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REVIEW ARTICLE **OPEN ACCESS**

Heart rate and laser based blood glucose monitoring system for early diagnosis of diabetes

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ABSTRACT
In recent years, diabetes is one of the reasons for leading causes of the deaths. Current blood glucose monitoring (BGM) techniques require a finger prick blood sample, a repetitively painful process that creates the risk of infection. In order to avoid diabetic complications due to abnormal blood glucose levels, a non-invasive BGM is required. Heart Rate has a significant relationship with diabetes. Laser light based monitoring systems have demonstrated a superior potential for BGM. Existing near-infrared (NIR) based BGM techniques have shortcomings, such as the absorption of light in human tissue, higher signal-to-noise ratio, and lower accuracy, and these disadvantages have prevented NIR techniques from being employed for commercial BGM applications. A simple, compact and cost-effective non-invasive device using laser light for BGM is implemented The laser light BGM monitoring device has three major technical advantages over NIR. Unlike NIR, red laser light has30 times better transmittance through human tissue. Red laser light also demonstrates both higher linearity and accuracy for BGM. The designed BGM device experimental results have to be identified to ensure the accuracy and precision of the proposed BGM system along with the heart rate monitoring system.
Keywords: Blood glucose, laser, heart rate, diabetes, non-invasive, continuous monitoring

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INTRODUCTION

Non-invasive monitoring is the process of monitoring parameters without taking blood samples. It will be a cost effective and time saving technique. There is less chance of infection. Here, glucose level and heart rate are monitored using arduino by the non-invasive method. The statistics in 2018 said that 34.2 million Americans, or 10.5% of the population, had diabetes and nearly 1.6 million Americans have type 1 diabetes, which includes about 187,000 children and adolescents. Undiagnosed are of the 34.2 million adults with diabetes, 26.8 million were diagnosed, and 7.3 million were undiagnosed. In 2019 statistics, the ninth leading cause for death happens by diabetes with an estimated 1.5 million deaths. We can say that a healthy diet, regular physical activity, maintaining a normal body weight and avoiding tobacco helps to prevent or delay the onset of type 2 diabetes. Treatment and its consequences can be avoided by the help of regular screening and treatment for complications.

Heart disease is the leading cause for death. According to the Centers for Disease Control and Prevention (CDC) approximately for every 40 seconds an American will have a heart attack. According to 2018 statistics from healthline, 30.3 million U.S. adults were diagnosed with heart disease. Every year, about 647,000 Americans die because of heart disease. One of the behavioural risk factors of heart disease is increased blood glucose level. Identification of people with high risk of cardiovascular disease is important. They have to receive treatment at an early stage to prevent premature deaths. National Health and Nutrition Examination Survey from 2013 - 2016 data estimated that about 26 million adults are diagnosed with diabetes. (Salim S et,al)Among adults with diagnosed diabetes in NHANES 2013 to 2016, 9.9% had a hemoglobin A1c ≥10.0%, and this was more prevalent among adults 18 to 44 years of age (16.3%) than adults ≥65 years of age (4.3%).

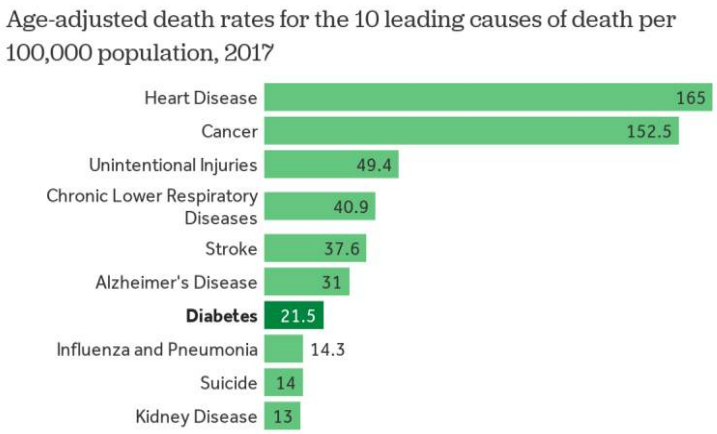

Figure.1 Diseases and mortality rate (Courtesy: https://img.datawrapper.de/sUTY8/full.png)

