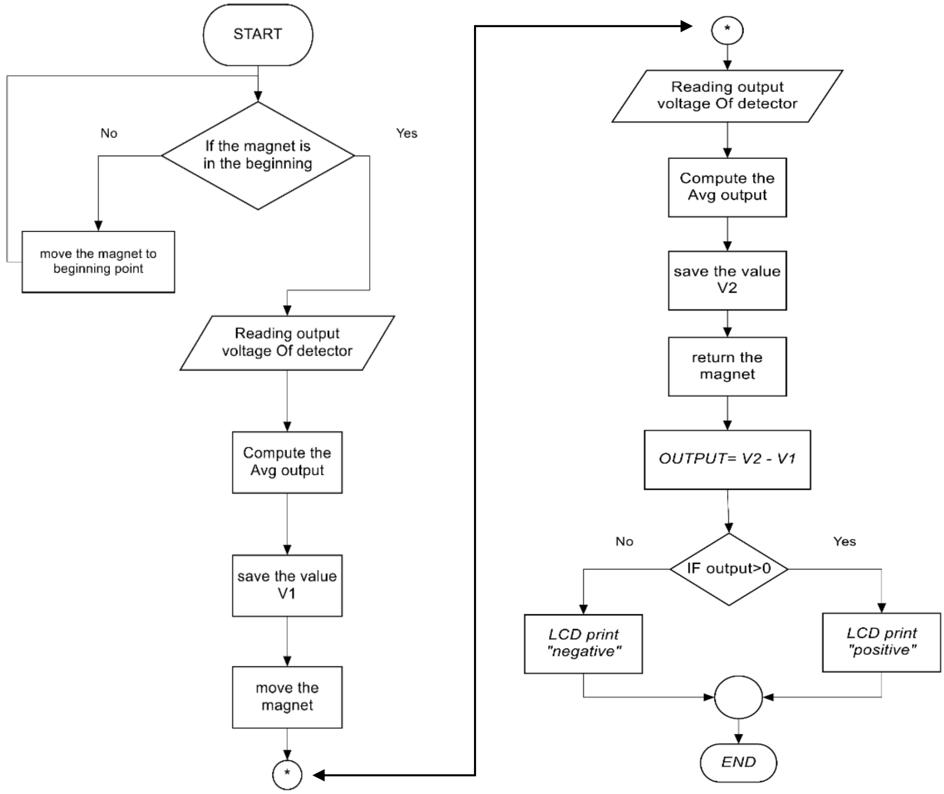

Figure 5: Flow chart of invasive & noninvasive rapid detection of malaria

7. Simulation and Implementation

7.1. Simulation

We use LabVIEW program to simulate our project. Our simulation consists of three-output part.

1) Measurement of output signal of detector without any sample.
2) Measurement of output signal of detector with healthy blood analytic
3) Measurement of output signal of detector for a blood sample, which infected with malaria parasite.

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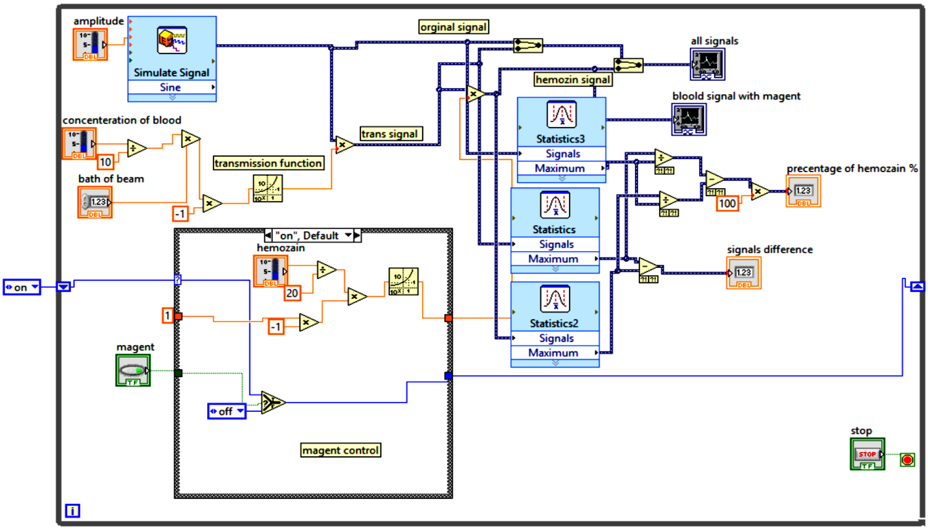
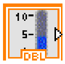
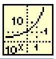
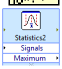
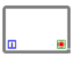


