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Development and Experimental Validation of a Non-Invasive Blood Group Detection System

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ABSTRACT

An individual's blood group consists of red blood cell antigens whose composition is determined by protein presence, antigen structure, and gene series. Persons aged above six months have significant anti-A and/or anti-B in their serum. During transplantation and transfusion, ABO blood group identification is the most essential factor. The conventional method involves drawing blood samples from patients, and the blood group is determined based on the antigen-antibody reaction. This method consists of adding chemical reagents. However, this requires time of operation, and throughput analysis is high, and the process is also challenging to interpret. Accurate and rapid identification of blood groups is therefore crucial in various medical fields, including blood transfusions, organ transplants, and prenatal care. Traditional methods for blood typing often require extensive laboratory equipment and trained personnel, leading to delays and potential errors in critical situations. This research focuses on developing a non-invasive, compact, and user-friendly device capable of determining blood groups quickly without invasively collecting patient's blood samples and using reagents. The system learns from a database of annotated blood samples by employing machine learning algorithms, enhancing its accuracy and reliability over time. A non-invasive blood group detection system was verified experimentally on a laboratory prototype, achieving an accuracy of 95.9% in identifying blood groups and rhesus factors. Furthermore, a comparative analysis was conducted between the proposed system and existing counterparts. This analysis demonstrated that the proposed system outperforms others in accuracy, indicating the rhesus factor.

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INTRODUCTION

A blood type, also called a blood group, is a classification of blood-based on the presence or absence of inherited antigenic substances on the surface of red blood cells (RBCs). Depending on the blood group system, these antigens may be proteins, carbohydrates, glycoproteins, or glycolipids. Antigens and antibodies in the blood identify blood groups. (Studholme et al., 2001), (Ferraz et al., 2010) Antigens are any substance that stimulates the immune system to produce antibodies. Antigens can be bacteria, viruses, or fungi that cause infection and disease. Antibodies, also

called immunoglobulin, are proteins manufactured by the body that help fight against foreign substances called antigens. When antigens enter the body, they stimulate the immune system to produce antibodies (Studholme et al., 2001), (Ferraz et al., 2010). The antibodies attach or bind themselves to antigens and inactivate them. Antibodies bind with antigens and inactivate them so other bodily processes can take over, destroy and remove the foreign substances from the body (Ferraz et al., 2011). There are many types of blood groups. But, the two major types of blood groups are the ABO blood system and rhesus blood system.

The ABO blood system is the most important blood group system in human blood transfusion. The associated anti-A and anti-B antibodies are usually immune globin M, abbreviated as IgM antibodies (Kominato et al., 2005). ABO blood system determines whether the person belongs to blood A or B or AB or O. There are four major blood groups defined by the presence or absence of two antigens, A and B, on the surface of red blood cells (Kominato et al., 2002). AB blood types have both A and B antigens and no A or B antibodies. As they lack antibodies, they can receive any type of blood (Dean, 2005). They are known as universal recipients. O blood has neither A nor B antigens, so any recipient's antibodies did not agglutinate their blood cells. Therefore, they are known as universal donors (Dean, 2005).

Before performing the blood transfusion, it is necessary to perform specific tests that are appropriately standardized (Ferraz et al., 2010; Brown & Crim, 2007). One of these tests is determining blood type. This test is essential for realizing a safe blood transfusion to administer a blood type compatible with the type of receiver (Myhre & McRuer, 2000 ; Henneman et al., 2007). However, there are certain emergencies due to a patient's life risk. As the currently available tests require moving the laboratory, there may be insufficient time to determine the blood type (Wagar et al., 2006). Therefore, the patient is administered blood type O negative from a universal donor, which provides less risk of incompatibility (Turner et al., (2003). The risk of incompatibilities is less; sometimes, transfusion reactions cause the patient's death, and it is essential to avoid them, administering blood based on the principle of the universal donor only in emergencies (Ferraz et al., 2010; Brown & Crim, 2007). Thus, the ideal would be to determine the patient's blood type even in emergencies and administer compatible blood type from the blood transfusion unit (Mueller & Seifried, 2006; Callum et al., 2001).