Heart disease is the leading cause for the death and diabetes is also one among 10 diseases which cause leading death according to figure 1.1. So monitoring both heart rate and glucose will be a better indicator to prevent death and helps in early diagnosis. Treatment can also be done correspondingly. Hyperinsulinemia and elevated blood glucose levels have both been associated with a higher heart rate. The researchers found that heart rate was correlated with type 2 diabetes incidence, as those with heart rates of more than 86 beats per minute(bpm) or with 80 bpm - 86 bpm or 73 bpm - 80 bpm or 67 bpm - 73 bpm were all at greater risk for developing diabetes than those with heart rates of 67 bpm or lower.

BACKGROUND

Less expensive, non-invasive method has been considered here. It will be suitable for continuous blood glucose monitoring. We are using a semiconductive diode laser as an optical source for monitoring. When electromagnetic radiation with such wavelengths irradiates the skin, light is transmitted through the skin to the blood vessel, where it interacts with the heterogeneous components of the blood. Then there is a diffusion reflection of the blood light, which reaches the blood. The reflected light will be modulated by the characteristic vibrations of the molecules, which are the main components of the blood.

MARKET ANALYSIS FOR NON-INVASIVE BGM DEVICES

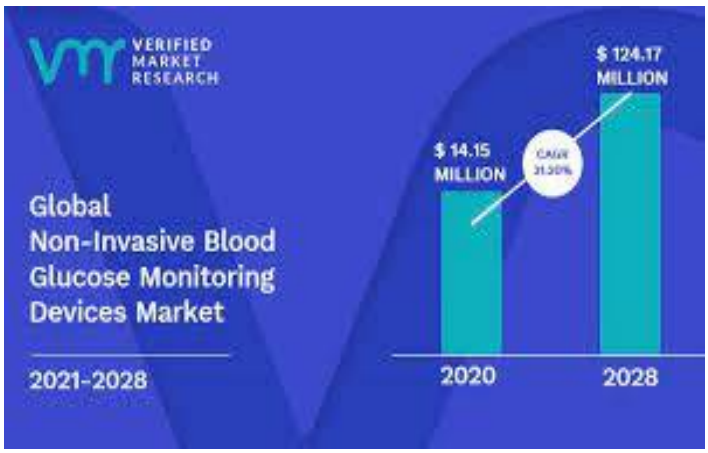

Figure.2 Non-invasive blood glucose monitoring devices market(Courtesy:https://www.verifiedmarketresearch.com/product/non-invasive-blood-glucose-monitoring-devices-market/)

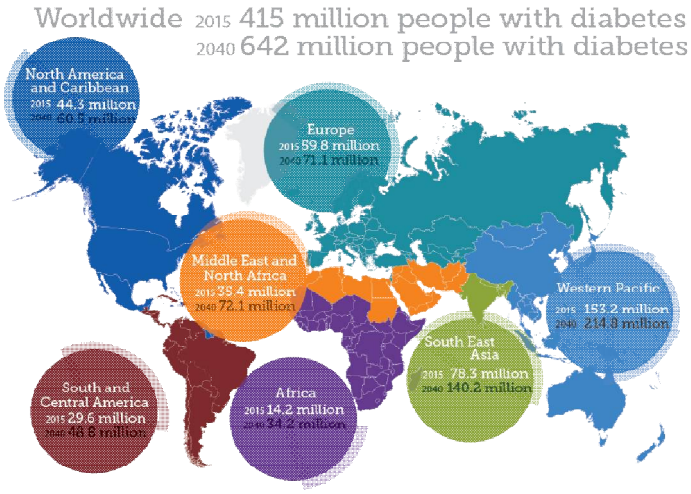

Figure.3 Diabetes prevalence in world(Courtesy: https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTR-iHgb4c1f82yMxqg6Yv4X_HkP7fkv3A2gy8FFp0Fvb9yRKjRpfluOgv_dx5bhov_FpI&usqp=CAU)