Figure 6: Simulation circuit by LabView

Table 2: Description of simulation component

No.	Icon	Name	Explanation
1		Simulate Signal	Simulates a sine wave
2		Numeric control	TO control the amplitude of Sine wave
3		Numeric indicator	To indicate the number of Interest
4		Power of ten	Expontial function
5		Statistics Express	To find the maximum amplitude of the signal
6		Waveform graph	To indicate the input signal
7		While loop	To repeat the code until the condition is investigated

7.2. Implementation

A blood sample tube or finger had been placed in the hole between the photodetector and the LASER light aperture inside the cuvette, when the LASER light strikes the sample or finger; the hemozoin particles –which are already aligned in the direction of magnetic flux- the absorption light will be detected by the photodetector which converts these changes in intensity to small current. These current values will be sent to the microcontroller as input, then the microcontroller program calculates the intensity of light according to based-in algorithms (this determine whether malaria is positive or negative), the result will be displayed on the LCD. A 12v adapter or a 12v battery charger used to supply the microcontroller and 12v reverse used to supply the photodiode.

7.3. Circuit Components

The proposed system basically consists of:

A. Laser diode line module.

B. Permanent magnet.

C. IR Si photodiode

D. Infrared circuit (transfer& receiver).

E. Power supply.

F. Microcontroller.

G. LCD.

H. I2c interface.

I. Motor.

J. Motor driver.

K. Current-voltage converter circuit

1) Light Source (Laser Diode Line Module):

To generate light signal that penetrate human body, IR wavelength with 200mW/808nm length was selected based on the fact that human tissue have low absorption factor at this range, so final selection was focusable 808nm 810nm IR Infrared 200mW Laser Diode Line Module.

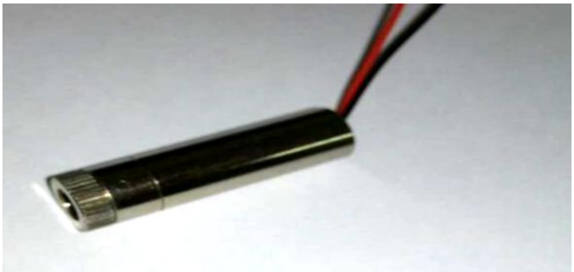


Figure 7: Laser diode line module

https://doi.org/10.59222/ustjet.3.2.2

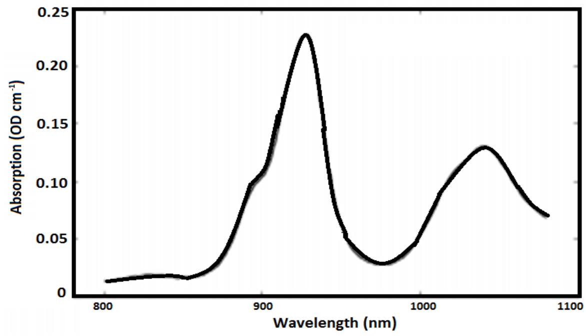


Figure 8: The absorption spectrum of hemozoin molecules in the IR from 800-1080nm

2) Permanent Magnet

In order to align hemozoin crystals 8 pieces of neodymium magnet Nd2Fe14B has been used to produce a 0.6T magnetic field.

Figure 9: Neodymium magnet Nd2Fe14B

3) Detector (IR Si Photodiode):

Si photodiode is a photodetector that has the ability to convert IR into electrical current.

This type is suited to low light level applications throughout the range 430 to 900 nm. According to the photodiode datasheet, the peak DC current is 10mA with a reverse voltage up to 15v.

Figure 10: IR Si photodiode

4) Infrared circuit:

The Infrared circuit is used to set the beginning point of the motor

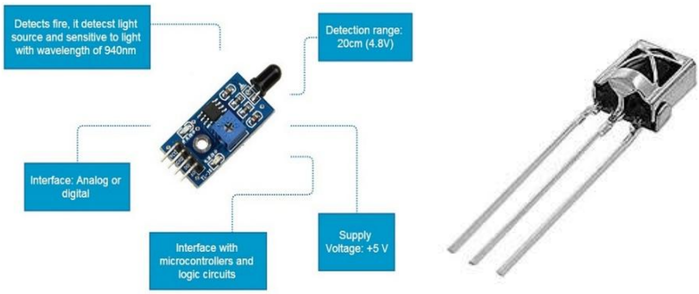


Figure 11: Infrared circuit (transfer& receiver)

5) Power supply:

An adaptive 12v output or 12v battery is used to supply the circuit by the needed power.

6) Controller

The controller is used to manage various type of operation and we use Arduino which is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board.