Figure 1: Traditional blood group identification using chemical reagents.

The traditional method of detecting blood type is usually a plate and tube test (Norfolk, (2013). Both are performed under complete analogue procedures with human observation, sometimes leading to human errors. It is insufficient to perform the most basic and necessary medical procedure in a completely analogous environment. Several techniques include microplate testing and gel centrifugation (Norfolk, (2013); Ravindran et al., (2017). These procedures are expensive and must be performed by people with solid skills.

In Tanzania, the Blood group is determined manually. This system added anti-A, anti-B, and anti-D solutions to the three blood samples (see Figure 1). After some time, agglutination may or may not occur. Depending upon the agglutination, the blood group can be determined manually by the person. To work out the blood group of a person, the red blood cells of that person are mixed with different antibody solutions. For example, if the solution contains anti-A antibodies and the person

has A antigens on the cells, it clumped together. If the blood does not react to anti-B or anti-A antibodies, it is blood group O (Dean, (2005). Manual blood grouping procedures present undesirable and unwanted drawbacks, such as requiring more time and using reagents. It is challenged with non-standardised accuracy since it depends on the operator's capabilities.

Many researchers and scientists are trying to reduce the drawbacks and shortcomings. Several methods have been proposed in the literature. Some are already in use, and others are still being studied. For example, the idea of fibre optics for identifying ABO has been explained by (Selvakumari, (2011). Figure 2 shows the blood group detection system using fibre optics, as described by (Selvakumari, (2011). The transmitter generates electrical pulses to modulate the IR LED, which emits infrared light that carries the modulated signal through the optical cable. The optical cable is a transmission medium that guides the modulated infrared light from the transmitter to the patient sample without significant loss. The PIN photodiode converts light signals into electrical current, then the current to a voltage converter, which converts the small current signal from the PIN diode into a proportional voltage signal that can be further processed. The differential amplifier is used to amplify the difference between light from the patient sample and ambient light. A high pass filter is used to eliminate any dc in the signal, and the resultant signal is then passed through the band pass filter and amplified to remove noises for better accuracy.

The drawbacks of this system are that the Rh (positive and negative) blood group type has not been discussed, and it requires more time to prick the skin to draw the patient's blood. Furthermore, the idea of identifying ABO and Rh-type using laser technology and by pricking the skin to draw the patient's blood has been explained by Noor Abduljabar Jadah (2016). Figure 3 shows the blood group detection and Rh-type using laser as Noor Abduljabar Jadah (2016) described. In this technique, Laser light, Photocell and comparator are used. First, the blood samples are taken on a test slide, and the laser light is passed through the blood sample placed on the test slide. Photocells, placed below the test slides, sense the light and generate voltage/current. Finally, the voltage level is compared with the help of a comparator. The observed voltage level is different for different blood types. In this way, the blood groups were analysed.

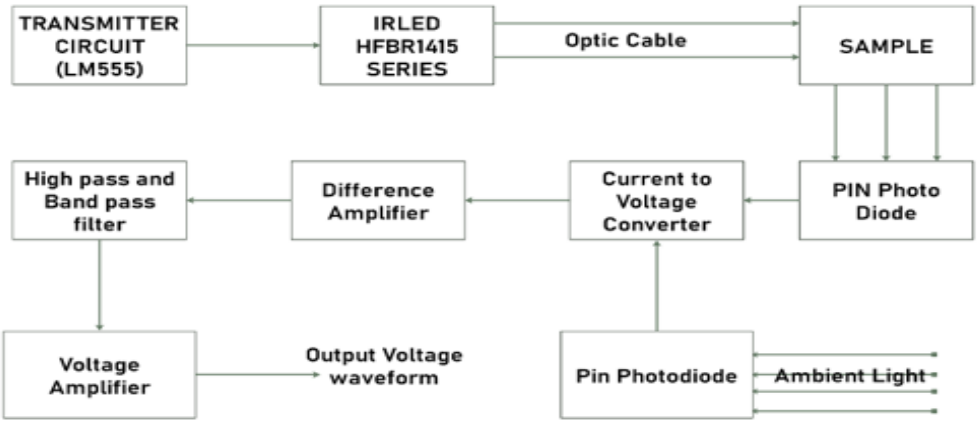

Figure 2: Conventional blood group detection system using fibre optics.

