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Tunnel Magnetoresistance Sensor for Point-of-Care and Rapid Label-free Malaria Diagnosis

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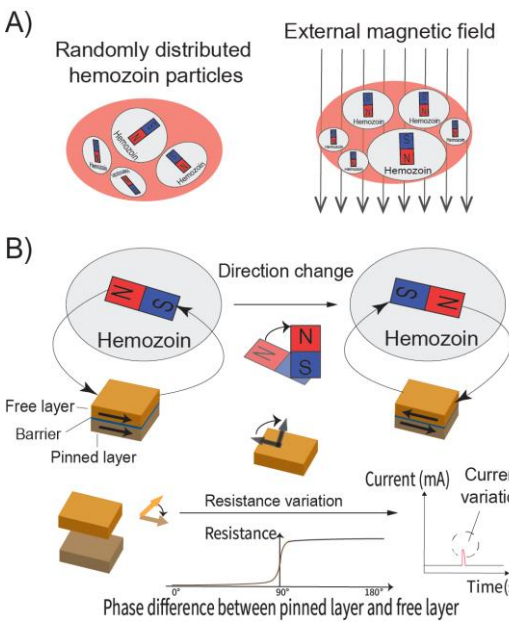
INTRODUCTION

To meet the demand for malaria diagnosis in malaria-endemic countries with low-resource, we need to design a cost-effective, easy-to-use, high-sensitivity and rapid diagnostic platform. However, all current diagnostics have their drawbacks, as is shown in Table.1, none of the existing malaria diagnostics can achieve rapid label-free diagnosis with high-sensitivity. Magnetic immunoassay is regarded as the most promising malaria diagnosis because hemozoin shows a paramagnetic property. Our objective is to use the tunnel magnetoresistance (TMR) sensor to detect the hemozoin and achieve a rapid label-free diagnosis with high sensitivity.

Table 1: Comparison table among malaria diagnostics.

Technique	Sensitivity (Parasites/μL)	Operation Time	Operation Cost	Operation Complexity
Microscopy	50-500	60 min	$5000 for a microscope $0.12–$0.40 for a test	Experts
RDT	100	15- 30 min	$0.55–$1.50	Easy-to-use
PCR	2-5	24 h	$100 for a PCR thermal cycler $3.3 for a test	Experts
MOT	50-100	1 min	25 euro cents	Easy-to-use
MRR	< 10	24 hours	< $0.55 cents	Expert