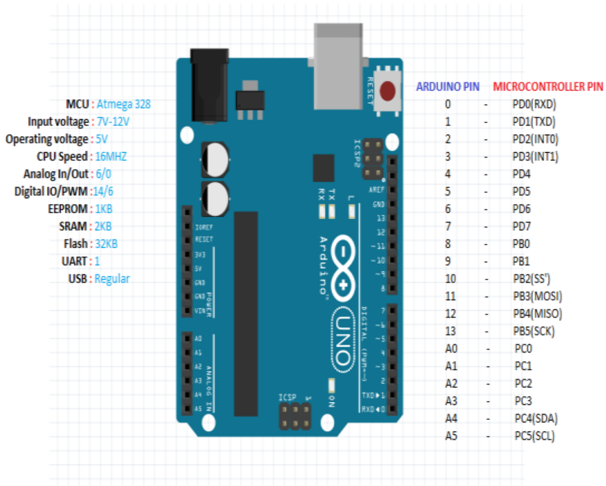


Figure 12: The Arduino pins

https://doi.org/10.59222/ustjet.3.2.2

7) Display (LCD)

To display the results processed by microcontroller we used (16x2) liquid crystal display which known as LCD. (16x2) LCD means that it shows 16 character in 2 rows.

Figure 13: LCD

8) I2C interface:

i2c interface Utilize regular 16*2 LCD display to just 4 connection pins are required (which means that fewer pins are necessary to use).

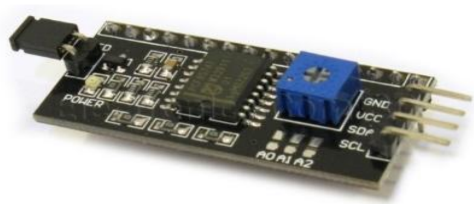


Figure 14: I2C interface

9)Stepper Motor and Steeper Motor Driver

An electric motor is an electrical machine, which converts electrical energy into mechanical energy. The reverse of this is the conversion of mechanical energy into electrical energy and is done by an electric generator. In normal motoring mode, most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force within the motor. In certain applications, such as in the transportation industry with traction motors, electric motors can operate in both motoring and generating or braking modes to also produce electrical energy from mechanical energy and found in many applications. [21] Driver: Convert pulses signals from the controller into motor motion to achieve precise positioning.

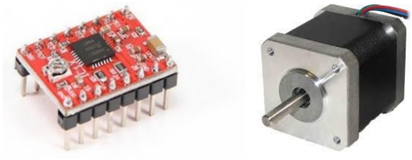


Figure 15: Steeper motor and driver

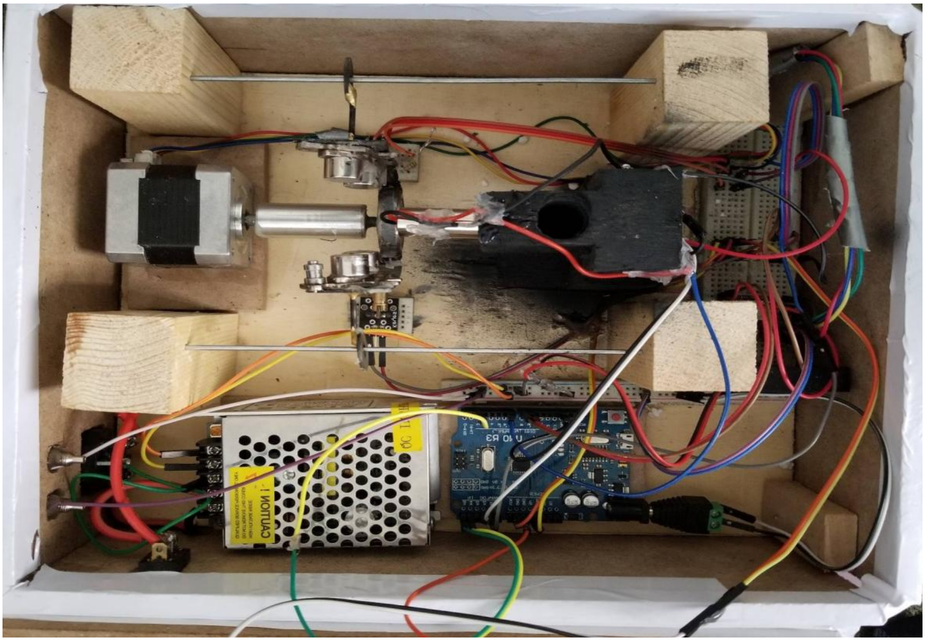


Figure 16: Implemented prototype

8. Results of Implementation and Simulation circuit

8.1. Implementation Results

Frist, we enable the device then the light source go through the blood sample and We measure the signal of the detector in two successive way when the magnet is on (Von) and when the magnet is off (Voff) thin will happen.

If the deference between (Voff) and (Von) equal to zero that, mean it is negative. Moreover, if the deference between (Voff) and (Von) does not equal to zero that mean it is Positive.