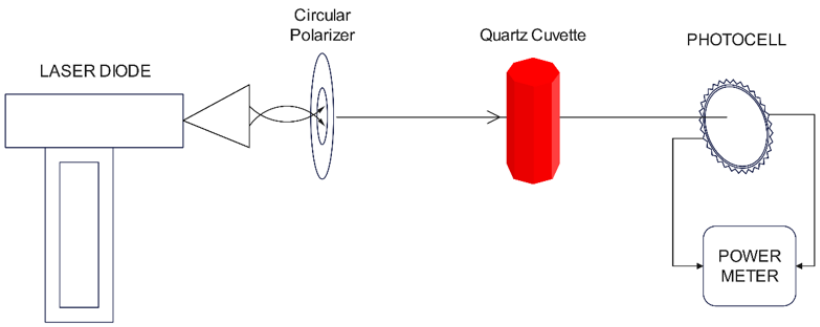

Figure 3: Conventional detection of ABO and Rh type of blood groups system by laser sensing.

The drawback of the system is that it takes more time since it takes a blood sample on a test slide to determine the blood type.

Moreover, the non-invasive techniques have been studied. The study of a non-invasive method for identifying the ABO of a person without pricking the skin to draw the blood has been explained by (Gayathri et al., 2018; Rubi et al., 2019). Figure 4 shows the non-invasive method for blood group detection using a light-emitting diode as described by (Gayathri et al., 2018; Rubi et al., 2019). LEDs emit light at specific wavelengths, which acts as a light source to illuminate the patient's finger without causing harm. Some light was absorbed by blood, and others were reflected in the detector, which converted the reflected light into voltage. Arduino processes the intensity readings and determines the blood group based on a pre-defined algorithm stored in its memory.

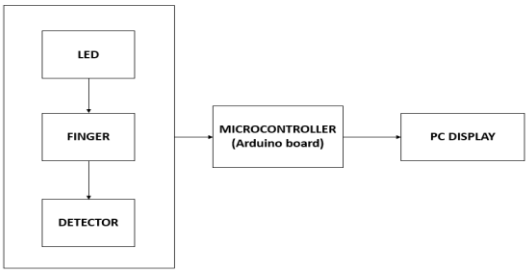

Figure 4: Conventional non-invasive blood group detection using LED.

The drawback of this system is the Rh (positive and negative) blood group type has not been discussed. Additionally, the idea of a non-invasive method based on IoT for identifying ABO has been explained by (Bhuvaneswari et al., 2021). Figure 5 shows the IoT-based non-invasive method for blood group detection as described in that work. The light that emerges from the LED is allowed to pass through the finger, and LDR is used to find the intensity of the light transmitted from the finger. LDR detects the intensity of the light signal and gives the corresponding voltage level. The obtained voltage level is compared with the microcontroller's preprogrammed voltage level of blood groups. The final result was displayed on LCD. In the case of an emergency, the Request Button is used to find the blood groups in the nearby blood banks with the help of IoT (Internet of Things) Technology. Here, Node MCU acts as a Wi-Fi. The connection between the node MCU and the server is bi-directional. The request is displayed in a mobile application. The donor can accept the request if they are ready to donate blood. The acceptance message is displayed on the LCD. It contains the donor's name and contact number. With the help of GSM, a request message was sent to the donors as an SMS.

The drawback of this system is the Rh (positive and negative) blood group type has not been discussed. Moreover, the recent technique of identifying ABO using a machine learning (ML) classifier has been explained by (Dannana & Prasad, 2022). Figure 6 shows the blood group detection using an ML classifier described by (Dannana & Prasad, 2022). The patient blood sample is mixed with a reagent on the glass slide. After a while, agglutination may or may not occur. Then, the slide test with a blood sample was captured using a

digital camera, and images were compared with the patients. Training data is executed, and the features are extracted using a grey-level co-occurrence matrix and colour histogram technique. The remaining images are then classified using an ML classifier.

