Design and Implementation of Portable Noninvasive Diabetic Ketoacidosis Detector

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الإهداء

إلى معلمنا وقائدنا وقدوتنا وحبيبنا وشفيعنا محمد صلى عليه وسلم.
إلى من رسموا بدمائهم خارطة الوطن وطريق المستقبل وهندسوا بأجسادهم معالي العزة
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عن شكرها
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Abstract

The idea of this project is to design a device that has the ability to deal with a special case of diabetes "type one" which called Diabetic Ketoacidosis (DKA) bout, which happens when the glucose level in the patient's body increased suddenly.

When the patient have an insulin deficiency and the glucose level in his body increased suddenly, the amount of glucose in his blood will increased to abnormal range and at the same time the amount of glucose inside of the cell will decreased, so the body attempt to produce energy by broken the fatty acids and the proteins. According to that process the broken of fatty acids will release a small parts of keton bodies. The huge amount of keton bodies will produce some physiological abnormalities such as increasing in blood Ph, spell, increasing in respiratory, heart rate and exit acetone ketones via patient exhalation.

Several studies demonstrate that patients with DKA have complex metabolic abnormalities and manifest, like high acetone concentration, low carbon dioxide concentration in exhaled breath, increase in heartbeat and respiratory rate. By monitoring these physiological parameters DKA bout can be early detected.

When the patient fells the previous symptoms, he will use the device to make sure of his health status, where it will measure the concentration of CO_2, the respiratory and the heart rate, after that it will display the readings on LCD screen and then will compare them with reference values in the arduino, and if the readings are abnormal the device will active a buzzer with a red light to be signs of emergency case (DKA). The device has voice commands that give the necessary instructions to the patient during the diagnostic, also, mentions the final diagnostic result.

الملخص

تحدث نوبات حماض السكر الكيتوني (Diabetic Ketoacidosis) نتيجة لارتفاع مستوى السكر في الدم، وعادة ما يحدث ذلك نتيجة عدم المواظبة على أخذ العلاج بالأنسولين، و تعتبر من أهم المضاعفات الحادة للنوع الأول من السكري والتي قد تؤدي للوفاة في حالات عديدة ، وتبلغ نسبة حدوثها 100-200 حالة لكل 10000 مريض مصاب بالسكري، وتزيد النسبة في المراهقين أكثر من الأعمار الأخرى نتيجة عدم مواظبتهم على العلاج.

نتيجة الارتفاع العالي لنسبة السكر في الدم والنقص في كمية الأنسولين يزداد السكر في الدم، وفي نفس الوقت يقل السكر داخل الخلية، ولإحتياج الجسم للطاقة فإنه يقوم بتكسير البروتينيات والدهون لإنتاج الطاقة ، وعند تكسر الدهون فإنها تتحول إلى الأجسام الكيتونية (Keton bodies)، ومع التكسر العالي للدهون ترتفع نسبة الكيتونات في الدم بسرعة، كما لا يمكن التخلص منها بسهولة، لذلك تظهر الأعراض المرضية ومنها : الغثيان ، ألم في البطن ، إزدياد حدة وسرعة التنفس ويكون غير طبيعي مع التوقف المستمر للتنفس وتكون رائحة الفم سيئة و يصاحب ذلك ازدياد سرعة دقات القلب واذا استمرت الحالة فقد تودي للغيبوبة.

تقوم الفكرة الرئيسية للمشروع على تصميم جهاز لدية القدرة على التعامل والتنبؤ المبكر بنوبة حماض السكر الكيتوني ، ويعتمد التنبؤ المبكر بحماض السكر الكيتوني على استخدام مجموعة من المجسات (sensors) التي تستخدم لقياس مقدار التغير الموجود في جسم الانسان لمجموعة من العلامات الفسيولوجية . حيث أنه تم استخدام (Temperature and CO_2 sensors) للاستشعار بمقدار كمية (CO_2) الخارجة مع زفير المريض وحساب معدل التنفس من خلال وضعهما على قناع يثبت على فم المريض ، وسيتم استخدام مجس لقياس عدد نبضات القلب للمريض بحيث يوضع هذا المجس على الاصبع .

عندما يشعر المريض بالاعراض المرضية التي تم ذكرها سابقا فإنه يقوم باستخدام الجهاز للتأكد من حلته الصحية، حيث يقوم الجهاز بقياس تركيز (CO_2) الخارجه من الفم و معدل التنفس و معدل نبضات القلب. بعد ذلك يقوم الجهاز بعرض القراءات التي حصل عليها من المجسات على شاشة مرفقة (LCD)،ومن ثم يعمل على مقارنة القيم التي حصل عليها مع قيم مرجعية مخزنة داخل (Arduino) ، فاذا تجاوزت القيم التي حصل عليها عن القيم المخزنة فان الجهاز يطلق انذاراً وضوء أحمر وهو عبارة عن مؤشر لدخول المريض لنوبة حماض السكر الكيتوني ، ليقوم بعدها المريض بأخذ العلاج المناسب عن طريق جرعات من الانسولين والبوتاسيوم. يحتوي الجهاز على خاصية التعليمات الصوتية التي تعطي للمريض الارشادات اللازمة اثناء عملية الفحص وأيضا ذكر نتيجة الفحص النهائية.

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List of Abbreviation

Abbreviation	Full Meaning
DKA	Diabetic Ketoacidosis
CO_2	Carbon Dioxide
HR	Heart Rate
PPM	Part Per Million
BPM	Beat Per Minute
PPB	Part Per Billion
IR	Infra Red
Op-Amp	Operational Amplifier
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
LED	Light Emitted Diode

Chapter One
Thesis Overview

Chapter One

Thesis Overview

Diabetes is a condition of elevated blood sugars where the body does not produce enough insulin to meet the body's needs, or the body does not respond properly to the insulin being made, there are two main kinds of diabetes mellitus: type 1 diabetes and type 2 diabetes. More than 90% of all people with diabetes have type 2. There is a special case of diabetes "type one" which called Diabetic Ketoacidosis (DKA) bout. This bout happen when insulin defective, which leads to increase release of fatty acids and glycerol, but unfortunately the most common methods to check and detect this bout are manual and invasive (by blood and by urine). These traditional methods involve a lot of drawbacks such as punctuating a patient taking a lot of time to get the result. .

1.1 Project Idea Description

In this project a portable noninvasive diabetic ketoacidosis detector will be designed and implemented, this device will read the respiratory rate, CO_2 concentration and number of heart rate beat and then send these data to the microcontroller system, this system is connected to the voice commands system and display the processed data on the LCD, and connected with alarm system that will be activated when the data excess the threshold amount memorized in the system, which enable the patient to treat by take a suitable amount of insulin, or visit doctor.

1.2 Project Motivation

Most people don't notice an increase in the DKA. Early detection and treatment are the keys to avoid serious symptoms that may cause comma within hours

if the DKA suddenly increased. In addition this technique helps kidney patient failure to avoid being subjected to DKA during dialysis.

A reliable, noninvasive diagnostic method will be invented to impose less physical and financial burden on patients who suffer from DKA bout, and protect the patient from the DKA side effects.

1.3 Project Aims

The main objectives of this project can be summarized as follow:

- Help patients with DKA to know CO_2 concentration, respiratory rate and heart beat rate.
- Aid the patient to treat this bout when it happens by taking a convenient amount of insulin.
- Help seniors and young who face different problems in dealing with traditional way that need blood sample or urine sample.

1.4 Literature Review and Related Work

Our project study comes to accomplish a lot of previous studies that include different techniques of early detect of DKA bout. Also the existing previous design like reading the acetone concentration invasively depends on take a blood sample or by urine, and using capnography device for reading the CO_2 concentration by patient breath.

Several scientific papers were published in different journals related of DKA bout and DKA sensors, one of these articles "Nanosensor Device for Breath acetone Detection", this paper describes a sensor nanotechnology suitable for non-invasive

monitoring of a signaling gas, such as acetone, in exhaled breath. This is a nanomedicine tool comprised of a selective acetone nanoprobe working on the principle of ferroelectric poling sensing, and a microelectronics circuit for comparing the actual sensor signal to a predetermined threshold value. These characteristics make the sensor an appropriate choice for designing a microsystem. The concentration of acetone in exhaled human breath normally falls within the range (0.3 to 0.9 ppm). In particular, at 1.8 ppm, this is set as DKA threshold, and this value is used in the breath analyzer design. This sensor was developed at the research group of L. Wang in the Department of Chemistry at the University of British Columbia.

In the other hand, the article of "Predictive Value of Capnography for Suspected Diabetic Ketoacidosis in the Emergency Department" explain the amount of CO_2 will exhaled by the patient, so this paper talk about the amount of normal range of CO_2 in exhaled breath is (35 to 45 mmHg), meanwhile in the DKA case the CO_2 will decrease to 24.5 mmHg.

In addition, the article of "Management of hyperglycemic emergencies" explains the number of heart rate per minute in hyperglycemia case, electrocardiogram (ECG) showed sinus tachycardia at about 120 beats per minute.

Moreover, the article “Noninvasive monitoring capnometry for continuous monitoring of metabolic status in pediatric diabetic ketoacidosis (DKA)”, shows that the relation between the respiratory rate and the amount of exhaled CO_2, where the respiratory rate of the DKA patient will increase to 35 bpm. So the continuous end-tidal CO_2 monitoring can be used as a noninvasive assessment of the metabolic status of the pediatric patient in DKA.

1.5 Economical Study

This section lists the overall cost of the project components that are considered in implementing this system.

Table (1.1) contains the main required hardware components of the project design, and its estimated cost.

Table (1.1): Estimated Component Cost.

Type	Price	Quantity
1- Arduino Mega & Uno	70 JD	1
2- CO_2 sensor	70 JD	1
3- Heart rate sensor	50 JD	1
4- Amplifiers, transistors	20 JD	4
5- Resistors, capacitors, ,wires ,solders	10 JD	(10,4,20)
6- Battery	40 JD	1
7- MP3 shield, SD card, headphone	50 JD	1
	Total Price = 310 JD	

1.7 Schedule Time

In this section we make a plan for the predictive project tasks due to the time zone of both coming semesters, this time plan shown in the table (1.3) and table (1.4).

Table (1.2): Timing Schedule of the First Semester.

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Collect Information															
Basic Design															
Specification Design															
Documentation															
Advance feature															

Table (1.3): Timing Schedule of the Second Semester.

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Full Designing															
Purchasing the components															
System implementation															
System analysis															
Documentation															

Chapter Two
Diabetes Pathophysiology

Chapter Two

Diabetes Pathophysiology

Diabetes mellitus commonly known as “diabetes” is a common health problem throughout the world. There are different pathological cases that can be diagnosed as a diabetic’s disease, in some cases the body –pancreas– can’t able to produce insulin or produce defective insulin or sometimes the body cells have no ability to accept insulin. The main function of this hormone -insulin- with other hormone also produced by the pancreas which is called Glucagon is to permit that the blood glucose concentration still within the normal range [80-110mg/dL]. This chapter talks about pathophysiology of diabetes disease including its types, effect of glucose variation in the blood, and Diabetic Ketoacidosis (DKA).

2.1 Types of Diabetics

According to the World Health Organization statics [1], the global prevalence of diabetes mellitus is approximately 155 million people and expected to increase to 300 million in the year 2025. Generally, this disease consists from two main types which are type 1 (insulin-dependent) and type 2 (non–insulin dependent). Type 1 is caused by a β cells injury, which leads to an absolute deficiency of insulin, and type 2 is caused by either a disturbed secretion of sufficient insulin from the β cells or a failure of insulin to carry out its important tasks. Type 1 diabetes is therefore related to a relative shortage of insulin, while type 2 is often treated with a diet, type 1 diabetes is always treated throw the administration of insulin. Our interest in this project is diabetes of type 1 in which the pancreas is not able to produce insulin hormone and this often cause DKA bout.

2.2 Properties and Effects of Glucose ($C_6H_{12}O_6$)

D-glucose or sometimes known as dextrose, or grape sugar is a simple monosaccharide found in plants. It is one of the three dietary monosaccharides, along with fructose and galactose that are absorbed directly into the bloodstream during digestion. It is an important carbohydrate in biology, which is indicated by the fact that cells use it as a secondary source of energy and a metabolic intermediate. Glucose is one of the main products of photosynthesis and fuels for cellular respiration. Glucose exists in several different molecular structures, but all of these structures can be divided into two families of mirror-images (stereoisomers). Only one set of these isomers exists in nature, those derived from the "particular chiral form" of glucose, denoted D-glucose, or D-glucose. Figure (2.1) depicts its molecular structures.