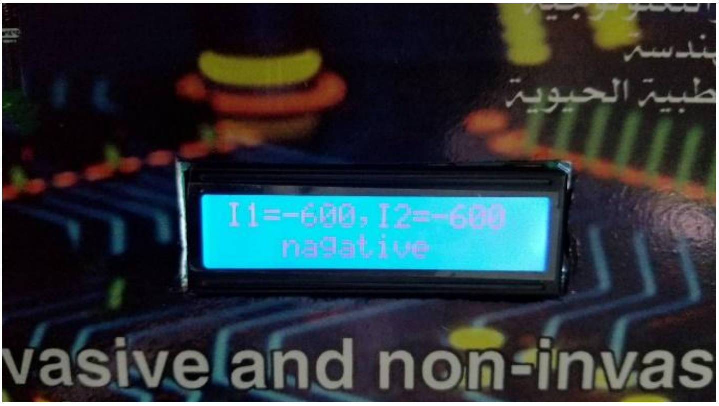


Figure 17: The result of device

8.2. Simulation Results

This section presents the simulation outcomes of the proposed malaria detection device, demonstrating its effectiveness in identifying malaria parasites under various conditions. The results highlight key performance metrics such as accuracy, sensitivity, and processing speed, validating the device's reliability. Through computational modeling and real-world scenario testing, the simulations provide critical insights into the system's functionality and potential for improving malaria diagnosis.

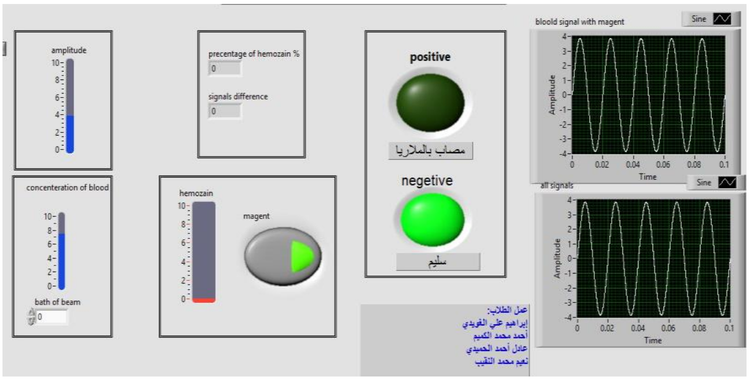


Figure 18: Resulting of simulation Circuit when negative

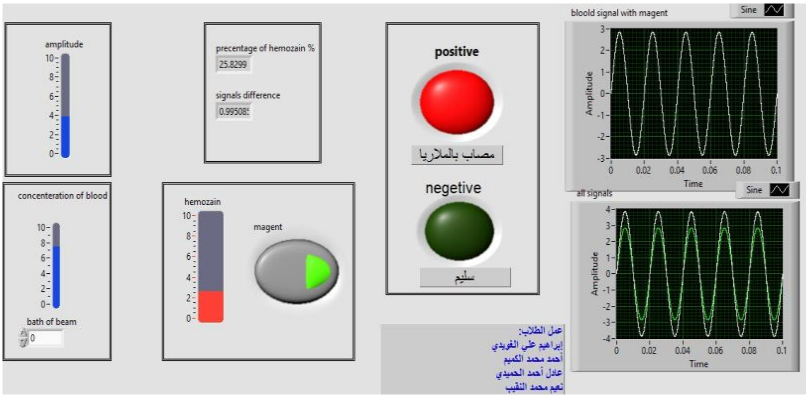


Figure 19: Resulting of simulation Circuit

9. Comparing the Device with Light Microscope

This section evaluates the performance of the proposed malaria detection device against the conventional light microscopy method—the current gold standard for malaria diagnosis. By comparing key parameters such as accuracy, sensitivity, specificity, processing time, and ease of use, we assess the potential advantages and limitations of the automated device. The analysis aims to demonstrate whether this innovation can offer faster, more reliable, and accessible malaria detection, particularly in resource-limited settings where microscopy may be less feasible.

Table 3 : Comparing the device with Light Microscope

WHO Metrics	INRDM	LM
Cost of Use (per test)	0.20$	0.92$
Detection level	1/ul	100/ul
Training needed	Low	High
Time	1 minute	1 hour

10. Future Work and Recommendation

This work could be extended as follows:

- Use the proposed system to test the other types of plasmodium.
- Design an adjustable testing hole for finger so that the device is able to perform for various sizes of fingers.
- Adding a memory to the device to provide the ability of saving test results.
- Manufacture the device for clinical uses.

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- Use an electrical magnet.
- We recommend to calculate the accuracy of device.
- We recommend to find the percentage of infect.

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