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Development Of A Low Cost Microcontroller - Based Haemoglobin Meter

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A B S T R A C T

This work looked at the determination of haemoglobin level in the blood using haemoglobin meter; an instrument for determining the absorbance value of haemoglobin in a sample of blood in g/dl.The haemoglobin meter was developed using light emitting diode (LEDs), a phototransistor, operational amplifiers, microcontroller (arduino board), liquid crystal display and a dark compartment. Samples of blood were smeared on a slide that was fixed between the LED and, phototransistor in the dark compartment. The LED emits radiation of visible light that pass through the blood sample which is detected by the phototransistor and is sent to the amplifier that amplifies the signal to a magnitude that can be picked up by the analog to digital converter (ADC) on the arduino board. The digital signal is then programmed by the microcontroller unit and the value is displayed on the liquid crystal display. The meter was calibrated against a standard (SH 120-1) and was examined for the accuracy of haemoglobin level. The developed system performed favourably well with the standard with a correlation value of0.98 at a percentage of 0.01% and the resolution is 0.001 g/dl.

1. Introduction

Blood has been held in high regard from ancient times and still plays important role today. It is the major source of life; hence it is necessary to know the state and level of blood in the body in order to avoid health risk (Alfred and Charles, 1960). The blood is a vital bodily fluid found in the circulatory system of mammals that delivers necessary substances such as nutrients and oxygen to the cells and transports metabolic waste products away from those cells (Kenneth, 2013). The blood helps in transporting oxygen and carbon dioxide to the tissues and lungs, aids blood clotting, protects the body against infection and helps to maintain the body temperature at the acceptable level without any health risk (Kienle *et.al,. 1996*).

Blood consists of two distinct elements: the fluid part and the solid part. The fluid called plasma consists of water plus dissolved gases, proteins, sugars, vitamins, minerals, and waste products. The plasma makes up about 55 percent of the blood volume. The solid (formed) of the blood consists of red blood cells, white blood cells, and platelets. These cells and platelets are produced in the bone marrow. The formed portion makes up the other 45% of the blood volume (Elert, 2012). The plasma is a clear yellowish liquid that helps to keep water from the cells and is also used for clotting and strengthening immunity. The platelets are small pieces of cells found in the blood whose major role is blood clotting. The white blood cells help to fight foreign invaders and infection. The red blood cells specialize in oxygen transport and contain haemoglobin (Kenneth, 2013).

Haemoglobin (Hb) is an iron containing protein in the red blood cells that play an important role in respiration by maintaining adequate supply of oxygen to the vital organs in the body (Ponni and Vinupritha, 2014). The oxygen carrying capacity of the blood is dependent on the number of red blood cells that are present and the amount of haemoglobin that each red blood cell contains. The haemoglobin is used for carrying oxygen from the lungs to the tissues of the body and it also transport carbon dioxide from the

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tissues to the lungs. It is also known to gives red colour to the blood. The haemoglobin concentration/level is an indication of its ability to carry oxygen and iron. It is usually measured in grams perdecilitre (g/dl). The normal range of haemoglobin level is widely dependent on the age and gender of a person. The range of haemoglobin level for women is between 12 g/dl and 16 g/dl, 13 g/dl and 18 g/dl for men while that of children is between 11 g/dl and 16 g/dl (Ponni and Vinupritha, 2014).

Low level of haemoglobin may cause anaemia, leukemia, kidney diseases, and cardiac disease while high level of haemoglobin level may cause polycythemia vera, lung diseases, cancer, dehydration and carbon monoxide poisoning (Ponni and Vinupritha, 2014). The haemoglobin level test is done to reveal the amount of haemoglobin in an individual's blood and also to determine if a person needs blood transfusion. There are various methods of measuring haemoglobin content in the blood but in this study, the photometric method has been employed.