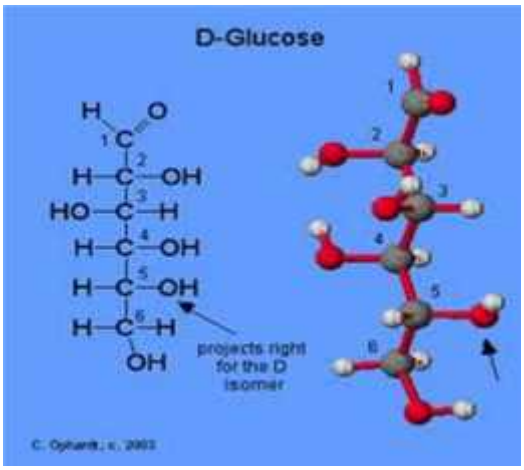

Figure (2.1): D-Glucose Molecular Structures[1].

The normal range of glucose level in blood is [80-110mg/dL] [2]. The disturbed glucose metabolism of diabetics can cause severe complications, such retinopathy, nephropathy, microvascular lesions and DKA bout. To avoid DKA bout we have to keep the glucose level in blood within the normal range, it is necessary to determine the optimal quantity and frequency of subcutaneously injected insulin. Even then, it is very difficult to achieve normoglycemia, since with type I diabetics no insulin syntheses

occurs within pancreas, result in increasing of blood glucose concentration (hyperglycemia) or sometimes decreasing of blood glucose concentration (hypoglycemia) [3].

2.3 Diabetic Ketoacidosis

DKA is a life-threatening condition that can occur when there is a complete lack of insulin, as in type 1 diabetes, or inadequate insulin levels associated with stress or severe illness in either type 1 or type 2 diabetes. DKA was originally described by Dreschfeld in 1886, until insulin was discovered in 1922; the mortality rate of this illness was almost 100%. Diabetes mortality for both types remains at 1% to 2%. Between 20% and 30% of cases occur in patients with newly diagnosed diabetes [4]. The incidence of DKA is 0.2 per patient year with type 1 diabetes. DKA tends to be more common in younger patients and is still the major cause of death in children with diabetes.

Further details about the physiology of DKA, etiology and precipitating factors and symptoms of DKA will be discussed in the following sections.

2.4.1 DKA Pathophysiology

The pathology is invariably the result of relative or absolute insulin deficiency which in combination with increased levels of stress hormones stimulates lipolysis resulting in the reduction of acetyl-coA from fatty acid. This acts as the substrate for hepatic synthesis of ketone bodies (acetoacetate, betahydroxybutyrate and acetone) as shown in Figure (2.2) ((a) Increased lipolysis results in the production of acetyl-coA from fatty acids which acts as the substrate for hepatic synthesis of ketone bodies .A lack of insulin results in decreased glucose utilization and a reduction in oxaloacetate production. (b) The amount of oxaloacetate available for condensation with acetyl-coA is reduced. (c)

acetyl-coA is thus diverted from entering the tricarboxylic acid cycle and (d) undergoes condensation to form acetoacetate followed by reduction to beta-hydroxybutyrate). In addition to increased lipolysis, the relative lack of insulin in DKA results in decreased glucose utilization by cells and increased gluconeogenesis (formation of new glucose) [4].

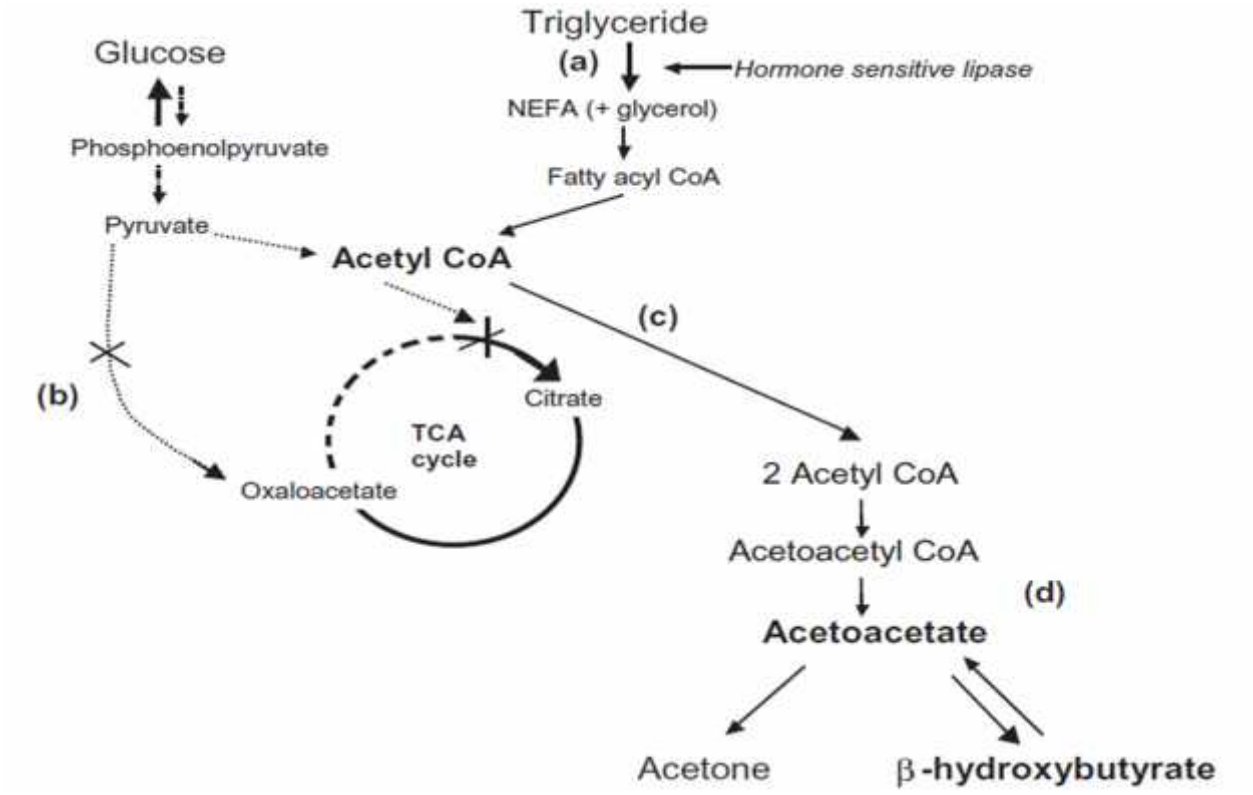

Figure (2.2): Hepatic Synthesis of Ketone [4].

2.4.2 Etiology and Precipitating Factors

There are several precipitating factors include medications and drugs that affect carbohydrate metabolism such as anti-hypertensive, anti-histamines, tricyclic antidepressants, alcohol, cocaine and ecstasy. DKA Often develops because of contributing factors such as pregnancy, gastroenteritis, trauma, burns, surgery, sepsis,

pancreatitis, stroke and silent myocardial infarction can also provoke DKA, and the patient fails to meet the increased insulin demand when these physical stressors occur. The stressors provoke an excessive release of counter regulatory [5].

2.4.3 DKA Main Characteristic

There are four main characteristic of DKA, including hyperglycaemia, ketosis and acidosis, dehydration, electrolyte imbalance.

2.4.3.1 Hyperglycemia

Insulin deficiency leads to accumulation of glucose in the blood as glucose cannot enter the cells. Normally insulin suppresses glucose production and lipolysis in the liver. Therefore insulin deficiency leads to hepatic glucose overproduction. Counter-regulatory hormones, glucagon, cortisol and catecholamine increase the glucose level through gluconeogenesis and glycogenolysis (breakdown of complex glycogen into simple glucose). The process of gluconeogenesis is driven by the high availability of all the precursors: amino acids (from protein breakdown), lactate (from muscle glycogenolysis), and glycerol (from increased lipolysis).

It is thought that when serum osmolality is high, even less insulin is produced and insulin resistance increases. These processes make it even more difficult for tissues to take up glucose, as a result hyperglycemia worsens [5].

2.4.3.2 Ketosis and Acidosis

Insulin deficiency and elevated counter-regulatory hormones promote lipolysis in adipose tissue and inhibit lipogenesis, leading to increased release of fatty acids and glycero. The liver is stimulated by glucagon to oxidise free fatty acids to ketone bodies such as beta-hydroxybutyrate and acetoacetate as shown in previous figure (2.2). The

production of ketone bodies exceeds the ability of tissues to utilize them, resulting in ketonaemia. Ketone bodies fully dissociate into ketone anions and hydrogen ions, and the body attempts to maintain extracellular pH by binding the hydrogen ions with bicarbonate ions.

The respiratory system compensates for acidosis by increasing the depth and rate of breathing to exhale more carbon dioxide, this breath called “Kussmaul respiration”. This breath has a fruity, acetone-like odour (nail polish remover), because the acetone ketones are exhaled.

The kidneys excrete ketone bodies (ketonuria), and large amounts of glucose spill over into the urine leading to osmotic diuresis, dehydration and haemoconcentration. This in turn causes tissue ischaemia and increased lactic acid production that worsens the acidosis. Increased acidosis causes enzymes to become ineffective and metabolism decelerates. Even fewer ketone bodies are metabolised and acidosis worsens. Acidosis can cause hypotension due to its vasodilating effect and negative effect on heart contractility.

2.4.3.3 Dehydration

Hyperglycemia raises extracellular fluid osmolality. Water is drawn from the cell into the extracellular compartment and intracellular dehydration follows. Hyperosmolality is the main contributor to altered mental status, which can lead to coma. Cellular dehydration and acid overload can also affect mental status.

The development of total body dehydration and sodium depletion is the result of increased urinary output and electrolyte losses. With marked hyperglycaemia the serum glucose threshold for glucose reabsorption in the kidneys of 10 mmol/L is exceeded, and glucose is excreted in urine (glucosuria) [6]. Glucosuria causes obligatory losses of water and electrolytes such as sodium, potassium, magnesium, calcium and phosphate (osmotic diuresis). Excretion of ketone anions also contributes to osmotic diuresis, and causes

additional obligatory losses of urinary cations (sodium, potassium and ammonium salts). Insulin deficiency per se might also contribute to renal losses of water and electrolytes, because insulin stimulates salt and water reabsorption by the nephron and phosphate reabsorption in the proximal tubule. Acidosis can cause nausea and vomiting and this leads to further fluid loss. There is increased insensible fluid loss through Kussmaul respiration. Severe dehydration reduces renal blood flow and decreases glomerular filtration, and may progress to hypovolemic shock.

2.4.3.4 Electrolyte Imbalance

Potassium is the electrolyte that is most affected in DKA. Acidosis causes hydrogen ions to move from the extracellular fluid into the intracellular space. Hydrogen movement into the cell promotes potassium out of the cell into the extracellular compartment (including the intravascular space). Severe intracellular potassium depletion follows, as the liver is stimulated by the counter regulatory hormones to break down protein, the nitrogen is accumulates, and this causing a rise in blood urea nitrogen. Proteolysis leads to further loss of intracellular potassium and increases intravascular potassium. The body excretes this mobilized potassium in urine by osmotic diuresis, and loses additional potassium through vomiting. Serum potassium readings can be normal or high, but this is misleading, because there is an intracellular and total body potassium deficit. Sodium, phosphate, chloride and bicarbonate are also lost in urine and vomits.

Figure (2.3) shows the effect of insulin deficiency on the body, which summarizes the pathophysiology of DKA.