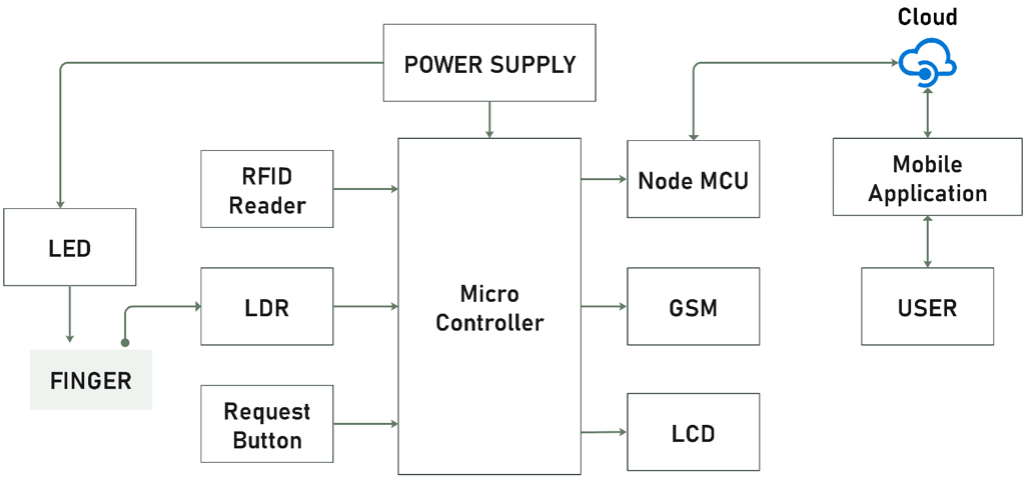

Figure 5: Conventional IoT-based non-invasive approach for blood group detection using LED.

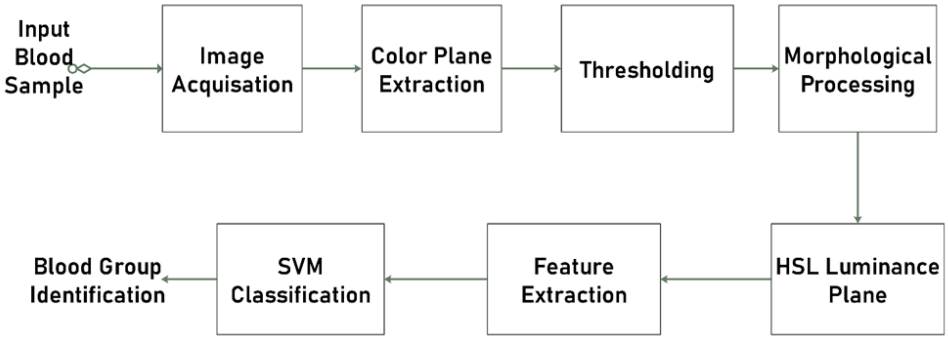

Figure 6: Conventional blood group detection using ML classifier.

The drawbacks of this system are that the Rh (positive and negative) blood group type has not been discussed, it requires more time to prick the skin to draw the patient's blood, it involves the use of reagents, and it requires more time since it takes a blood sample on a test slide to determine the blood type. The purpose of this study is to develop a more efficient and accurate method for determining blood types, specifically addressing the drawbacks of current systems that overlook the Rh factor, require prolonged skin pricking, and rely on the use of reagents and time-consuming blood sample analysis. The goal is to create a streamlined process that eliminates these inefficiencies, offering a quicker, non-invasive, and more comprehensive solution for blood typing. By incorporating advancements in technology and methodology, this work aims to improve the accuracy and convenience of blood group determination, ultimately benefiting both healthcare professionals and patients.

METHODS AND MATERIALS

Description of the proposed system

The idea of a non-invasive method of identifying the ABO and Rh (positive and negative) type of the blood group of a person without pricking the skin to draw the blood is explained by using a Python algorithm to capture images of scattered light. Figure 7 shows the proposed non-

invasive method for blood group detection. The primary continuous wave laser light emits light 90 degrees to the surface of the patient's finger. The camera is inserted at 40 degrees to capture the scatted light based on the incident light that hits the epitopes on the RBC pattern. Hence, computer and software are essential for detecting blood groups.