DESCRIPTION

Human blood sugar consists of D-glucose that exists mainly in the water base of blood plasma in terms of chemical composition. The daily variation of glucose concentration in the human body ranges from 60 - 160 mg/dl. Arterial and Capillary blood from the fingertip have an identical glucose content, while the glucose level of venous blood is lower than the corresponding arterial blood value (1 - 17 mg/dl in healthy subjects and up to 30 mg/dl in diabetic patients). Blood glucose is also present in other biofluids such as intracellular fluid, interstitial fluid, humour, saliva, sweet and urine. In the steady state condition, the glucose level in the intracellular and interstitial fluid is identical with the concentration of glucose in the blood. The glucose level in humour correlates strongly with the glucose content of blood, while the glucose level in saliva, sweet and urine does not. The basic energy source for cellular metabolism is glucose. Glucose concentration varies between different regions and in different parts of the blood. When there is an increase in glucose concentration of plasma, the initial response is water movement from ISF to plasma; then the glucose diffuses into the ISF, where it is used as an energy source by the cells. Due to these gradients, the glucose concentration in tissues is not constant.

Diabetes or Diabetes Mellitus occurs when someone has abnormal blood sugar content in their body. There are two major types of diabetes: (1) Type 1 diabetic patients, diabetes occurs due to the autoimmune destruction of the insulin producing beta cells in the pancreas whereas in (2) Type 2 diabetics the diabetes mellitus occurs from the insulin resistance and relative insulin deficiency. Diabetes may cause other serious secondary health problems such as blindness, stroke, kidney failure, Ulcers, Infections, obesity and blood vessels damage among other health complications.

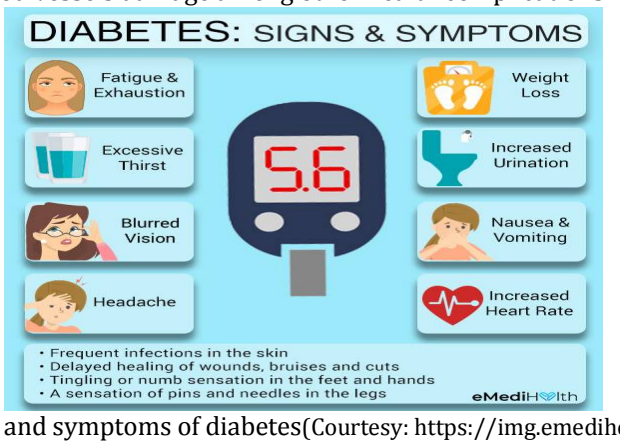

Figure.4 Signs and symptoms of diabetes(Courtesy: https://img.emedihealth.com/wp-content/uploads/2019/09/diabetes-signs.jpg)

According to the International Diabetes Federation (IDF) the number of diabetes patients in 2011 was 366 million worldwide and this number is expected to rise to 552 million by 2030. There are two methods in measuring blood glucose level. They are invasive and noninvasive methods. Invasive methods involve the sampling of the patient's blood and the glucometer device. Both are finger pricking processes. These methods are painful and can cause infectious diseases. Invasive techniques require a blood sample which is currently extracted from the fingertip using a lancet. This method of determining blood glucose