The haemoglobin concentration depends on the theory of colour light transmission and absorption because the colour of a substance depends upon the interaction between visible light and the molecules that make up the substance (Rajashree and Anagha 2013). Substances absorb certain wavelength of white light and this determines the colour that is observed and it depends on the molecules that make up the substance. Any red coloured substance absorbs yellow and green light to reflect red colour using the Beer-Lambert law (Ezebuiro, 2000).

MATERIALS AND METHODOLOGY

The design of the haemoglobin meter system was based on the principle of Beer Lambert law as earlier stated. The Haemoglobin meter was developed and constructed in such a way that it is accurate and easy to use. The haemoglobin circuit consists of several units which include the power supply unit, the sensing unit, dark compartment, amplifying unit, microcontroller unit and the display unit. The block diagram of the system is as shown in Figure 1

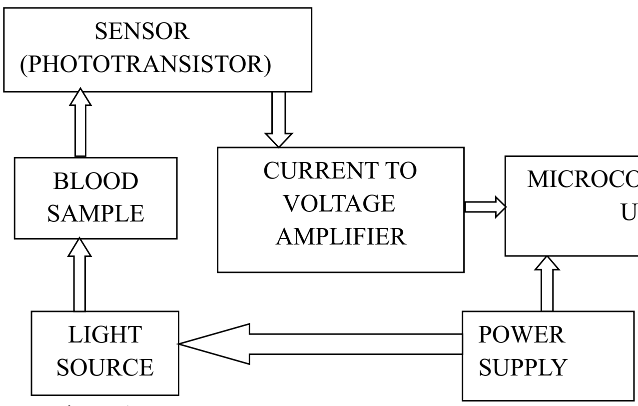

Figure 1.

LIGHT SOURCE AND SENSING UNIT

This unit comprises of bright coloured detachable light emitting diodes, a phototransistor and a dark compartment integrated together. A green and blue LEDs which served as the emitter having wavelengths of 570 nm and 490 nm respectively were chosen because haemoglobin could be easily absorbed within this region (Ponni and Vinupritha, 2014). The LEDs were so positioned in the compartment so that it could easily be detached. The wiring of the LED is as shown in Figure 2.

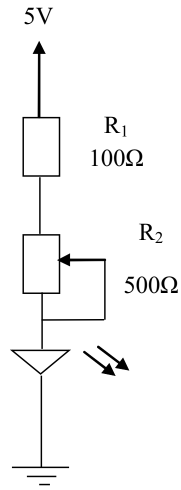

Figure 2. The Circuit Diagram of LED Connection

The phototransistor (IK36) which served as the detector/sensor was chosen because of its high sensitivity and response to little amount of current. It was positioned at the bottom side of the dark compartment so that it will be able to directly and easily detect the transmitted light through the sample of blood. Figure 3 shows the circuit diagram of the phototransistor with the power supply.

A dark compartment was used to avoid external sources of light on the sample apart from that of the LED. A slide which is held by two clips at the opposite ends is smeared with blood and fixed between the LED and the phototransistor in the dark compartment.

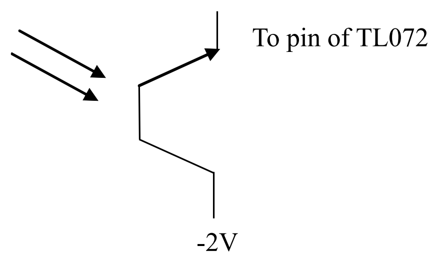

Figure 3:The Circuit Diagram of Phototransistor with a Power Supply

POWER SUPPLY UNIT

The power supply unit supplies power to the other units in the equipment. Rechargeable batteries of 3.5 volts each were used and connected serially to give positive 10.5 volts and negative 10.5 volts to power the entire system. Two voltage regulators 7805 and 7905 were used to regulate the 10.5volt to 5volt because the microcontroller and light emitting diodes require 5 volt supply. Two 1N4001 diodes were used to prevent excess flow of current. The rechargeable battery was used so that there will be a smooth running of the equipment during test without interrupted power supply and for easy mobility of the equipment. Figure 4 shows the circuit diagram of the power supply unit.