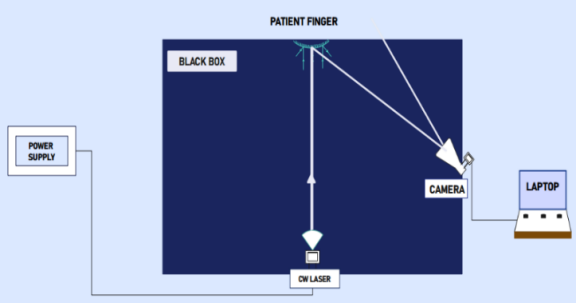

Figure 7: Proposed system of non-invasive blood group detection

Data collection

The case study for this research was conducted at Muhimbili National Hospital, located in Dar es Salaam, Tanzania. This hospital detects blood groups during patient medication. The average blood group detection per day is 1500 samples. These data were used in designing and training the proposed research system to solve the existing problem. Some of the data were collected by reviewing the relevant literature from different books, journals, and material from the internet and by passing through different hospitals to observe how blood groups are measured. The technical data concerns the properties of various components and other physical and electrical parameters used to accomplish the design objectives.

System modelling and algorithm

The quantification process, focusing on standard deviation (SD) and mean (M), was central to analysing the laser-induced interactions with the thumb. Before reaching the quantification stage, each image underwent several processing steps, including colour conversion, colour extraction, thresholding, and morphological operations. These methods ensured that the relevant features were accurately captured and enhanced for analysis. The data collected through this process helped identify the blood groups of the participants. The mean intensity value, *M* was calculated as:

$$\mathrm{M} = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad (1)$$

where, *N* is the total number of pixels in the region of interest and x_i is the intensity value of the *i*-th pixel. The standard deviation of pixel grey level, SD was calculated as:

$$SD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(xi - M)^2} \qquad (2)$$

where, *M* is the mean intensity calculated in equation (1), $(xi - M)^2$ is the squared deviation of each pixel's intensity from the mean.

Modal was trained to set the constant setpoint of the blood group by capturing the image of scattered light from the thumb. The collected data were analysed using a Python algorithm, and different types of blood groups (A, B, AB, and O) were obtained. Figure 8 shows the model training flow chart for the non-invasive blood group detection system. The effect of varying blood group results was studied before and after installing the system.

Data analysis

Figure 9 shows the flowchart of the proposed non-invasive blood group detection system. First, the patient's thumb was placed on the hole, present on the top of the black box. The box contains laser light and a camera. The device is turned on to fire laser light onto the skin surface. When illuminating at certain frequencies, light is absorbed by the haemoglobin in the red cells, and light gets scattered after hitting the edges of the antigenic determinants having a specific structure/shape.

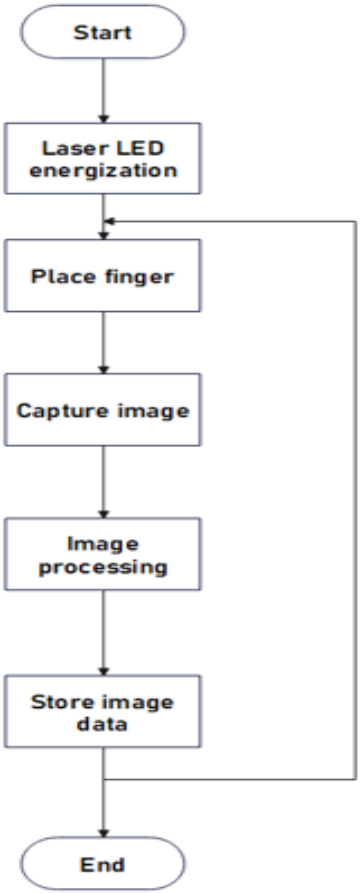

Figure 8: Flow chart of model training non-invasive blood group detection system.