is currently the most commonly used technique and is a highly accurate method for blood glucose monitoring. Minimally invasive techniques involve attaching electrodes to the skin tissue. This method is not preferred due to its low accuracy and poor signal to noise ratio (SNR) even though this electronic method reduces the chances of infection and minimizes the pain. The latest advances introduced to the field of BGM are non-invasive technologies to detect blood glucose concentration using body secretions such as sweat, urine, saliva or tears. But continuous monitoring is not possible by the latest methods. Besides these secreted fluids glucose concentration is also measured in the skin, earlobe using non-invasive techniques. Therefore, non-invasively and continuous blood glucose measurement methods are needed. Non-invasive methods include optical methods, microwave waves, health apps, freestyle libre patches. Measurement using body fluids is also a non-invasive method. Optical methods are highly preferred, some techniques are Infrared spectroscopy, Raman spectroscopy, photoacoustic, fluorescence, polarimetric, and so on [3]. Electromagnetic sensing has the limitation that Temperature has a strong effect on this form of measurement, because it influences the optimal investigation frequency. Infrared LED source with wavelength range 700 nm – 1 mm is highly preferred because of its absorption with glucose in blood. It radiates the body and the reflected light from the body is absorbed by a photodiode sensor. Blood glucose level is determined which is based on comparison of radiation intensity before and after interactions [4]. MIR has limitations of poor penetration. MIR-based detection methods can only be implemented in reflective mode, due to the much weaker ability of MIR light to penetrate tissues [5].NIR presents some disadvantages, including a higher degree of scattering in the tissue and interference of proteins and acids that share similar absorption features with the glucose molecule, leading to increased complexity and unreliability when analyzing the detected signal[6].Raman spectroscopy has shortcomings that differences in skin tone, skin thickness, basal metabolic rate and hydration status frequently lead to non-linear variances in glucose concentration between dissimilar individuals and diverse parts of the body [5]. Prone to interference from other molecules such as haemoglobin. Bioimpedance Spectroscopy (BS) has limitations that are Sensitive to variations of temperature and motion. Sensitive to sweat and to water content. Affected by physiological conditions affecting the cell membrane. Therefore, a non-invasive continuous monitoring system with the help of laser source was developed for glucose level detection.

METHODOLOGY

DESCRIPTION

Glucose has several absorption peaks. The glucose content in the dermis layer is the amount of blood glucose content. The concentration of glucose can be determined by photos absorbed; this results in an increase of light intensity. Here they choose the principle of absorbance transmittance photometry. Intensity of light leaving the matter is used as an indication of concentration of glucose content. Here they choose the scattering property because they have a direct effect on glucose. The method is passing a red laser light through the finger and the amount of light reaching the detector on the other side is measured. The presence of glucose blocks the light from passing through the finger. The blood glucose presence can be measured by analyzing the variations present in the light intensity.

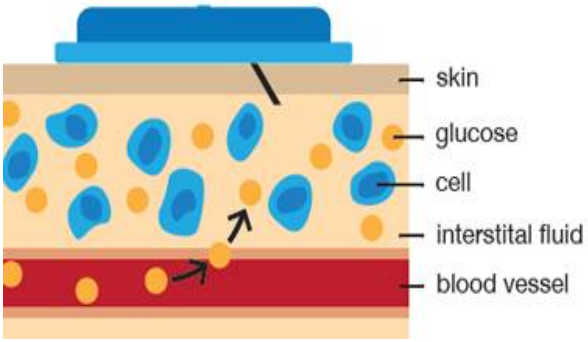

Figure.5 Skin anatomy

(Courtesy: https://www.ndss.com.au/wp-content/uploads/images/fact-sheets/flash-gm-interstitial-400px.png)