METHODOLOGY



MAGNETIC-ASSISTED MALARIA DETECTION PROCESS

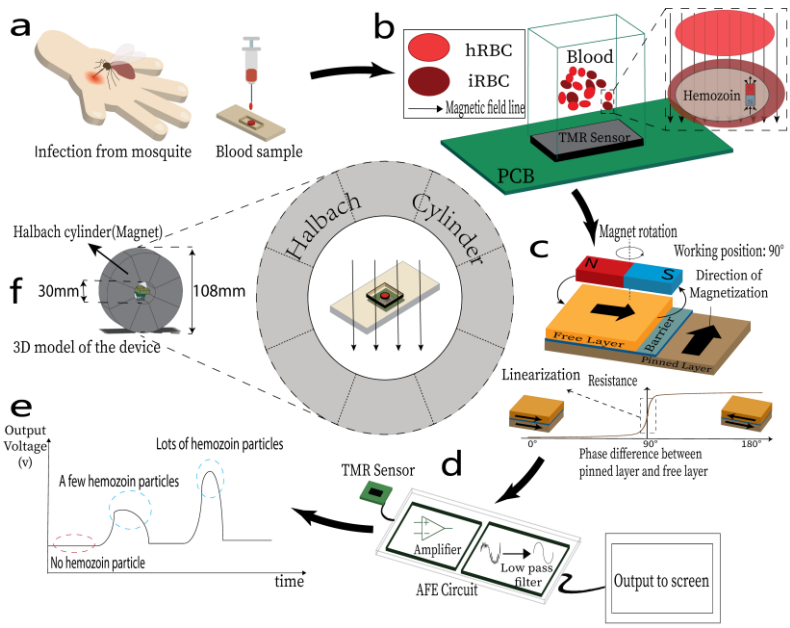


Figure 1: (A) Paramagnetism of hemozoin particles; (B) The relationship between the sensor resistance and the direction of the hemozoin.
Figure 2: Schematic diagram of the margination device. (a) blood sample infected by malaria; (b) blood sample placed on the TMR sensor container; infected red blood cells (iRBC), healthy red blood cells (hRBC) and the external parallel magnetic field exerted by the Halbach cylinder; (c) TMR sensor to detect in-plane magnetic field produced by iRBC, linearization region is suitable for the design in this device (d) analogue-front-end circuit; (e) displaying obtained voltage signal using LABVIEW interface (f) Halbach cylinder composed of 8 arc-shape permanent magnets to produce maximum and minimum perpendicular magnetic field.

HIGH-PRECISION BIOMAGNETIC MEASUREMENT SYSTEM BASED ON TMR EFFECT

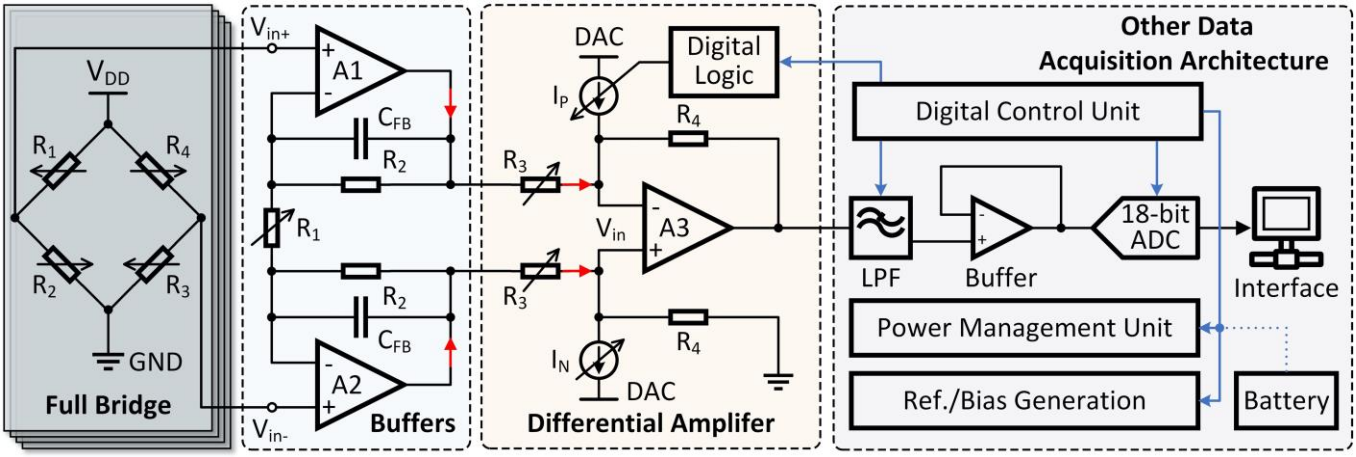


Figure 3. A processing chain of the portable magnetic-assisted malaria diagnosis system.

The readout circuit is so small with only 4 parts, amplifier, filter, Analog-digital converter (ADC) and microprocessor. The structure of the TMR sensor is equivalent to 'Wheatstone Bridge' circuit, which suppresses the offset at the output of TMR sensor. A transimpedance amplifier (TIA) will amplify the tiny current and transfer it into a measurable voltage signal. However, the noise is also amplified by TIA, a low-pass filter is needed to filter the noise from the TIA. Because the current signal output from TMR sensor is a direct current (DC) signal, the filter part in our design can decrease the influence of all alternating current (AC) signals. An ADC is placed after filtering, a microprocessor is used to process and display the final direct current (DC) signal.