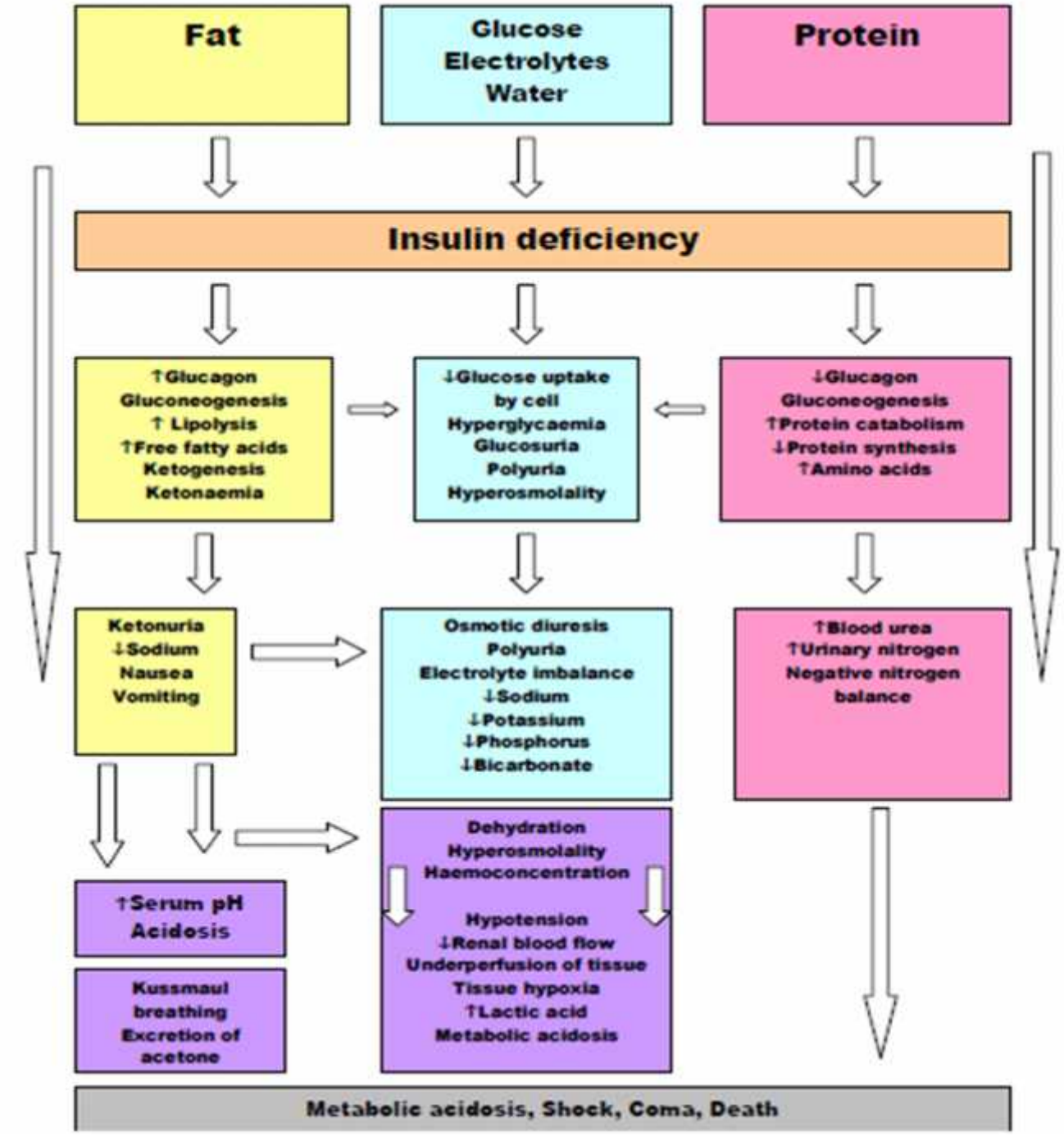

Figure (2.3): Pathophysiology of DKA [7].

2.4.4 DKA Symptoms

DKA have many of symptoms that appear on the patient such as feeling unwell for a short period often less than 24 hours, polydipsia and increased thirst, polyuria , nocturia, polyphagia, weight loss, nausea and vomiting, abdominal pain due to dehydration and acidosis, weakness, neurologic signs as restlessness, agitation, lethargy and drowsiness, coma, deep and rapid breathing known as kussmaul breathing, signs of dehydration due to fluid loss through polyuria, vomiting and breathing, signs of hypovolemia as tachycardia, hypotension, postural hypotension due to fluid loss over 3 liters and mild hypothermia due to acidosis-induced peripheral vasodilatation and warm dry skin.

2.4.5 Main DKA Physiological Signs

- Hyperglycemia (blood glucose >11 mmol/L [≈200 mg/dL]) [2].
- Venous pH <7.3 [2].
- Bicarbonate <15 mmol/L [2].
- The acetone concentration in the breath increases from (0.3 - 0.9) ppm for healthy humans to more than 1.8 ppm for diabetic patients [8].
- The CO_2 partial pressure < 24.5 mmHg [9].
- Tachycardia (heart rate >110 bpm) [5].
- Increasing of respiratory rate (>30 bpm) [10].

Chapter Three
Background and Context

Chapter Three

Background and Context

Introduction

As discussed in the previous chapter, the known of blood glucose level is very important to specify the type of blood glucose and to specify the DKA bout. The fasting blood is sampled for glucose determination. The concentration of glucose can be determined in whole capillary, venous blood, serum or plasma. In whole blood, glucose can only be determined by manual methods, whereas determination of glucose in serum or plasma can be performed by automated methods. This chapter talks about several background technologies and new technologies that is employed to achieve project aims, which is including acetone sensor, CO_2 sensor, heart rate sensor, respiratory rate sensor, programmable micro controller, and every things that is used in order to understand the behavior system.

3.1 Glucose Measurement Methods

For the past few decades, the dominant method for monitoring blood glucose, whether at home or in the hospital environment, has been intermittent measurement of capillary blood glucose, usually coupled with finger pricking. However, such measurements only provide isolated single-time point measurements that cannot fully reflect variations throughout the day and night. While there has recently been great progress in the development of subcutaneous implantable electrochemical glucose sensors that provide real-time monitoring capability, there remain some issues regarding the lag time in response between changes in blood glucose levels and subcutaneous fluid concentrations, and requirements for frequent recalibration with blood levels. For critically ill hospital patients, in particular, there is growing evidence that tight control of blood glucose levels can be of benefit not only to diabetic patients, but also to non-diabetics. Basically, two measurement techniques can be

utilized to achieve glucose concentration in the blood; invasive and noninvasive based methods.

3.1.1 Non-invasive Glucose Measurement

Non-invasive measurement method means that no existence of direct contact between the blood and the glucose sensor. However, the main non-invasive measurement of blood glucose concentration accomplished using spectroscopy optical technique in which optical transmitter and receiver fixed on the outer organ skin to determine the glucose concentration depend on optical property variation at the interface.

Spectrophotometry is an established method for the quantification of solutes in liquids. It is based on solute specific absorption bands in the visible (VIS), near infra-red (NIR) or mid infra-red (MIR) spectral range. Quantification of the solutes is possible by determination of light attenuation caused by absorption at a single wavelength when taking the light path length into account. In using infra-red spectroscopy this interaction produces molecular vibration & absorption of energy in infrared region. This vibrational absorption corresponds to the wavelength in order of 4000-400 cm-1. It's important to mention that this novel technique still has a lot of complications including the difference in determine the optimal wave length according the organ skin nature of patients and also the need for an optimal shielding to block the optical interference that greatly affect the desired light signal.

3.1.2 Invasive Glucose Measurement

Invasive measurement method means that the existence of the direct contact between the measurement tool and the human blood. Intravenous sensor placement would be the preferred mode to gain the most accurate assessment of real-time blood glucose levels because its direct contact with blood stream result in increasing the sensitivity and accuracy of the system, in addition decreasing the time required for measurement.

3.2 Acetone Sensor

The acetone sensor is Chemo-resistive gas sensors, made of nanostructured metal-oxide semiconductors offer a promising alternative to more sophisticated systems. It senses acetone concentration in the exhaled breath stream based on electro-chemical principle.

3.2.1 Principle of Operation of Acetone Sensor

Acetone is a reducing gas (that is when an-type semiconducting oxide is used as a sensing element, the presence of acetone will result in lowering its electrical resistance).

The nanostructuctured sensor is linear in the detection range of interest to diabetes monitoring. Figure (3.1) shows the relationship between acetone concentration and WO_3 from 0.2 ppm to 2.0 ppm. The concentration of acetone in exhaled human breath normally falls within this range. In particular, at 1.8 ppm, which is set as diabetes diagnosis threshold, the sensitivity is 4.3. This value is used in the breath analyzer design [8].

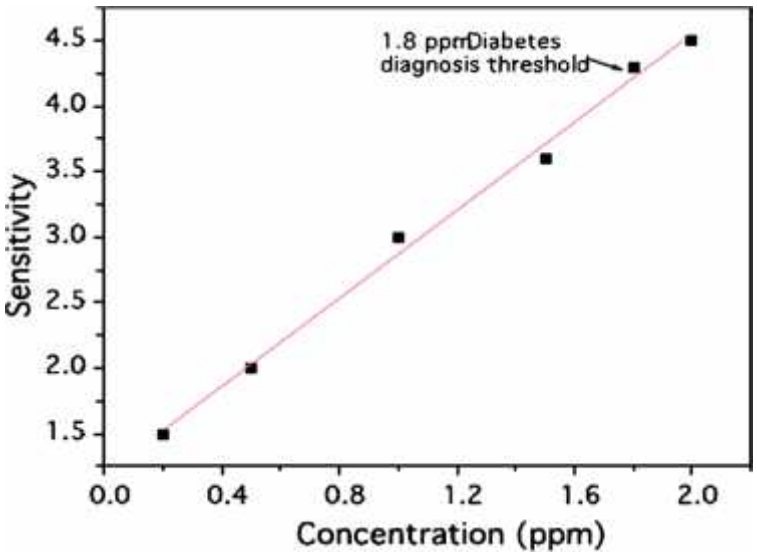

Figure (3.1): Relationship between Acetone concentration and Sensitivity [8].

"The basic concept of the sensing device is to compare the resistance of the sensor material to a comparative resistor. The resistance of this comparator is determined by a pre-assumed biomarker concentration threshold in the human breath

for certain disease diagnosis as well as the behavior of the sensing material. The sensing material's resistance is determined by the actual biomarker concentration. Assuming the biomarker is a reducing gas, if this resistance is lower than that of the resistor, the actual concentration of the biomarker is then higher than the threshold, which implies that the patient has a high probability to be afflicted with a given disease or suffer metabolic malfunction" [8].

The response time of the device is 20 seconds. At 1.8 ppm acetone exposure, the resistance lowers down to around 3.5 MΩ which was set as the lower threshold value of the analyzer. The upper threshold was set to 20 MΩ a little higher than the sensor's baseline value.

3.2.2 Construction of Acetone Sensor

For this implanted system lots of existing challenges must be resolved, one of them is the size of this implantable system which play an important role in acceptance of this system also provide multiple choices for its locations, in the other hand the need for a power source which is an important factor that determine the life time of this implant. Approach to overcome the mentioned problems is to miniaturize the implantable unit by microfabricated the acetone sensor and integrating all of the interfacing circuits into an integrated-circuit attached to the microfabricated acetone sensor. Figure (3.2) shows key component of the breath analyzer (sensor and heater assembly).

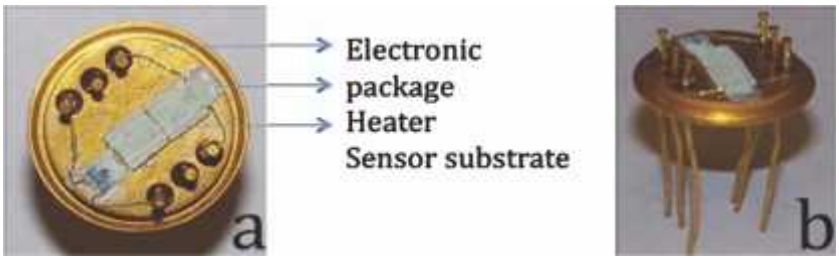

Figure (3.2): Key component of the breath analyzer: sensor and heater assembly (a) Top view, (b) Side view [8].

The fabrication of Cr-WO_3 nanopowders for use, with 80% -WO_3 phase content were used to prepare resistive sensors. The sensor materials were deposited

onto a homemade Pt-electrode coated alumina substrate (3 mm × 3 mm).One sensor or two parallel connected sensors are adhered to commercial heater (M1020, Heraeus Sensor Tech.). The heater, whose temperature is controlled by the voltage applied on it, is able to heat the sensor up to 500C .This sensor/heater pair is the key component of breath analyzer. It is connected with a transistor outline (TO-8) header, which is ready to be integrated into the device.

The available acetone sensors in the market are out of the required range for the project (1.8 - 4 ppm); for example the range for TGS822 and MQ-3 acetone sensors are (50 - 4000 ppm) and (10 - 1000 ppm) respectively. The team of the project have asked several international research groups and universities (such as L. Wang research groups, from department of electrical and computer engineering of the university of British Columbia, M. Righetton research groups Particle Technology Laboratory (Zürich, Switzerland), and department of Biochemistry of Los Anglos University) about the sensor with the required range, where all of them assured the poverty of the sensor commercially.

3.3 CO_2 Sensor (MG811)

CO_2 sensor is an instrument for the measurement of carbon dioxide gas. The most common principles for CO_2 sensors are infrared gas sensors (NDIR) and chemical gas sensors. CO_2 sensor used to sense carbon dioxide concentration in the exhaled breath stream based on electro-chemical principle.

3.3.1 Principle of Operation of CO_2 Sensor

Sensor adopt solid electrolyte cell Principal. The voltage of sensor heater is supplied from other circuit, when its surface temperature is high enough, the sensor equals to a cell, its two sides output voltage signal [9].

3.3.2 Construction of CO_2 Sensor

CO_2 gas sensors consist of sensitive layers based on polymer or heteropolysiloxane have the principal advantage of very low energy consumption, and can be reduced in size to fit into microelectronic-based systems. On the downside, short- and long term drift effects as well as a rather low overall lifetime are major obstacles when compared with the NDIR measurement principle. Most CO_2 sensors are fully calibrated prior to shipping from the factory. Over time, the zero point of the sensor needs to be calibrated to maintain the long term stability of the sensor.