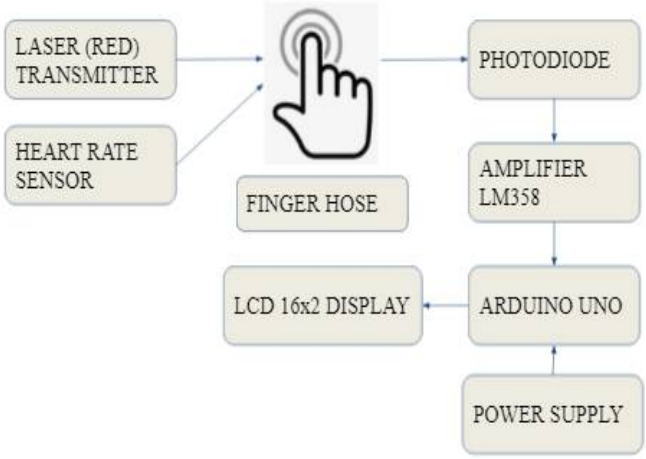

Figure 6. Block diagram

WORKING

There will be a RED LASER light source, it sends the light of range 700 nm – 1mm. This light interacts with the finger in the hose and light will be scattered from the blood having less concentration of glucose. The scattered light will be received by the detector which is a photodiode. It receives the input in the form of volt that is analog value. Driver circuit is placed which will amplify the obtained signal from the photodiode. The amplified value is given to the arduino board and through the arduino IDE, analog voltage is converted to glucose level. Now the glucose value will be displayed in the 16x2 display. For heart rate monitoring, the heart rate detector MAX20323 will detect and send to the driver circuit. This again will amplify the value and give to the arduino board and finally heart rate will be displayed in 16x2 LCD.

The design consists of LASER light source, photo diode, power supply, arduino UNO board and LCD. When power supply is given the laser starts sending the light source and the photodiode receives it. Received signal is given to the arduino UNO for processing it. After converting analog to digital, the LCD displays the glucose level if the patient kept the finger in the light having a hose or it displays the heart rate when the patient kept the finger in the heart rate monitoring sensor.

COMPONENTS

- Glucose detector
- Heartbeat sensor
- Arduino UNO
- LCD (16 x 2)
- Step down transformer
- Power Supply
- LM358 amplifier
- Voltage Regulator - IC 7805
- Capacitors
- Resistors
- Transistors
- Bridge rectifier

GLUCOSE SENSOR

Continuous glucose monitoring automatically monitors blood glucose levels (blood sugar) throughout day and night. It helps in analyzing the variation in glucose level over a few hours to days. Analyzing glucose levels in real time helps to make more informed decisions throughout the day about how to balance food, physical activity, and medicines. This will be a support system for diabetic people.

SEMICONDUCTOR PHOTODIODE LASER

A diode laser is a semiconductor device which converts optical energy into electrical energy. White light is made up of all the colours of the visible light spectrum. This is a very wide band of many different frequencies. Ordinary LEDs will give a light output consisting of one colour. Even that light will contain electromagnetic waves covering quite a wide band of frequencies. The light from diode lasers is coherent and emits a very narrow beam. This laser module has a transmitter and receiver which are placed side by side for a reflective surface. Both will operate at 5V, powered by a microcontroller(Arduino). The laser diode is used to measure continuous wave fiber light source and convert the optical power from the

transmitter to an electrical current value. A semiconductor laser (LD) is a device that causes laser oscillation by the flow of an electric current to a semiconductor. The mechanism of light emission is the same as a LED. When the two meet at the junction, an electron drops into a hole and light is emitted at the time. The electrons from n- region and the holes from the p- region cross the junction and recombine with each other when a p-n junction diode is forward biased. During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductor like Ga-As.

Current blood glucose monitoring (BGM) techniques are invasive as they require a finger prick blood sample, a repetitively painful process that creates the risk of infection which may also take time for testing of the sample. Glucose molecules have the ability to vary the refractive angle of light to an extent proportional to its concentration, and the overall refractive index of a given media. Estimation using refraction is based on the principle of Snell's law and the magnitude of each parameter is related to the concentration of glucose in the aqueous solution. According to Snell's law, the refractive angle is inversely proportional to the concentration of glucose in the aqueous sample. The light ray tends to incline towards the normal ac and decreases the refractive angle as the glucose concentration increases hence more photons strikes the photo-transistor.

HEART BEAT Sensor

A heart beat monitor (HBM) for calculating the heart rate signal and measures the beats per minute (bpm). It helps in analyzing the information of heart condition. For detecting the heart signals, the HBM devices employ electrical and optical methods. Normal heart rate of a healthy adult at rest is 72 bpm. Small babies have a higher heartbeat (120 bpm) compared to older children (90 bpm). During exercise heart rate increases. It comes back to normal after finishing the exercise. If the heart rate is lower than the normal heart rate, it is an indication of bradycardia, if it is higher it is tachycardia.