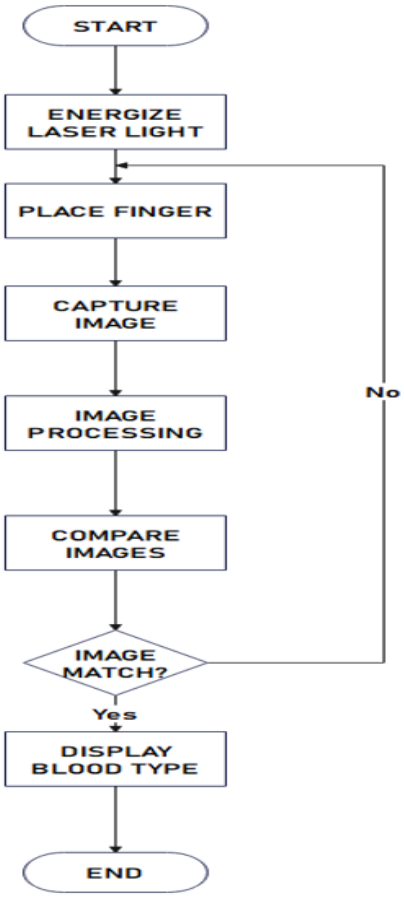

Figure 9: Flow chart of proposed non-invasive blood group detection system.

The pattern of this light scattering is captured by keeping the optical device ON for a specified time to capture the after-effects of scattering. The device takes multiple images in succession to trace/track scattered light. The recorded pattern gives an estimate of the type of antigens in the blood cells, which provides an estimate of the blood type.

The criteria were estimated based on the mean and standard deviation as shown in Table 1, to identify the blood group with their rhesus factor. For example, the blood sample is identified as O+ when the mean value is within the range of [31.897, 37.483] and the standard deviation is in the range of [63.328, 68.094]. Such criteria extended to other blood groups, as shown in Table 1.

Table 1: Mean and standard deviation intervals used in blood group estimation

Blood group	M range	SD range
A+	22.898 28.271	54.423 59.994
A-	20.343 21.404	51.232 53.455
B+	36.891 38.464	68.534 69.982
B-	23.057 24.057	64.849 67.785
AB+	27.389 32.528	59.049 63.315
AB-	25.758 26.746	57.935 58.049
O+	31.897 37.483	63.328 68.094
O-	29.034 30.848	61.486 62.959

After capturing the image, it passes through four image processing stages. The details are as follows.

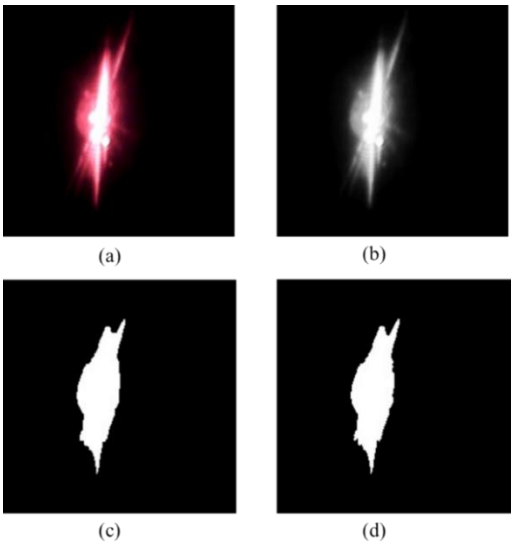

Figure 10: Image processing obtained in the experiment (a) original image, (b) colour extraction and HSL analysis, (c) thresholding, and (d) morphology.

The original image shows the reflected light from the person's finger captured by the camera and stored in the database, as shown in Figure 10(a). The stored image is pre-processed using colour plane extraction. Each image's foreground and background colour has different mean and standard deviation values. Any colour display mapping does not modify the colours in the colour plane. The colour extraction and HSL analysis are shown in Figure 10(b). Then, the image goes through thresholding, i.e., converted from grayscale images to binary images, as shown in Figure 10(c). Lastly, the binary image, in which morphology is obtained from morphological operations such as erosion, dilation, opening and closing, as shown in Figure 10(d). This image is used to compare blood image shapes to the stored database.

Experimental setup, equipment and materials

The tools and materials used in this research are described in Table 2.