The structure of the CO_2 sensor and testing circuit it is composed by : solid electrolyte layer（1），Gold electrodes（2），Platinum Lead （3），Heater （4），Porcelain Tube （5），100m double- layer stateless net（6），Nickel and copper plated ring（7），Bakelite (8)，Nickel and copper plated pin（9）.

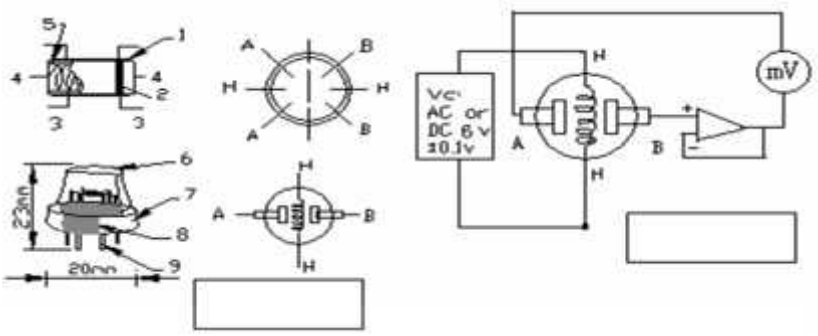

Figure (3.3): CO_2 sensor structure and testing circuit. [Appendix-A]

3.4 Heart Rate Sensor

Heart rate sensor indicates the soundness of the heart and helps assessing the condition of cardiovascular system. In clinical environment, heart rate is measured by

several measurements like blood measurement, heart voice measurement, and Electrocardiogram (ECG), and it can be measured in home environment also.

The heart pounds to pump oxygen-rich blood to muscles and to carry cell waste products away from the muscles. The more use muscles, the harder heart works to perform these tasks- means the heart must beat faster to deliver more blood. A heart rate monitor is a simply device that takes a sample of heartbeats and computes the beats per minute (bpm) so that the information can easily be used to track heart condition. There are two types of methods to develop heart monitors - electrical and optical methods.

The average resting human heart rate is about 70 bpm for adult males and 75 bpm for adult females. Heart rate varies significantly between individuals based on fitness, age and genetics, in (DKA) case, the number of heart beat (120 bpm), which may cause tachycardia [5].

Several techniques can be used to measure heart rate like ear lobe, wrist, and by finger, but the most comfortable way and less expensive by using finger heart rate sensor.

3.4.1 Principle of Operation of Finger Heart Rate Sensor

The heart rate finger sensor works in the same way as the pulse monitors often seen in hospital emergency departments.

An infra-red light is sent through the tip of the finger with a sensor on the other side measures changes in the amount of light received. As the heart beats blood is sent around the body, with each beat the blood density in the finger changes and it is these changes that are recorded by the finger sensor.

Figure (3.4) shows the main components of heart rate sensor, and show the way to put the finger in the sensor.

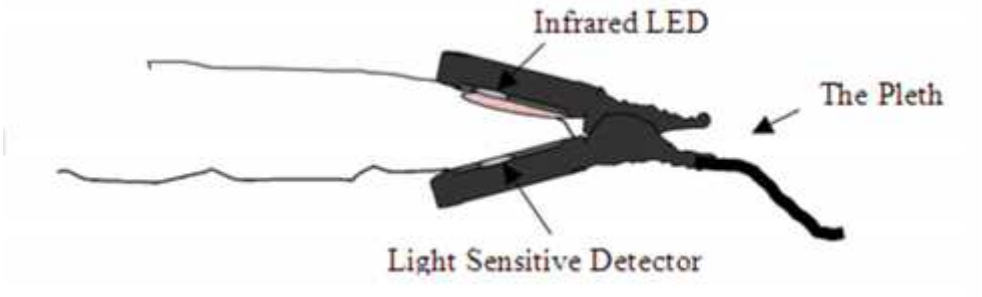

Figure (3.4): Heart Rate Sensor

The heart rate sensor is used to measure the cardiovascular pulse wave that is found throughout the human body. This pulse wave make changes in the volume of arterial blood with each pulse beat. This change in blood volume can be detected in peripheral parts of the body such as the fingertip or ear lobe using a technique called Photoplethysmography. The device that detects the signal is called a plethysmograph, show in figure (3.4).

3.4.2 Construction of Heart Rate Sensor

The photoplethysmography consists of:

- An infrared LED which illuminates the tissue.

•A light sensitive detector (LSD), which has been tuned to the same color frequency as the LED, and detects the amount of light transmitted from the tissue.

The infrared LED and the light sensitive detector (LSD) are mounted in a spring- loaded device that can be clipped onto the fingertip or ear lobe.

The infrared light emitted by the LED is diffusely scattered through the fingertip tissue. A light sensitive detector positioned on the surface of the skin on the opposite side can measure light transmitted through at a range of depths. Infrared light is absorbed well in blood and weakly absorbed in tissue. Any changes in blood

volume will be registered since increasing (or decreasing) volume will cause more or less absorption. Assuming the subject does not move the level of absorption of the tissue and non-pulsating fluids will remain the same.

3.5 Respiratory Rate Sensor

Respiratory rate sensor counts the number of patient's breath per a unit of time that indicates some abnormal metabolic activities in living tissue, such as the air exchanging in the lungs, Ph, heart activity, glucose concentration, and DKA bout. Portable respiratory rate can be measured using several techniques, such as strain gauge, thermistor and thermometer.

The strain gauge technique depends on a resistance change of the strain gauge that fixed on the patients thoracic as a belt. During patient's inhalation, the diaphragm contracts and will be pulled down, this increases the volume of the thoracic cavity. During exhalation, the abdominal muscle moves upward and pushes the diaphragm results in decreasing the thoracic cavity. The strain gauge monitors the changing of thoracic cavity volume during inhalation and exhalation. This technique is not comfortable for patients and requires a relatively sensitive strain gauge to obatain acceptable signal to noise ratio.

The thermistor technique is used to measure the temperature difference between the patient's exhaled air and the ambient environment by measuring of the thermistor resistance at each temperature. The temperature of the exhaled air is almost the same as that in the human body, whereas the temperature of the enhaled air is close to the ambient temperature. So the respiratory frequency can be obtained by putting a thermistor (such as NTC) close to patient's mouth to detect the change of temperature of inhaled and exhaled air. This technique has some problems; the signal to noise ratio of the output signal is relatively low, as a result further processing circuits are required such as differential amplifier, band reject filter, differentiator and hysteresis comparator. These electronic systems require large space in the board; make it not compatible for portable device, in addition to make it more expensive.

The thermometer technique is almost has the same procedure of the previous technique for obtaining the respiratory rate, but it is directly convert the change of air temperature to voltage. So this technique does not need any excessive components or stages, and also more accuracy than previous techniques. Thus the temperature sensor that is used for this purpose is DS18B20 digital thermometer. This sensor is suitable for this project due to its small size. It is cheap and has relatively high resolution, high accuracy, and can be powered from 3.3-5 volt.

3.6 Microcontrollers

A microcontroller is a highly integrated chip that contains all the components comprising a controller, this includes a CPU, RAM, some form of ROM, I/O ports, and timers, and a microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals.

As microcontroller is an integrated circuit, the cost of the total system decreases, a smaller and cheaper circuit board used, the labor required to assemble and test the circuit board reduces, and the number of chips and the amount of wiring reduces. Microcontrollers are designed for using in embedded systems, which mean that they are part of embedded systems, so they are sometimes called "embedded microcontrollers".

A microcontroller is designed for a very specific task to control a particular system and is used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, and toys. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes.

Most microcontrollers deal with a digital data, so analog-to-digital converter (ADC) must be exist to convert analog data to digital, but in some microcontrollers there is a digital-to-analog converter (DAC) that allows the processor to output analog signals or voltage levels.

There are many microcontroller types and architectures different in length of register and instruction word. We can mention here the most known types of microcontrollers:

- PIC (8-bit PIC16, PIC18, 16-bit dsPIC33/PIC24)
- Intel 8051
- Arduino
- AT mega

The microcontroller that used in this project is arduino (Mega and Uno) microcontroller. Arduino is an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. Arduino can be used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical outputs. The main advantages of arduino microcontrollers:

- Inexpensive - Arduino boards are relatively inexpensive compared to AT mega microcontroller platforms.
- Simple, clear programming environment - The arduino programming environment is easy-to-use for beginners, yet flexible enough for advanced users.
- Open source and extensible software- The arduino software and is published

as open source tools, available for extension by experienced programmers.

- Open source and extensible hardware - The arduino is based on Atmel's ATMEGA8 and ATMEGA168 microcontrollers.

There are several kinds of PIC which is largely similar in hardware: Arduino Mega, ArduinoUno and Arduino Nano.

Chapter Four
System Design

Chapter Four

System Design

This chapter talks about the system design including all the hardware and software components required. Each stage of the system will be explained in detail, the hardware components of each stage are chosen carefully to achieve the desired objectives.

The main system architecture is depicted in figure (4.1); it is composed of two main parts; sensing and processing parts. The sensing part contains CO_2 sensor to measure CO_2 gas from exhaled breath, respiratory rate sensor to measure the respiratory frequency, and heart rate sensor to determine the number of heart rate per minute. The main functions of the processing parts are receiving data from the sensing parts and process the output signal processing of each sensor, and send the results to the Microcontroller to analyze, compare with standard values, and display it using display device. The overall system is supplied by a rechargeable 8-V battery.

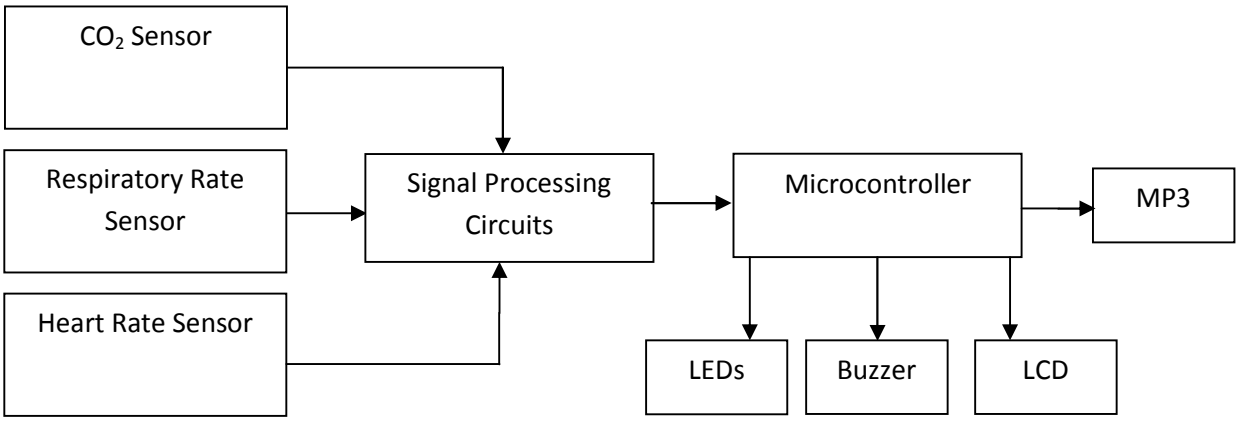

Figure (4.1): Main Block Diagram for the System.

An explanation of each stage within the system is given in the following sections.

4.1 CO_2 Sensor Design

CO_2 sensor is required in the project to measure the percentage of CO_2 in the exhaled air which gives indication of DKA. According to the preceding study regarding CO_2 sensors, MG811 CO_2 sensor is implemented in the system. A calibration curve for this sensor, shown in figure (4.2), is studied to recognize the relationship between CO_2 concentration variation and the output voltage. This curve is nonlinear, and it is necessary to determine the range of the sensor output voltages which correspond to the range of exhaled CO_2. This output range is used in choosing and processing the stages that may be followed.

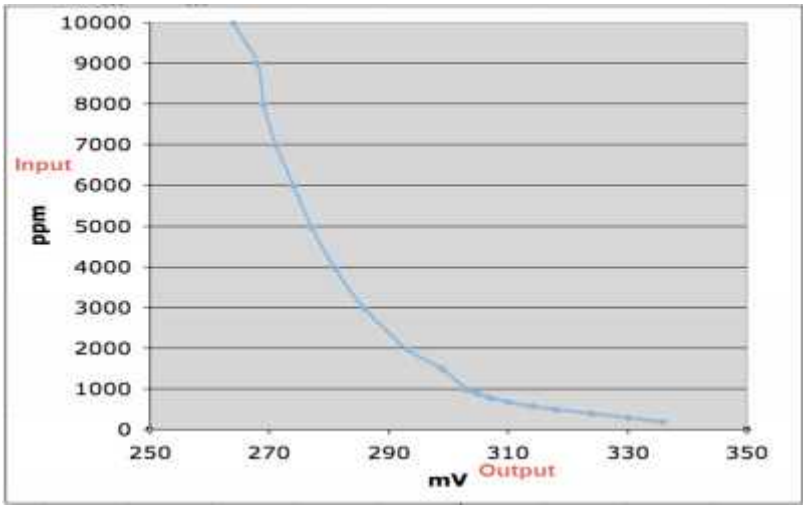

Figure (4.2): Relation between CO_2 Concentration and Output voltage [Appendix-A].