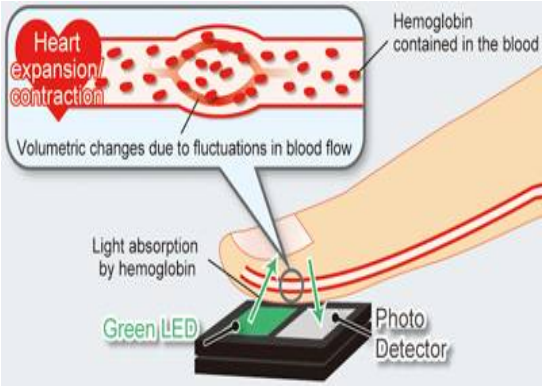

Figure.7 Pulse sensor optical detection

(Courtesy: https://www.rohm.com/image/image_gallery?uuid=c9855b85-63d6-4345-9aec-7c413d492016&groupId=11308&t=1486756421559)

Here, it is a reflective type pulse rate sensor. This has an infrared transmitter which emits infrared rays called an IR Transmitter. For receiving the signal, photodetector is used.

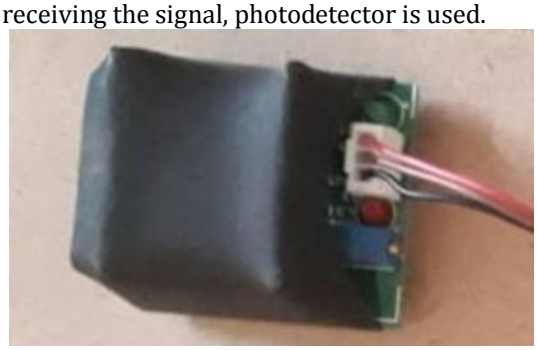

Fig.8 Heartbeat detector

The IR transmitter and receiver are placed in the pulse rate sensor. When you want to measure the pulse rate, the pulse rate sensor has to be clipped in the finger. The IR receiver is connected to the Vcc through the resistor which acts as a potential divider. The potential divider output is connected to the amplifier section. When supply is ON the IR transmitter passes the rays to the receiver. Depending on the blood flow, the IR rays are interrupted. Due to that IR receiver conduction is interrupted so variable pulse signals are generated in the potential divider point which is given to low pass filter through the capacitor C1. The coupling capacitor C1 is used to block the DC component because the capacitor reactance

depends on the frequency. For the DC component the frequency is zero so the reactance is infinity now the capacitor acts as an open circuit for the DC component.

ARDUINO UNO BOARD

The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc as shown in figure 3.4. Along with ATmega328P, it also has a crystal oscillator, serial communication, voltage regulator, etc to support the microcontroller. Arduino is an open source microcontroller in which a program can be easily created, erased and reprogrammed. Arduino uses the hardware as the arduino development board and software for developing the code known as arduino IDE (integrated development environment). This program can be done by c or c++ language in software. Coding to board happens through the USB cable port.

Figure.9 Arduino UNO board

The Arduino Uno is powered via the USB connection or with an external power supply. External (non-USB) power may come either from an AC-to-DC adapter (wall-wart) or battery.

Figure.10 ARDUINO IDE

The board is equipped with sets of digital and analog input/output pins that may be interfaced to various expansion boards and other circuits. It has 14 digital input/output pins. It consists of 14 digital input/output pins, 6 analog input pins, a USB connection, A Power barrel jack, an ICSP header and a reset button.

LIQUID-CRYSTAL DISPLAY (LCD)

LCD is a flat-panel display or electronic visual display which uses the light-modulating properties of liquid crystals. Liquid crystals will not emit light directly. This is to display arbitrary images or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and 7-segment displays as in a digital clock.

Figure.11 Liquid crystal display

STEP DOWN TRANSFORMER

For converting high primary voltage to secondary voltage a step down transformer is used. Here, the primary winding of a coil has more turns than the secondary winding as shown in figure 3.7.