Table 2: Materials used in designing the blood group identification system

Material	Specification
CW laser diode	650nm – 690nm
Camera (Logitech C920)	8 megapixels, USB 3.0 interface
Laptop	Corei5, 8GB RAM

Random blood samples were selected from different people, with ages between 16-60 years old. With the help of the designed prototype, a 100-person blood group database was created. Individuals were asked to place their finger into the set-up. A database included people with dark and light skin; their skin was either dry or wet, some had natural or artificial fingernails, and some had painted nails. The ambient temperature was 29°C at the time of experimentation. Five trials were undertaken for each individual for both left and right hands were examined for acquiring the values of mean and standard deviation range for the ABO blood group and Rh factor.

RESULTS AND DISCUSSION

Experimental results

In the experimental setup, the person inserts their finger after the laser is energized, and the camera captures the image. The captured images are then processed using a Python algorithm, which implements various image-processing techniques. These include color plane extraction to isolate specific color channels, thresholding to distinguish relevant features from the background, and morphological operations to enhance or refine image structures. Multiple images are processed in this manner to ensure accurate results and improve the quality of the captured data for further analysis.

Blood Groups (A+, B+, AB+ and O+) Results

Notably, the blood groups A+, B+, AB+, and O+ were identified due to the mean and standard deviation values observed in the

images falling within the expected range. Figures 11 (a), (b), (c), and (d) show the experimental results of blood group identification corresponding with established reference ranges for each blood type, confirming the accuracy of the identification process. The statistical analysis of the data, including the mean and standard deviation, ensured that the detected values were consistent with the known characteristics of these blood groups.

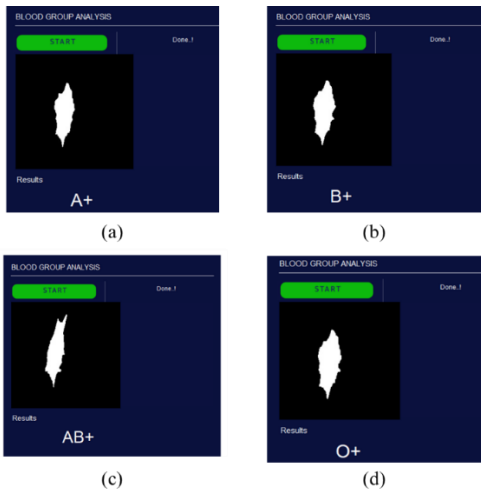

Figure 11: Experimental results of blood group identification: (a) blood group A+, (b) blood group B+, (c) blood group AB+, and (d) blood group O+.

Blood Groups (A-, B-, AB- and O-) Results

Moreover, the blood groups A-, B-, AB-, and O- were identified due to the mean and standard deviation values observed in the images falling within the expected range. Figures 12 (a), (b), (c), and (d) show the experimental results of blood group identification corresponding with established reference ranges for each blood type, confirming the accuracy of the identification process. The statistical analysis of the data, including the mean and standard deviation, ensured that the detected values were consistent with the known characteristics of these blood groups.

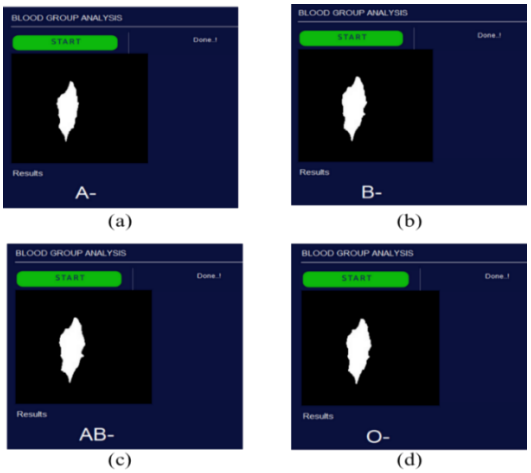

Figure 12: Experimental results of blood group identification: (a) blood group A-, (b) blood group B-, (c) blood group AB-, and (d) blood group O-.