The expected exhaled CO_2 concentration from the breath will be less than 3500 ppm, this is value for the DKA patient, so according to the curve for CO_2 sensor shown in figure (4.2), and the output voltage is:

At 5000 ppm ⟶ 278mV

According to the data analysis the sensor output voltage ranges between 278mV and 337 mV. These signals need further processing as shown in figure (4.3), which depicts a system block diagram for CO_2 including the steps required to obtain readable signal with high signal to noise ratio that can be acquired by the microcontroller with good resolution.

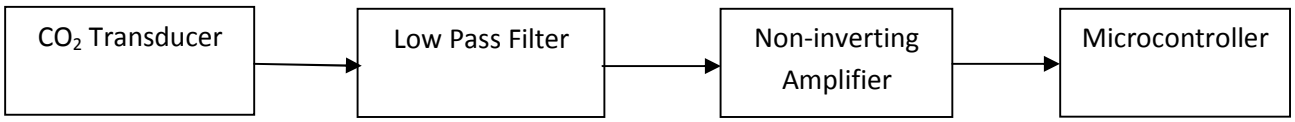

Figure (4.3): Main Block Diagram for CO_2 Sensor**.**

4.1.1 Low Pass Filter

The output signal from the CO_2 transducer is superimposed with high frequency noise interference, first order LPF come to attenuate these noisy signal leave only the interested CO_2 signal. The low pass filter is designed with a cutoff frequency (F_C=10Hz) to attenuate all high frequency signals above this critical value. The electrical circuit of the first order low pass filter is shown in figure (4.4).

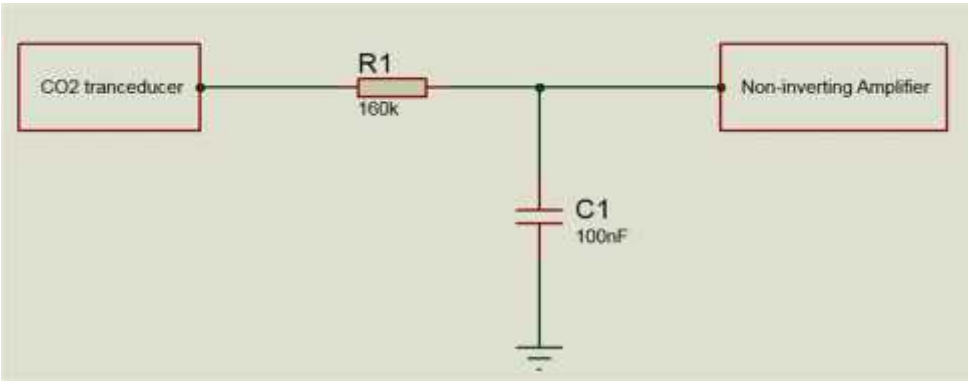

Figure (4.4): Low Pass Filter Circuit.

The critical frequency of the low pass filter given by:

$$F_C = \frac{1}{2\pi * R1 * C1} \qquad (4.1)$$

To obtain a cutoff frequency of (10Hz), let Cf=100nF, hence

$$R_1 = \frac{1}{2\pi * c1 * Fc} = \mathbf{160K\Omega.}$$

4.1.2 Non-inverting amplifier

According to the predetermined min and max values of the voltage, the gain must be chosen to have good signal to noise ratio without reaching the saturation. The output voltage signal of the CO_2 microsensor is a weak signal, hence, a non-inverting amplifier with a gain of (G1=11) is required to magnify the signal within the desired range that is readable by the microcontroller. Circuit shown in figure (4.5) is employed to accomplish this task.

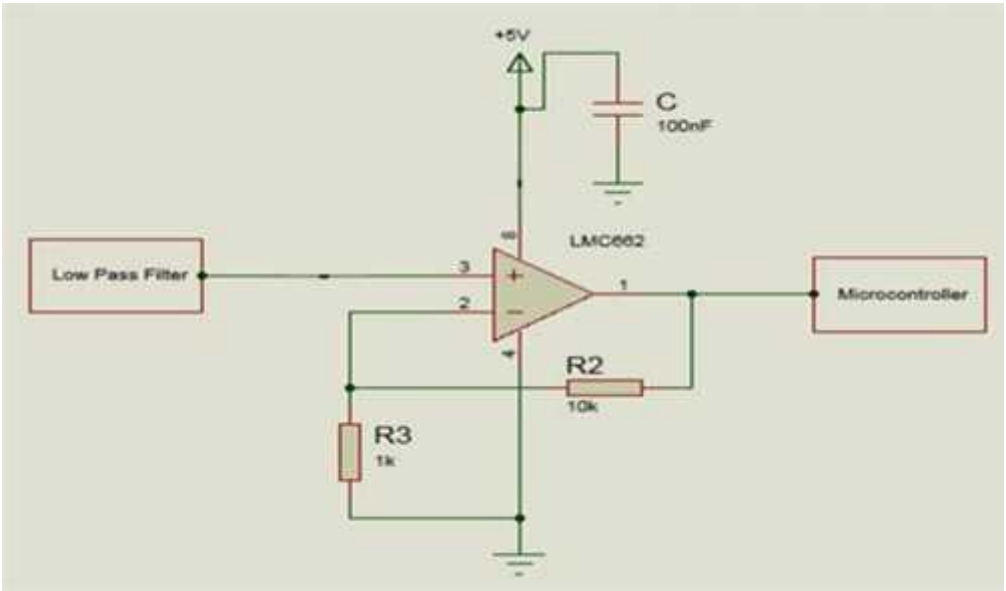

Figure (4.5): Non-Inverting Amplifier.

The transfer function of this non-inverting amplifier is:

$$G1 = \frac{Vout}{Vin} = 1 + R2/R3. \quad (4.2)$$

Let R3=1KΩ and R2=10 KΩ. Hence, G1=1 + 10K / 1K = 11.

The LMC662 is ideal for operation from a single supply. It is rail to rail output swing and low power consumption. In this application, the LMC662 is used as the amplifier, because of its ultra-high input impedance. According to the datasheet of MG-811[Appendix-A], this sensor require an input impedance of 100-1000 GΩ, the LMC662 has an input resistance above 1TΩ, which meets this requirement. The typical input offset voltage of this OPA is about 3mv, which is insignificant.

4.2 Heart Rate Sensor Design

The heart rate sensor, mentioned in the previous chapter, is used in this project to monitor the rate of heart-beat of the patient. The chosen transducer works on photoplethysmography technique. This technique depends on the change of blood volume in the finger that produced by heart rate beat. The block diagram shown in figure (4.6) is built to illustrate the basic design of the proposed heart rate system.

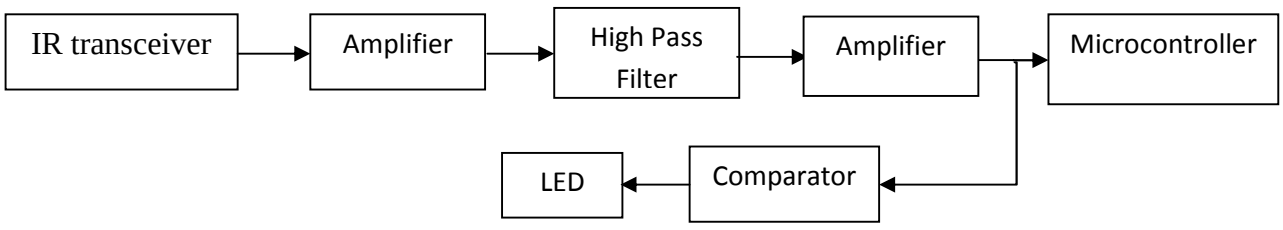

Figure (4.6): Main Block Diagram for Heart Rate Sensor.

The changing blood volume with heartbeat results in a train of pulses at the output of the phototransistor, so the magnitude of which is too small (micro volt) to be detected directly by a microcontroller. So high gain operational amplifiers are designed to amplify and filter the signal to appropriate voltage level so that the pulses can be counted by the microcontroller.

4.2.1 Infra-Red Transceiver

The photoplethysmography technique, discussed in the preceding chapter, depends on the amount of infra red (IR) lights that transmit through the finger. Hence an IR LED is used to transmit IR light, where a photo transistor sensing the portion of light that is transmitted. The intensity of the transmitted lights depends upon the blood volume.

A "TCRT-1010" IR transceiver is used in this project. It consists from IR emitting-light source (LED) on wave length 940nm and light detector (phototransistor). The LED and phototransistor are arranged in the opposite direction to sense the transitive IR-beam from the changes in arterial blood volume in the patient's finger. The circuit of IR transceiver showed in figure (4.7).

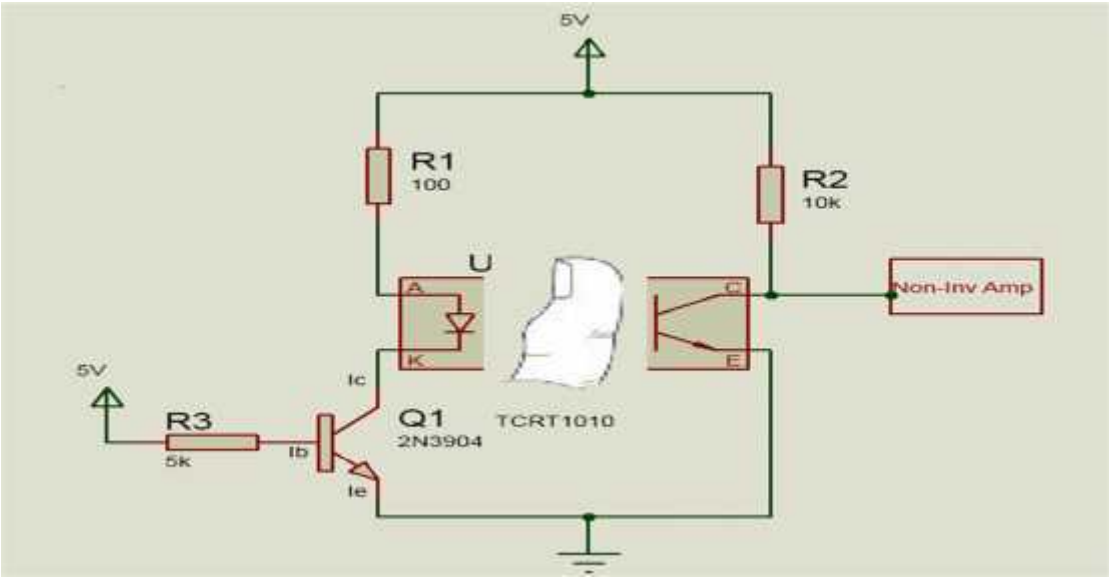

Figure (4.7): IR Transceiver Circuit.

The transistor (2N3940) [Appendix-C] is chosen to deliver a constant current for IR- LED. According to TCRT-1010 data sheet [Appendix- B], the forward current (I_F) at which the LED will transmit the desired wave length is at 20mA. This current is delivered by the transistor as collector current (I_C). From data sheet of the transistor the DC gain current (β) is equal 60 when I_C=20mA.By using equation (4.3), the base current (I_B) given by the following equation:

$$I_B = \frac{I_C}{\beta} \qquad (4.3)$$

$$I_B = \frac{20}{40 * 1000} = 0.5mA$$

The resistance R3 that generates the desired I_B is calculated by the following equation:

$$R3 = \frac{V_{CC} - V_B}{I_B} \qquad (4.4)$$

The base-emitter voltage (V_{BE}) and V_{CC} are 0.8V and 5V respectively [Appendix- B], hence the value of R_B equal 8.4KΩ

4.2.2 Non-Inverting Amplifier

A non-inverting amplifier (U1) with gain (G1=200) is designed to amplify the phototransistor output voltage to obtain adequate electrical signal to be considerably acquired by the filtration circuit. Circuit shown in figure (4.8) is designed to achieve this task.

The op-amp that is used in this design must have high input impedance to make the whole current passes thorough the phototransistor, so the op-amp that chosen for this design is (LMC662). This op-amp has features make it very suitable to this design such as, it is rail to rail amplifier, has very high input impedance reach to 1TΩ, and has low power consumption.