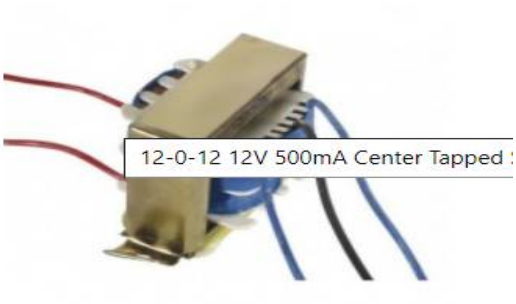

Figure.12 Step down transformer

The Transformers work based on the principle of "Faraday's law of electromagnetic induction". Mutual induction between the windings will be responsible for transmission action in a transformer. Faraday's law states that "when the magnetic flux linking a circuit changes, an electromotive force is induced in the circuit which will be proportional to the rate of change of the flux linkage". The number of turns in the primary and secondary winding will determine the emf (ElectroMotive Force) induced between the two windings.

POWER SUPPLY

The ac voltage, typically 220V rms, is connected to a transformer, which will step that ac voltage down to the level of the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage.This resulting dc voltage usually has some ripple or ac voltage variation. A regulator circuit removes the ripples and also remains the same dc value even if the input dc voltage varies. This voltage regulation is obtained using one of the popular voltage regulator IC units.

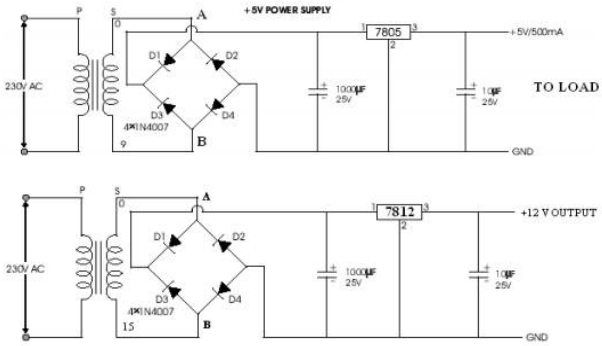

Figure.13 Schematic diagram of power supply

The Microcontroller used requires 12v D.C supply. The Receiver used requires 5v D.C. So, design of these regulated power supplies is also an important part in hardware design. For design of a regulated power supply components used are:

- Transformer
- Diodes
- Rectifiers
- Regulated IC chips
- Capacitive filters

CIRCUIT DIAGRAM

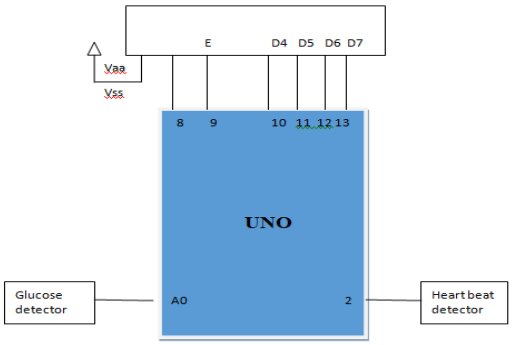

Figure.14 Pin diagram

RESULTS AND DISCUSSIONS

Current blood glucose monitoring (BGM) techniques are invasive as they require a finger prick blood sample and for continuous monitoring repetitive pricking has to be done and it is a painful process that creates the risk of infection.

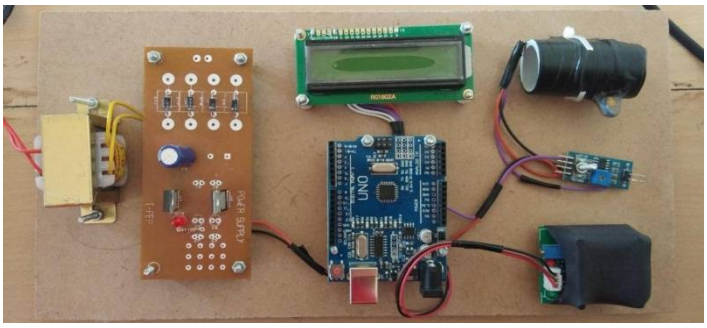

Figure.15 Product setup

Existing near-infrared (NIR) based BGM techniques have shortcomings, such as the absorption of light in human tissue, higher signal-to-noise ratio, and lower accuracy. These disadvantages are overcome by semiconductor photodiode laser techniques from being employed for commercial BGM applications. Our setup is shown in figure 4.1. Unlike NIR, red laser light has 30 times better transmittance through human tissue. Furthermore, when compared with NIR, the refractive index of laser light is more sensitive to the variations in glucose level concentration resulting in faster response.