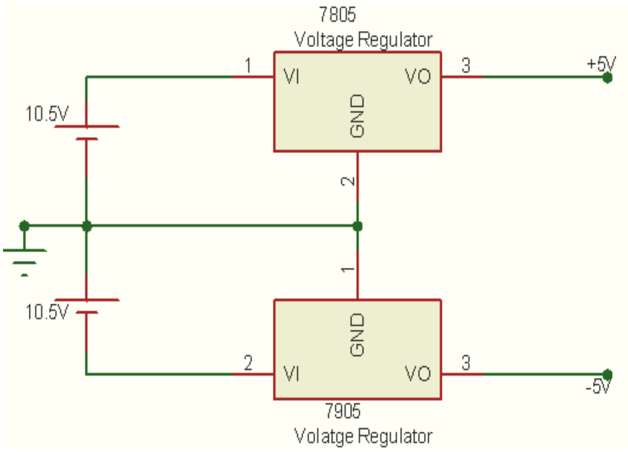

Figure 4: The Circuit Diagram of the Power Supply Unit

MICROCONTROLLER UNIT

This is made up of the Arduino UNO 3 board. It consists of an inbuilt analogue to digital converter (ADC) which senses the voltage from the amplifier and converts it from analogue to digital for evaluation. Instructions are programmed into the microcontroller using C language for the required application of the system.

The board was powered with a 10.5V external power supply via a plug into the unit's power jack. This voltage was chosen because the required voltage range for the Uno board is between 7 and 12V to prevent overheating of the internal regulator and the damage of the board.

DISPLAY UNIT

This unit consists of the liquid crystal display (LCD). It displays the output readings from the microcontroller unit. The LCD used in this work is the HD44780; a 16 by 4 display unit interfaced with the microcontroller.

AMPLIFYING UNIT

This unit is made up of an operational amplifier. The maximum output from the phototransistor is in the microvolt range. The detection of this voltage is practically impossible as most of them only displays detect voltages in the millivolt range and above (Mamman *et al.,* 2002). In order to display the voltage with high accuracy and for easy calibration, the voltage needs to be amplified; Hence an operational differential amplifier (TL02) was used to amplify the signal. The TL072 Op -Amp was chosen because of its low noise and high input impedance to amplify the voltage. The circuit diagram of the operational amplifier is as shown in Figure 5.