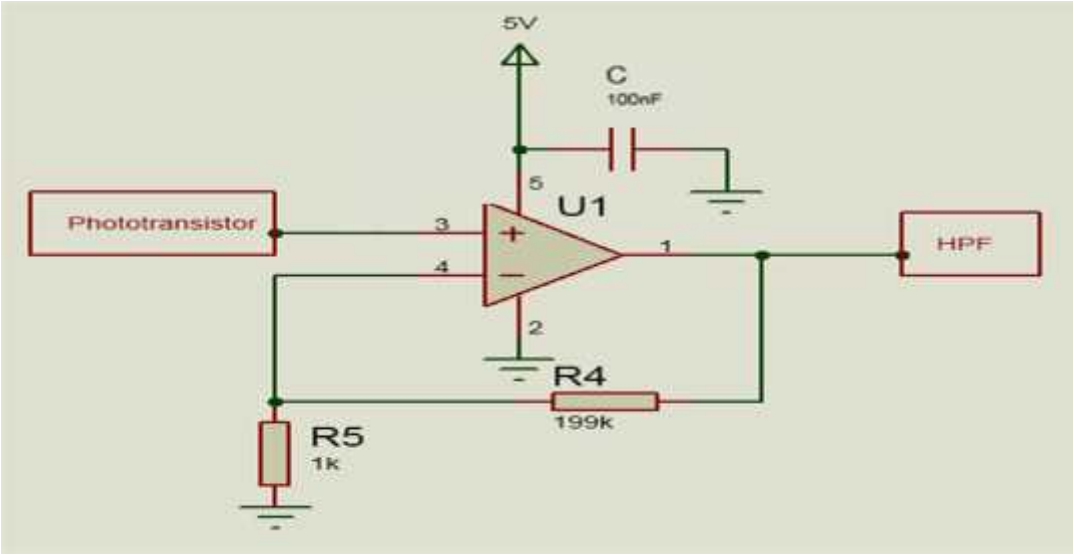

Figure (4.8): Non-Inverting Amplifier Circuit.

4.2.3 High Pass Filter

The output signal from the amplifier (U1) consists of AC and DC signals. The AC signal represent the pulse train of the arterial blood, this signal carry the information about the heart rate. While the DC signal represents the DC offset voltage which produced by the tissue and venous blood. Therefore a Sallen-Key, Butterworth high pass filter with cut off frequency (F_C=0.05 Hz) is used. The electrical circuit of the unity gain high pass filter is shown in figure (4.9).

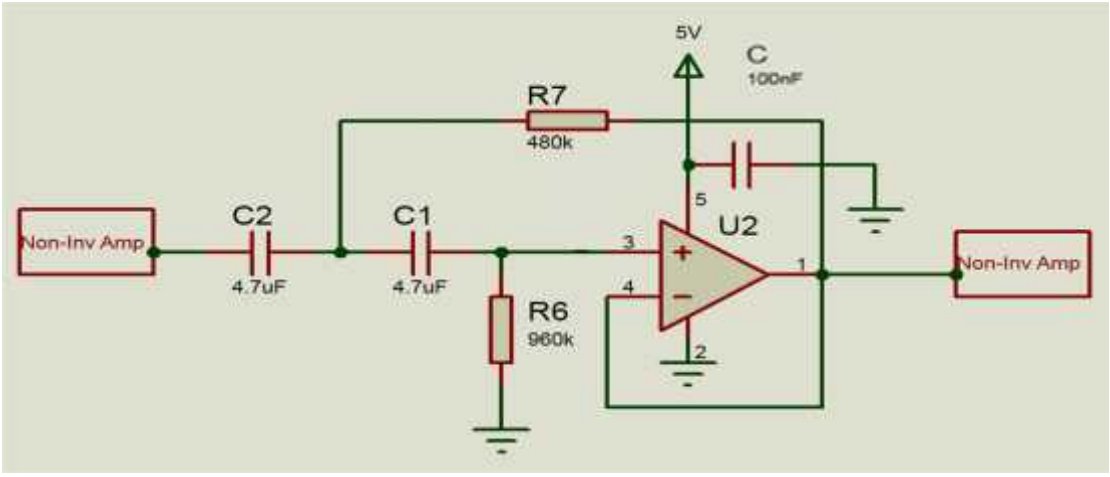

Figure (4.9): Unity Gain High Pass Filter Circuit.

The general transfer function for this filter is:

$$G(s) = \frac{1}{1 + \frac{a}{s} + \frac{b}{s^2}} \qquad (4.5)$$

F_C can be calculated by using R6, R7, C1 and C2 as expressed in following equation:

$$F_C = \frac{1}{2\pi\sqrt{R7 * R6 * C1 * C2}} \qquad (4.6)$$

Let C1=C2=C, the transfer function of the circuit shown in figure (4.9) is:

$$G(s) = \frac{1}{1 + \frac{2}{w_C R6 C s} + \frac{1}{w_C^2 R7 R6 C^2 s^2}} \qquad (4.7)$$

The coefficient comparison between this transfer function and equation (4.5) yields:

$$a = \frac{2}{w_C R6 C} \qquad (4.8)$$

$$b = \frac{1}{w_C^2 R6 R7 C^2} \qquad (4.9)$$

For Butterworth high pass filter, a=1.4142 and b=1 [11]. Let C=4.7µF so the resister R6 and R7 are:

$$R7 = \frac{2}{4 * \pi * C * F_C * b} = 478.8K\Omega$$

$$R6 = \frac{2}{\pi * C * F_C * a} = 957.8K\Omega$$

4.2.4 Non Inverting Amplifier

After removing the DC offset voltage which produced by the reflection light form fingers tissue and bone, this filtered signal must be amplified by non inverting amplifier with high gain (G2 = 250) to be suitable for the next stage as shown in figure (4.10).

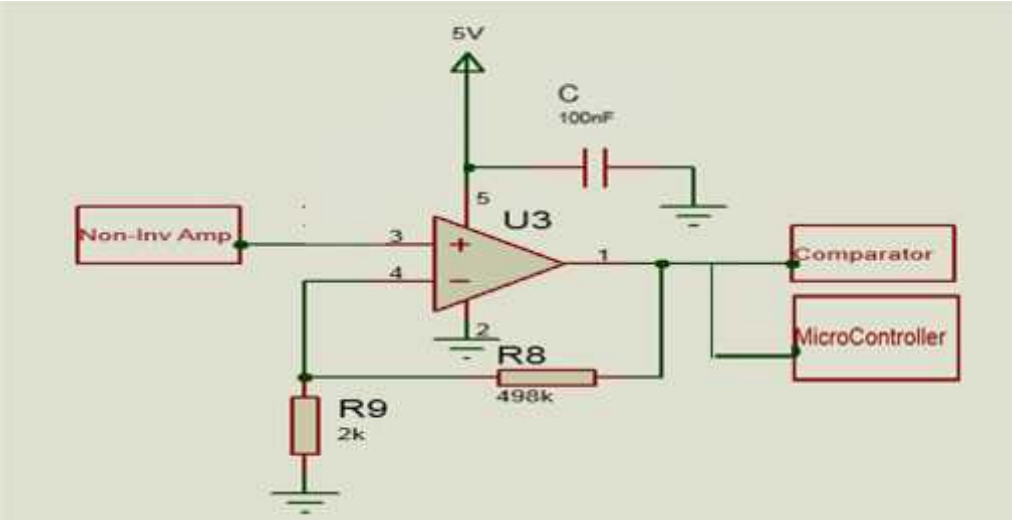

Figure (4.10): Non-Inverting Amplifier Circuit.

The total gain (G_T) of the heart rat circuit which resulted by U_1 and U_3:

$$G_T = G_1 * G_2 \qquad (4.10)$$

Hence G_T equal 50000.

The transfer function of the non-inverting amplifier is described in equation (4.2). So let R8 = 498KΩ and R9 = 2 KΩ. Hence, G2 = 1 + 498K / 2K = 250.

4.2.5 Comparator

A comparator is used to provide a 5V amplitude square wave train depending upon the changing of blood volume. This square wave is provided to LED, so the light of the LED depends on the patient's heart pulses. A reference voltage (V_{REF}) is used to detect if the amplified signal represents a heart beat or not. So when the amplified signal is smaller than V_{REF}, the output of U5 is zero that means no heart beat, and when the amplified signal is larger than V_{REF}, the output is 5V. Figure (4.11) shows the circuit diagram of the comparator.

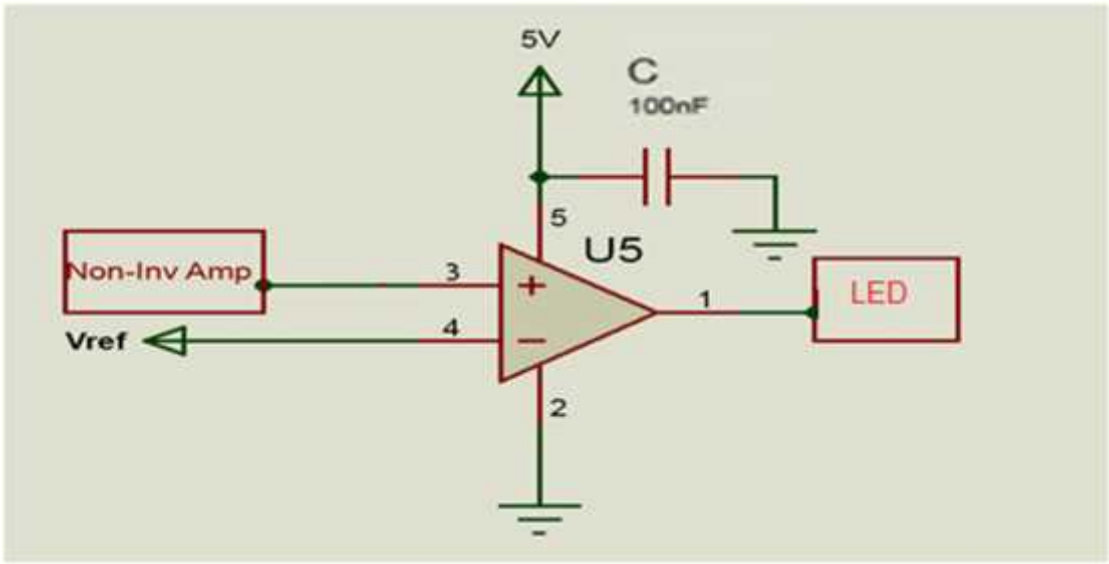

Figure (4.11): Comparator Circuit.

4.3 Design of Respiratory Rate Measurement

The respiratory rate sensor is used to count the number of patient's breath per minute which is achieved by measuring the temperature difference between human body (37 C) and ambient temperature. The output signal is processed and sent to the microcontroller to analyze it and print the result on the display device as shown in figure (4.12).

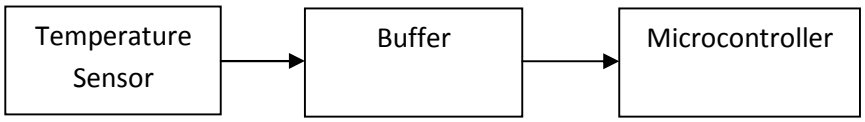

Figure (4.12): Main Block Diagram for Respiratory Rate Measurement Circuit.

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4.3.1 Temperature Sensor

In this project DS18B20 digital thermometer is used due to simplicity and low priced; it provides 9 to 12-bit (configurable) temperature readings which indicate the temperature of the ambient environment. These data are sent to the microcontroller serially. The power for reading and performing temperature conversions can be derived from the data line itself with no need for an external power source.

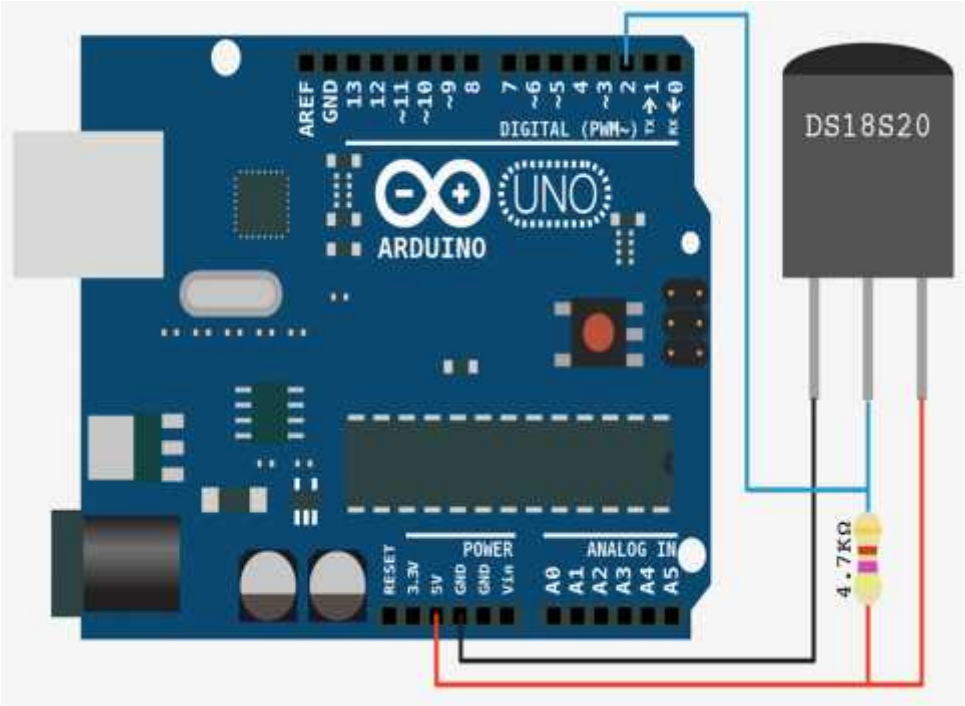

Figure (4.13): Temperature Sensor Circuit.