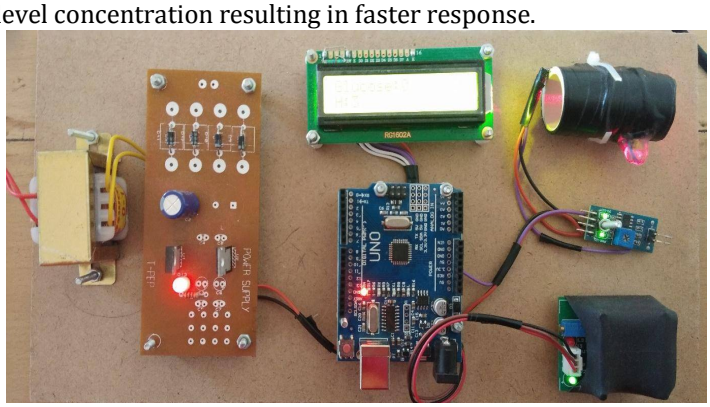

Figure.16 Experimental result

Red laser light demonstrates both higher linearity and accuracy for BGM. Further accuracy can be tested for both in vitro and in vivo cases to ensure the accuracy and precision of the proposed BGM sensor. Figure 4.2 is the view during working. Power supply was received as alternating current and it was converted to direct using step down transformer rectifier circuit. Driver circuit was placed after the glucose sensor for amplification. Our sensors (glucose and heart rate) got the power supply. While keeping the finger in the hose (glucose sensor) or in the heart rate sensor, respected outputs were displayed in LCD.

CONCLUSION

A CGM does not actually measure blood glucose levels, it measures the amount of glucose in the fluid that surrounds the body cells called interstitial fluid. The glucose level in humans can be detected by non-invasive methods by passing a light source instead of using a blood sample. This will not affect the comfortable behaviour of people. This testing group included both healthy and diabetic patients. The results of the BGM hand held device were checked for accuracy. The semi-conductive photodiode laser light of 1mm to 3mm wavelength used for non-invasive BGM. This semi-conductive photodiode laser of 1mm to 3mm wavelength has 30 times higher transmittance through both water and human finger as compared to NIR laser light. In-vitro experimental results proved that increasing glucose concentrations in the aqueous solution decreases the refractive angle of the laser light rays and in turn maximizes the intensity of the laser light falling on the photo-sensor which correspondingly increases the output voltage. The suitable wavelength for BGM is determined experimentally by measuring the transmittance and absorbance of different wavelengths ranging from 500nm to 1200nm. The results concluded that the absorption of laser light differs with the wavelength. The highest absorbance wavelength from 700 nm to 1000nm makes it suitable for BGM application. So according to the discussion, we can say that we are getting an approximate glucose level using diode laser. Heart rate sensor is giving accurate output. There is a small time delay when checking the glucose level, especially after eating or if during exercising. So the

CGM result is not always similar to the finger-prick result. Therefore, there is a need to do a finger prick test if thinking of changing the treatment at any point like if need to take more insulin or if treating a hypo, so can get the most accurate result. Further testing on a large population has to be done for various conditions to analyze the efficiency of the device. After that we could identify a successful technique. A continuous glucose monitor should be a small device that people will feel comfortable with and it should not affect regular activities. It measures glucose (sugar) levels continuously throughout the day and night, which lets to see trends in levels and alerts when it become high and low. The information can be viewed with the help of a display device using Bluetooth. The information collected about blood sugar levels can be accessed instantly by transmitting the data to healthcare professionals and they can review. It helps in planning the person's treatment accordingly. It also means that the information can be shared easily during virtual appointments with the healthcare team.

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