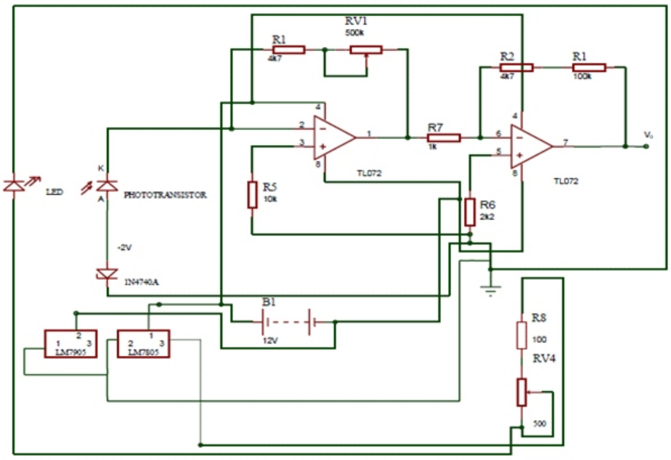

Figure 5: The Circuit Diagram of the Amplifying Unit

WORKING PRINCIPLE OF THE HAEMOGLOBIN METER

The LED is connected to the power supply with a probe and fixed into the hole of the device and then the device is powered on. Different blood samples were used and a mark was made on the slide to indicate where the blood samples are to be placed. The slide which contains the blood sample that has been smeared on it is then fixed into the slide hole. As the light from the LED passes through the blood sample due to absorption of light by the sample, a variation in the light intensity will be detected by the phototransistor. Since the absorption varies between different blood samples, the voltage generated by the phototransistor also varies between each blood sample of different haemoglobin concentration. This variation is sent to the amplifier which amplifies it to a signal that can be received by the microcontroller. The analogue signals are then converted to digital signals by the ADC in the microcontroller. The values from the microcontroller are then sent to the LCD to be displayed. An important factor to be considered in this work is that the LED source, blood sample and the phototransistor must remain in the same axis; the transmittance is used to determine the haemoglobin level (Ponni and Vinupritha, 2014).

CONSTRUCTION PROCEDURE

The working conditions of the components used for the construction of the Haemoglobin meter were ascertained by using a multimeter. The components were soldered unit by unit on the prepared circuit boards. Confirmation tests were carried out on the output of the phototransistor, input of the operational amplifier, output of the operational amplifier and input to the microcontroller board to ensure conformity with the desired circuit design's requirements.

PERFORMANCE

The appropriate light source was made to pass through the red colour materials in which red blood was used. The colours chosen were green, blue and white light emitting diodes (LEDs) as the light source. The white LED is used to examine the performance of the system. When light falls on the phototransistor without blood sample, it reads maximum value.

The developed haemoglobin system was taken to the State Specialist Hospital, Akure for calibration. The available instrument there was a Microhematocrit Centrifuge (SH 120-1). This available instrument (regularly calibrated for correctness by the hospital's personnel) is used for determining the packed cell volume (PCV) in the red blood cell. A blood sample was drawn from a patient into the capillary tube and sealed with a sealant. It was then put into the machine to be spinned for 5 minutes at 10,000 revolutions per minute. The spinning process enabled the blood cells to be separately packed (white blood cell, red blood cell, platelets and plasma). After spinning, the tube was brought out and the level of PCV was read and compared using the Micro hematocrit reader. The haemoglobin level is determined by multiplying the PCV value by 3. The sample was placed in the developed one; the calibration port of 1MΩ was adjusted until the result was equivalent to the available (standard) one at the hospital.

Several other samples available were tested in the SH 120-1 system and as well as the developed instrument using the blue and green LEDs. The values from SH 120-1 system and the developed one were then compared. The instrument measured in the range of 4 g/dl to 25 g/dl. The complete circuit diagram of the developed Haemoglobin Meter, the internal wiring and the pictorial view are as represented in Figures 6, 7 and 8