4.4 Arduino Interfacing

An Arduino Mega acquires the CO_2, respiratory rate and heart rate signals via "digital and analog" pins on the Arduino mega board. It processes the different signals, display the result on LCD, and activate alarm system. It has 55 digital input/output pins and 15 analog input pins and powered by 5V. CO_2, respiratory rate and heart rate systems outputs are connected to the arduino mega through the serial data line ANALOG A0, ANALOG A1 and ANALOG A2 pin on the arduino mega board, as shown in figure (4.14).

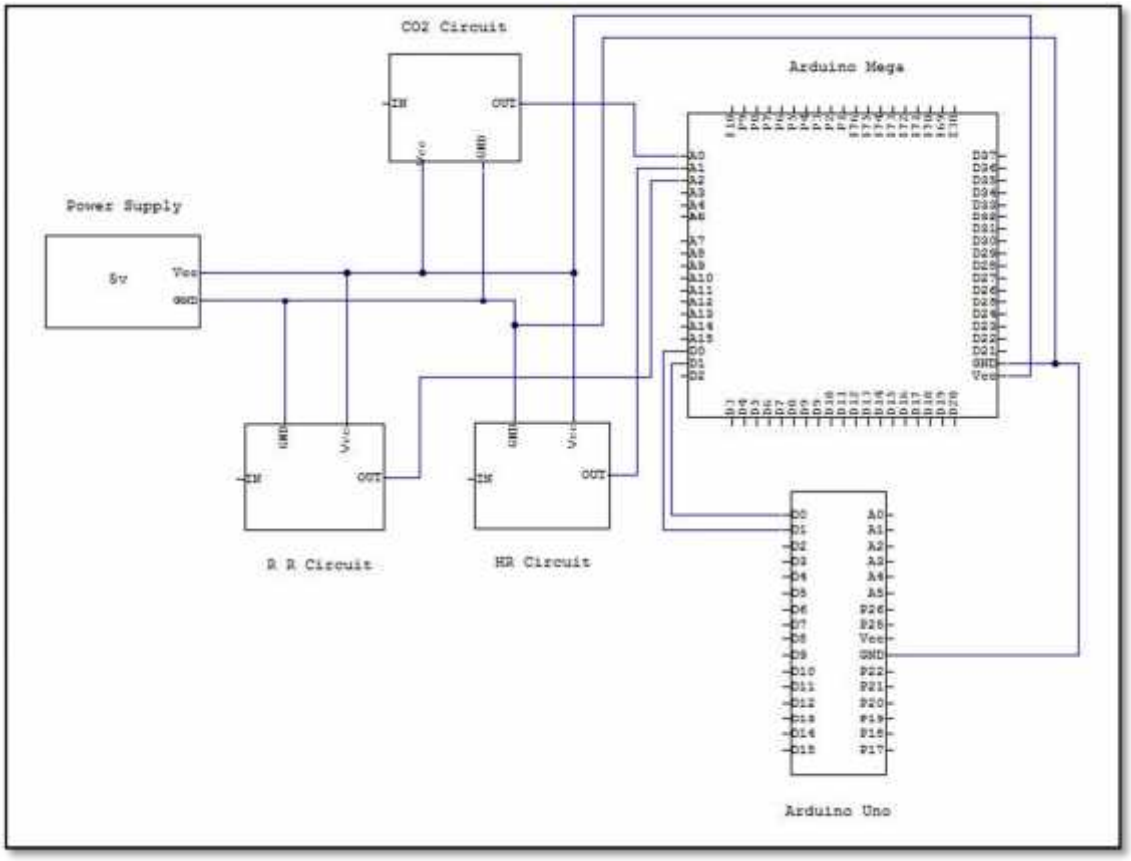

Figure (4.14): Arduino Mega Interfacing with Respiratory Rate, CO_2, Heart Rate Circuits and Arduino Uno.

Arduino Uno is chosen to acquire the sound file from SD card which exists in the special shield (VS1053 MP3 Shield) to display the instruction of the device and then display the status of the patient by a special headphone. The arduino Uno and

mega were connected together through serial communication using pins (RX0-TX1, RX1-TX0). The MP3 shield can be implemented easily with an arduino. Therefore an arduino Uno is used to hold the MP3 shield as shown in figure (4.15). The necessary connection between the arduino Uno and the arduino Mega and MP3 shield is implemented as shown in figure (4.14).

Figure (4.15): MP3 Shield with Arduino Uno.

The idea of use the MP3 shield is to give a voice command to the patient during the usage of the device. Music shield (MP3 Shield) is the best choice to serve this project due to its simplicity of implantations, compatibility with project microcontroller and the capability to give voice instructions to the patient in order to get accurate readings. A set of voice commands were stored on a SD card that inserted in the MP3 shield, these voice commands assist the patient in using the device and provide him the result of examination.

4.5 Display Circuit

It is necessary for the patient to know the process of measurement and the diagnostic result. The display circuit provides the patient with this information. It consists of diagnostic LEDs, LCD and buzzer as shown figure (4.16)

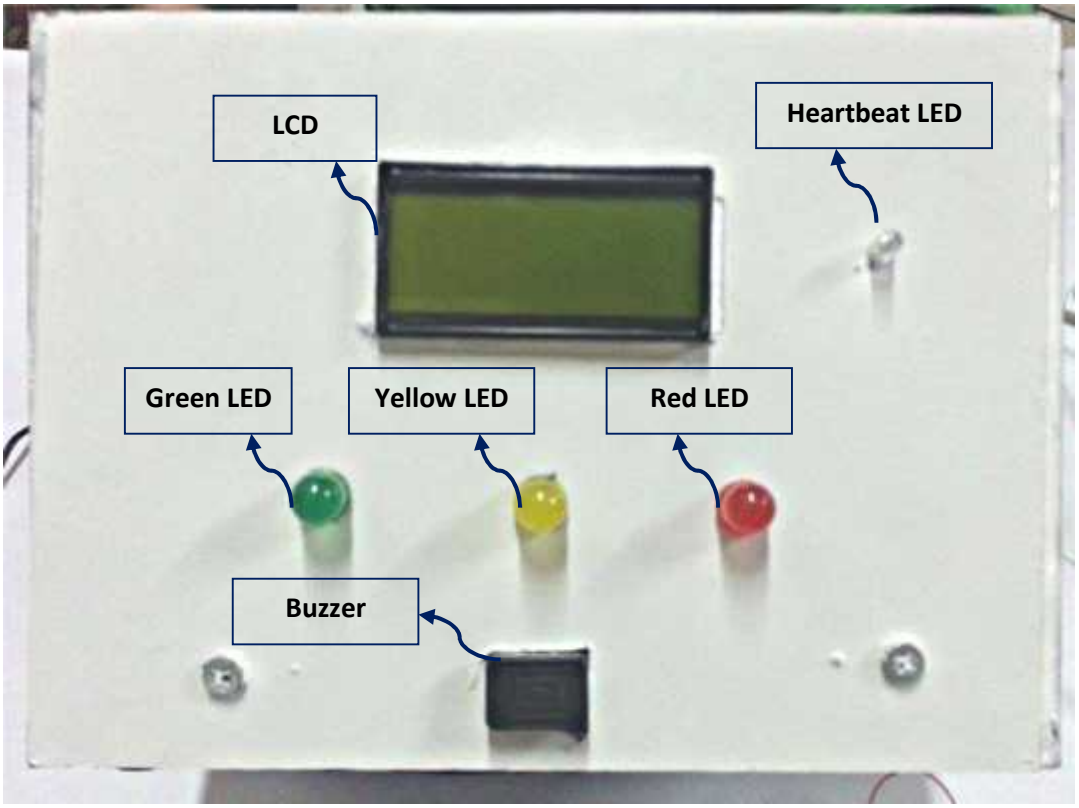

Figure (4.16): Display Circuit Components.

4.5.1 LCD Display

The display device that used in the project is LCD (4*16); it can display sixteen characters on four rows which is very good for the project. The data that displays on the LCD are hear rate, respiratory rate, CO_2 concentration and the heath condition (emergency case and normal case).

4.5.2 Alarm System

The alarm system consists of three LEDs (yellow, Green and red) and a buzzer. The yellow LED is ON during the controller processing. The green LED will be ON when the diagnostic result within the normal range. The red LED and the buzzer will be ON when the diagnostic result is out of the normal range.

4.5.3 Heartbeat LED

The heartbeat LED is connected to the heart rate circuit which light when there is a beat form the patient, so it is used to show the patient if his finger placed correctly in the rubber coating. The overall circuit diagram of preceding display circuit is shown in figure (4.17).

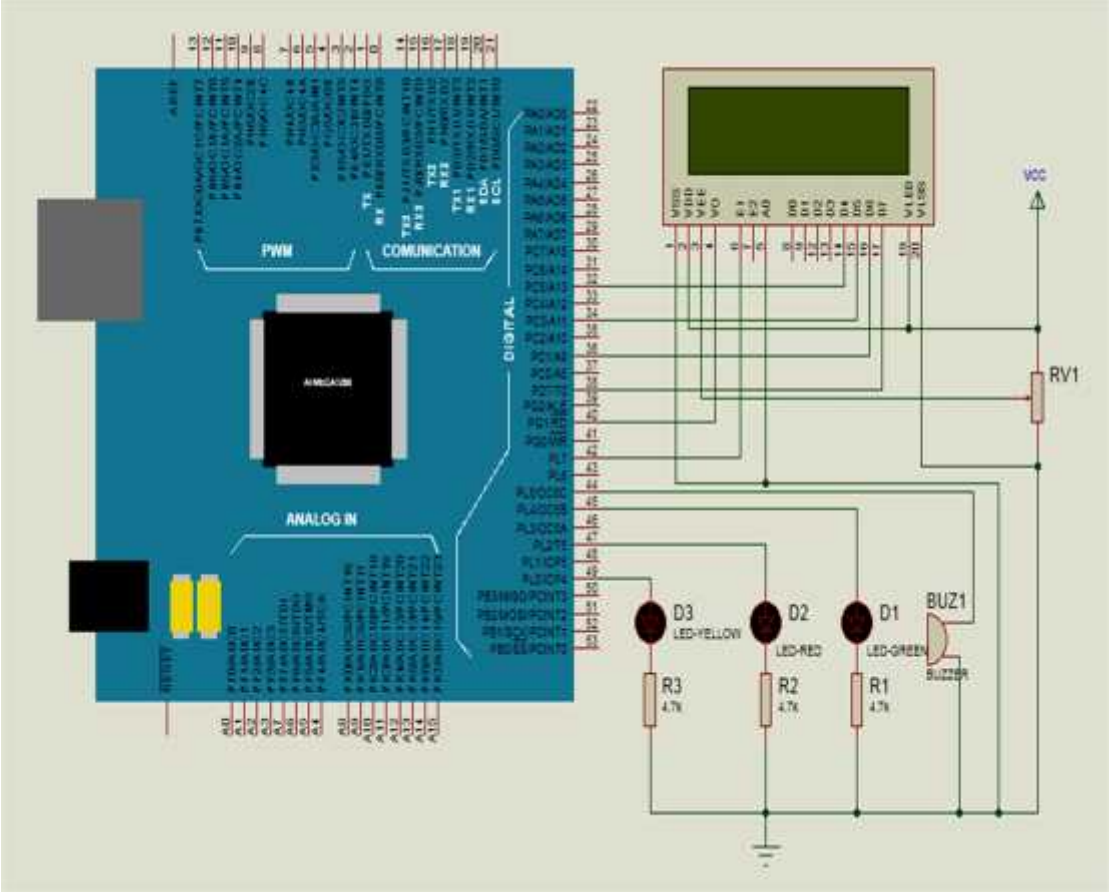

Figure (4.17): Display Overall Diagram Circuit.