EXECUTION & EXPERIMENTAL RESULTS

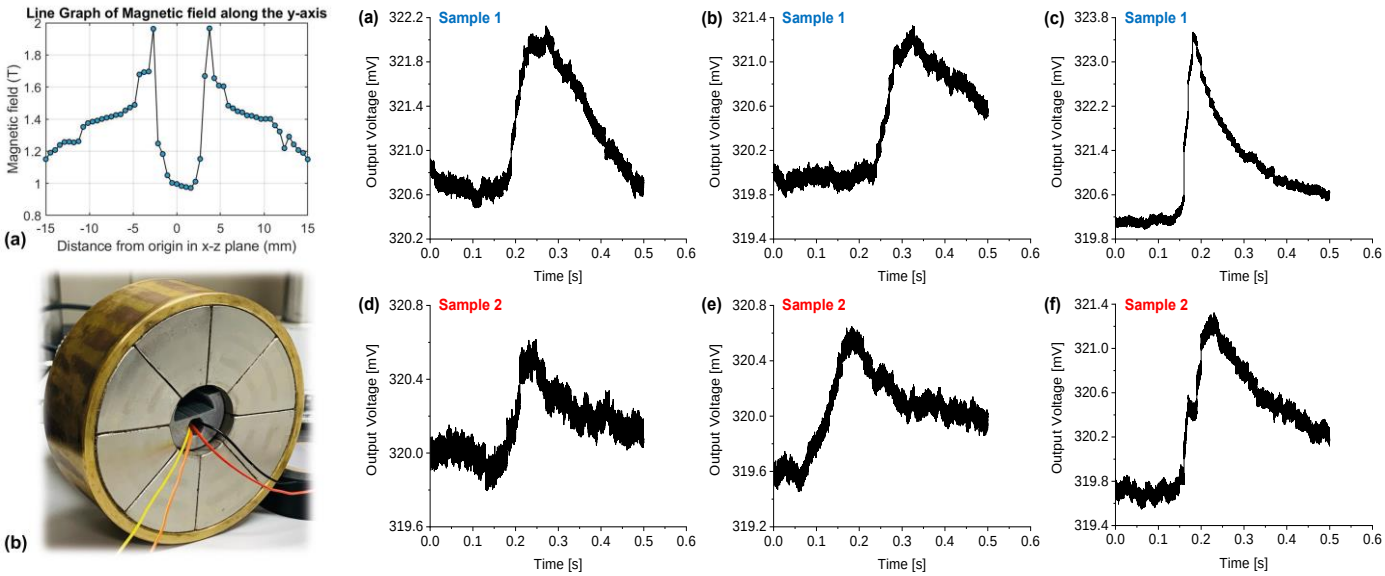


Figure 4. Portable Halbach Cylinder: (a) Produced magnetic fields along the y axis (-15mm to 15mm); (b) Experimental photo.
Figure 5. Measurement results of the proposed TMR-based system with real Malaria samples: (a-c) sample 1 & (d-f) sample 2.

CONCLUSION AND FUTURE WORK

In this project, we design and develop a miniaturized and handheld on-chip magnetoresistive-based device for a rapid label-free diagnosis of malaria. The device consists of four major components; (i) Tunnelling magnetoresistance (TMR) sensor; (ii) Halbach array of magnets (iii) Analog front end (AFE); (iv) LabVIEW interface. The system includes sensory and electronic boards to collect the data, cancel the noise, amplify and to transfer them to be displayed. A LabVIEW interface, as a display module, is utilized to display detected voltage signal by sensor due to the malaria pigment.

[1] S. Zuo, K. Nazarpour and H. Heidari, 27th IEEE International Conference on Electronics, Circuits and Systems (ICECS), Glasgow, 2020.
[2] Z. Yin, E. Bonizzoni and H. Heidari, IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, September 2018.