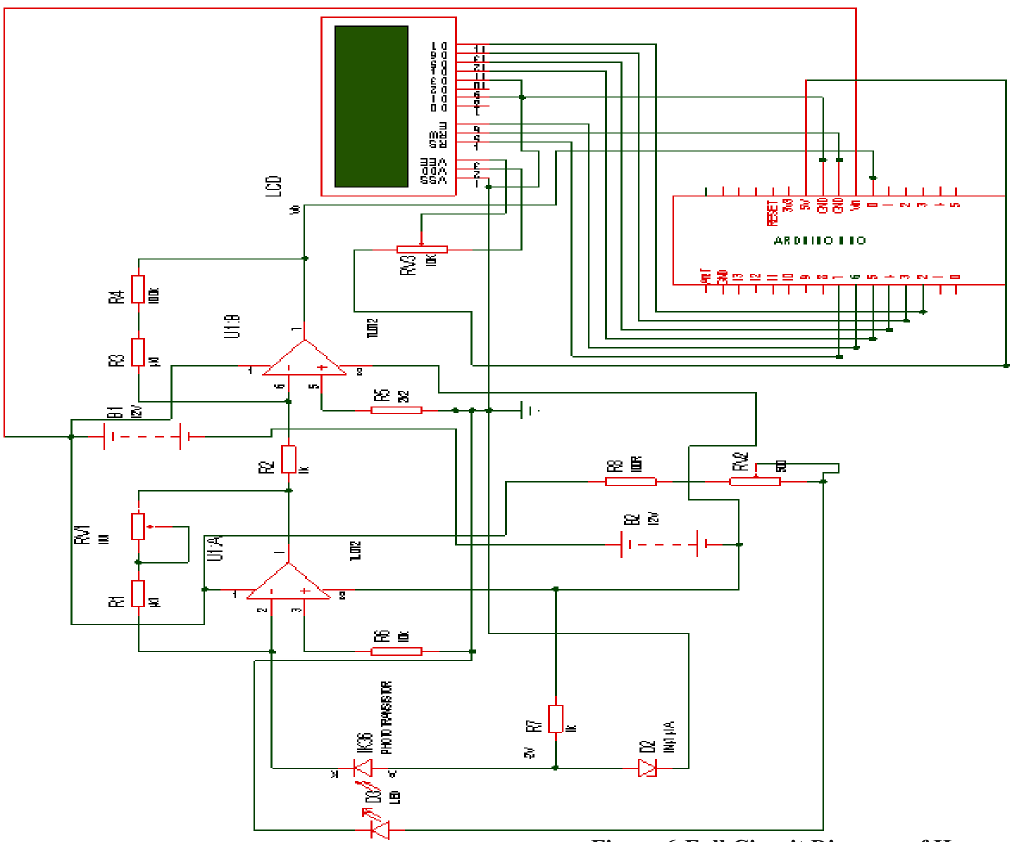

Figure 6:Full Circuit Diagram of Haemoglobin Meter

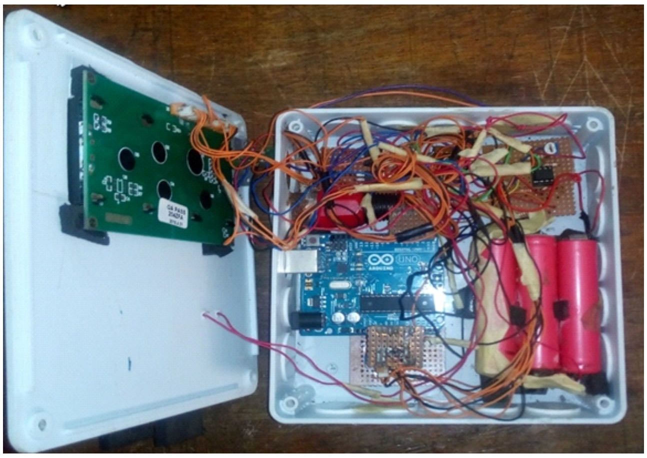

Figure 7: Internal Wiring of the Developed Haemoglobin Meter

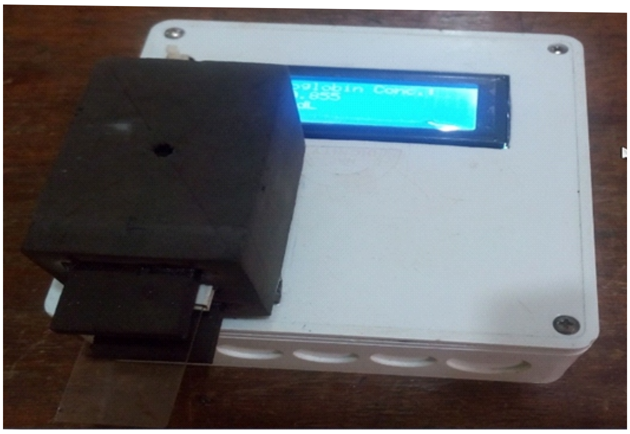

Figure 8: Pictorial View of the Developed Haemoglobin Meter

RESULTS

The haemoglobin (Hb) test was carried out for several patients and the results obtained from some of them areas shown in Table 1.