The proposed system is challenged by the effect of skin colour on laser interaction, the impact of ambient light on environmental conditions, temperature sensitivity, surface moisture, and oil interference. To address these issues, solutions such as calibration for individual physiological differences, controlling environmental conditions and refining the image processing algorithms were implemented. These steps resulted to significant improvement of the system's performance. From the tested image samples, the developed system achieves a sensitivity of 0.959 and an accuracy of 95.9% because the possibility of obtaining the same results after measuring different individual with the same blood group is high see Table 3. However, the proposed system is insensitive to wet fingers and fingers with artificial or painted nails.

Table 3: Means and standard deviations ranges of individuals with different blood groups

SAMPLE	A+		A-		B+		B-		AB+		AB-		O+		O-	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD

1	26.08	57.63	24.94	53.40	25.58	56.08	23.39	60.69	30.36	62.17	28.85	60.85	33.55	65.36	31.69	63.39
2	23.94	55.21	22.84	53.50	24.89	58.20	23.90	57.76	30.64	62.46	28.61	61.77	34.61	66.38	31.57	66.17
3	25.32	56.77	25.11	57.92	24.70	60.48	23.44	59.56	30.60	62.41	30.43	60.37	34.10	65.90	32.29	65.75
4	26.75	58.36	24.66	58.22	25.21	56.27	24.01	58.63	31.09	62.92	30.30	61.67	34.10	65.88	34.50	62.95
5	27.06	58.7	22.94	58.39	24.94	57.86	23.58	55.44	30.36	62.17	29.69	59.15	34.46	66.24	30.09	64.34

Comparative study

The comparative analysis of the proposed non-invasive blood group compared to counterpart systems developed previously is detailed in Table 4.

Table 4: Comparative analysis of the proposed blood group detection system and its counterparts

Methods	Need of reagent	Time needed	Accuracy	Rhesus factor	Non-invasive
Selvakumari,(2011); Dannana & Prasad, (2022); Atici et al., (2020)	Yes	High	Low	No	No
Jadah, (2016)	Yes	High	Low	Yes	No
Gayathri et al., (2018); Rubi et al., (2019); Bhuvaneswari et al., (2021); Rukkumani et al., (2021)	No	Low	High	No	Yes
Proposed	No	Low	High	Yes	Yes

From Table 4, the proposed method and the methods by (Gayathri et al., (2018); Rubi et al., (2019); (Bhuvaneswari et al., (2021); Rukkumani et al., (2021) have higher accuracy than the methods by (Selvakumari, (2011); Jadah, (2016); Dannana & Prasad, (2022); Atici et al., (2020). Additionally, it is noted that the method presented by (Gayathri et al., (2018); Rubi et al., (2019); Bhuvaneswari et al., (2021); Rukkumani et al., (2021) is non-invasive, takes less time to test without pricking the skin to draw the person's blood, does not need use of reagent similar to the proposed system. However, the proposed method has the advantage of indicating the rhesus factor.

CONCLUSION AND RECOMMENDATIONS

This paper highlights the limitations of traditional blood group detection methods, which often involve skin puncturing and require time-consuming procedures and reagents. In contrast, the proposed non-invasive blood group detection system overcomes these issues by being compact, cost-effective, and time-efficient while maintaining high accuracy. The system's ability to quickly identify blood groups without needing skin puncturing or reagents is particularly beneficial in emergencies. The system achieved a sensitivity of 0.959 and an accuracy of 95.9% in testing with blood image samples, making it a promising solution for improving blood group detection in clinical settings. For future work in non-invasive blood group detection systems, here are several recommendations that can be pursued to enhance the technology by making it more accessible, reliable, and efficient for both healthcare providers and patients are SMS-based alerts, Cloud integration and Mobile application for monitoring.

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NOMENCLATURE

ABO Antibodies Blood Group
CCD Charge Coupled Device
C.F Compared Figure
CW Continuous wavelength
DC Direct Current
GSM Global System for Mobile Communication
HDD Hard Disk Drive
HSL Hue, Saturation and Lightness
IgM Immune globin M
IoT Internet of Things
IR Infrared
LCD Liquid Crystal Display
LDR Liquid Dependant Resistor
LED Light Emitting Diode
MCU Micro Controller Unit
ML Machine Learning
NM Nanometer
RAM Random Access Memory
RBC Red Blood Cells
Rh Rhesus factor
USB Universal Serial Bus

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