Table 1: Comparison Table of Hb between the Standard and the Developed Haemoglobin Meter

Samples	standard Hb (g/dl)	measured Hb (g/dl) for Green	measured Hb (g/dl) for Blue
A	8.840	8.345	8.071
B	9.860	9.548	8.891
C	10.200	10.080	9.970
D	10.540	10.441	9.958
E	10.880	10.245	10.151
F	10.880	11.071	10.881
G	10.880	11.011	10.777
H	10.880	10.818	10.721
I	11.220	10.631	10.941
J	11.220	11.124	10.763

DISCUSSION

The results obtained from the experiments were computed and were transformed into graphs. Figures 9 and 10 represent the calibrated graphical results of the available with the developed haemoglobin meter with the blue and green LEDs respectively. The validity of the device was tested by finding the percentage absolute deviation, standard error and the P-value. It was observed that the green LED follows the standard system more than the blue LED. The percentage absolute deviation was calculated as 0.3% (green) and 0.5% (blue). The percentage error was 0.01% for both LEDs which indicate that the developed system is relatively accurate when compared with the standard. The correlation is 0.9758 (available and blue) and 0.9757 (available and green) which indicates a good result as seen from the graphs in figures 9 and 10 respectively. The P-value obtained is 0.3491(blue) and 0.1333(green) which follows the scientific value (Nuzzo, 2014) that the P-value should be greater than 0.05 significant levels. The average deviation was also calculated as 0.2572 (green) and 0.4677 (blue). The haemoglobin values used as standard for comparison in this work were obtained indirectly by dividing the PCV values obtained from a standard measuring instrument by 3. Since the standard values were obtained indirectly, the difference in the values obtained between the standard and the developed could account for the little variation between the standard and the measured (blue and green) values.

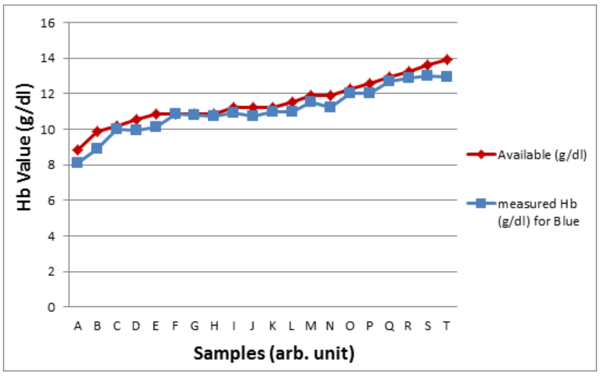

Figure 9: The Calibration Curve for Sample-Haemoglobin Values for the available Instrument and the Blue LED

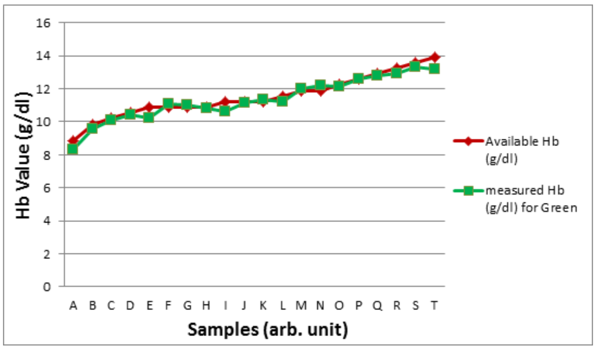

Figure 10:The Calibration Curve for Sample-Haemoglobin Values for the Available Instrument and Green LED

Conclusion

This work has produced an instrument that can detect and measure the haemoglobin level in the body within the range of 4g/dl – 25g/dl using 470nm and 570nm as its wavelength. The principle of Beer Lambert's law was used and it was calibrated by comparing the developed instrument with a standard one. The results showed that the haemoglobin level for the LEDs developed instrument is proportional to the available system with P-value greater than 0.05 and the percentage error of 0.01% for both LEDs. The device performed favourably well and can be recommended for haemoglobin level test in the laboratory.

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