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4.6 Power Design

The hardware system needs power supply to provide its components with the required power. As the system is required to be portable a battery that has the following characteristics is required:

1. Light weight.
2. Provide required system power.
3. Has relatively long life.

Due to limitation of power supply in the system, choosing of system parts should fulfill the need for an optimal with minimum current consumption leading to increase the life time of the battery. The system intended to operate using a rechargeable (8- volt) battery, but all stages need to operate within a voltage supply of (5) volt. This stage use voltage regulator (LM317) to obtain these voltage values from the battery keeping in mind the current consumption of all electrical parts used in the system. Table (4.1) explain the name of different parts used in the system with the power consumption relate to each one to find the overall system current consumption and verify that the power source able to give this desired value, also calculate the expected life time for the battery.

Table (4.1): Current Consumption of the Internal System Components.

Part Number	Function	Quantity	Current Consumption
LMC662	OP-Amp	4	0.75mA*4=3mA
TCRT1010	Phototransistor	1	100mA
2N3904	Transistor	1	150mA
Arduino Mega	Output Pins	12	20mA*12=240mA
Arduino Uno	Output Pins	4	20mA*4=80mA
LCD	Display	6	5mA*6=30mA
LED	Display	3	20mA*3=60mA
CO_2	Sensor	1	220mA
DS18b20	Temperature sensor	1	5mA
Total Current Consumption		900mA	

All data exist in the previous table obtained from the datasheet of each part [Appendix-B-C-D]. After this estimation about the expected current and voltage values of all system components, now it's important to choose the power supply parameters to meet these requirements reaching to optimal system operation. Polymer-Lithium 8v rechargeable battery with (2100mA/h) current capability, this battery is good enough to supply the portable system with its required power.

Figure (4.18) shows the schematic electrical connection of voltage regulator to obtain (+5v).

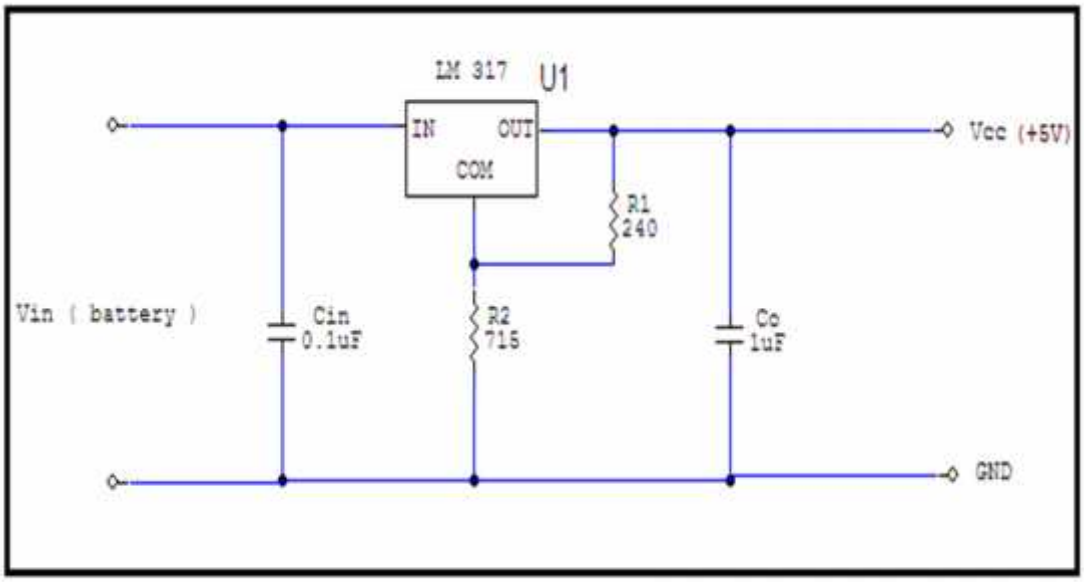


Figure (4.18): Circuit Diagram of Power Supply.

LM317 (U_1) was chosen as positive voltage regulator due to its relatively high output current capability (1.5A), adjustable output voltage, and low cost features. Desired output voltage can be computed according to the following formula:

$$V_{out} = 1.25V\left(1+\frac{R_2}{R_1}\right)+I_{adj}R_2 \qquad \textbf{(4.11)}$$

According to U_1 datasheet [Appendix-E], R_1, C_{in}, and C_o equal 240Ω, 0.1µF, and 1µF respectively. R_2 was adjusted to obtain 5v output voltage, also I_{adj} is controlled to less than 100µA, and the error associated with this term is negligible in most applications. Hence, substituting I_{adj} by 100µA into equation (4.12) results in 5V output voltage as follows:

$$5 = 1.25v^{*}\left[1+\frac{R2}{240}\right] + 100\ \mu A^{*}R2 \qquad (4.12)$$

Solving equation (4.12) for R_2, obtaining $R_2 = 715\ \Omega$.

4.7 System Flowchart

A controller is necessary in the project to acquire the data from the three sensors, analyze them, and provide the display system with the results. The time required for measuring heart rate and respiratory rate is 1 minute for each, where as measuring CO_2 concentration requires 3 minutes. Hence, the controller is programmed to activate the measurement sensors according to the stages shown in table (4.2).

Table (4.2): Measurement Stages.

Time / Stages		1st minute	2nd minute	3rd minute
1st Stage	Heart Rate			
2nd Stage	Respiratory Rate			
3rd Stage	CO_2 Concentration			

After measuring the variables required to diagnose the DKA and processes them including filtration and amplification circuits. It is necessary to analyze them to diagnose the patient. Arduino mega microcontroller is used in this project for this task. It is programmed to work according to the flowchart shown in figure (4.19).

Arduino mega microcontroller is used in this project to fulfill this task and compare each sensor reading with the normal case and provide the user with the diagnosis result according the flow chart shown in figure (4.19).

If the heart rate per minute excess the limited value (more than 110 bpm), the respiratory rate more than the limited value (30bpm), and the CO_2 concentration less than the limited value (< 3500 ppm), the patient suffers from DKA, hence, the alarm system will be activated. Else, the system will monitor the breath rate, CO_2 concentration and heart rate continuously.

It's clearly shown in this flowchart that the system will measure the respiratory rate and CO_2 concentration through sensors which located on the mouth of the patient, and measure the heart rate through heart rate sensor which located on the finger. After this stage we used the amplification and filtration stage to get the desired values, these values will be analyzed by arduino mega microcontroller to diagnose the condition, and then display the analyzing data on LCD.

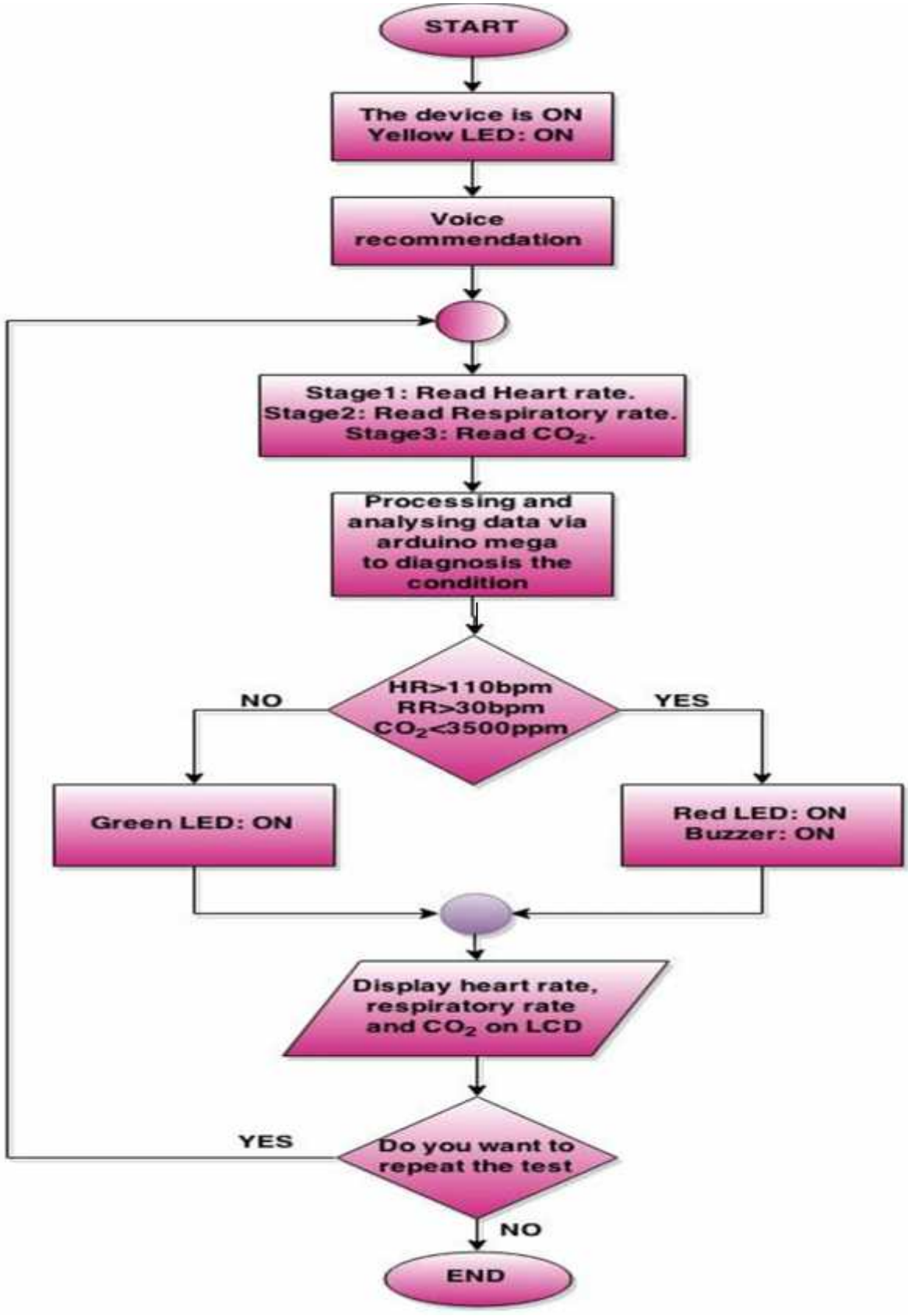


Figure (4.19): System flowchart.

Chapter Five
System Implementation and Testing

Introduction

In this chapter the hardware system designed in the preceding chapter is implemented to accomplish the project as a one unit which achieves the purpose of the project. In this section, subsystems circuits will implemented before final implementations to the system.

5.1 Project Implementation

The temperature and CO_2 sensors have to be close enough to the patient's breath; therefore these sensors were located in a mask. The mask that used is made by a reinforced rubber material which is suitable for the patient's face. The mask used in this project is shown in figure (5.1).

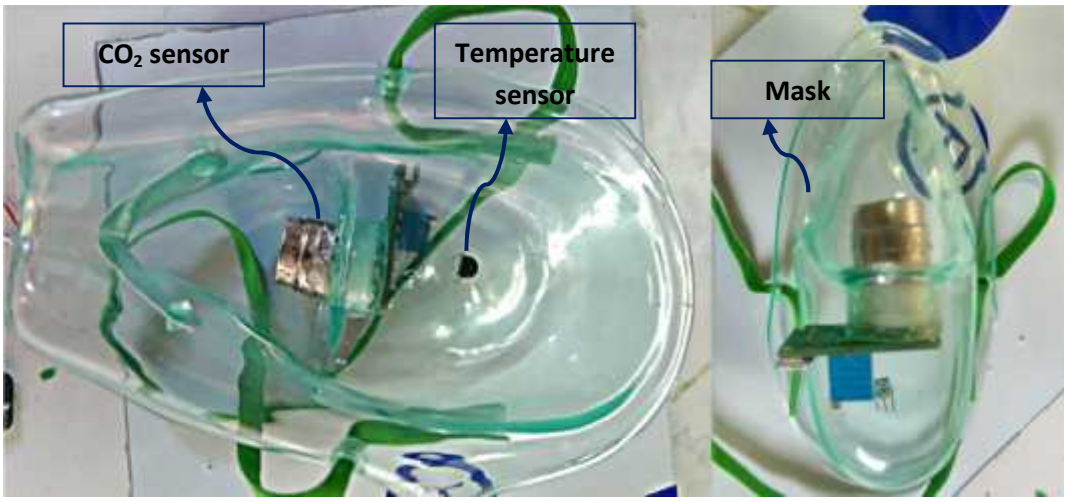


Figure (5.1): Mask and its CO_2 and Temperature Sensors.

5.1.1 Respiratory Rate Measurement Circuit

The temperature sensor used in the respiratory circuit needs calibration in addition to software programming. It is calibrated, tested and programmed on the Arduino as shown in figure (5.2).

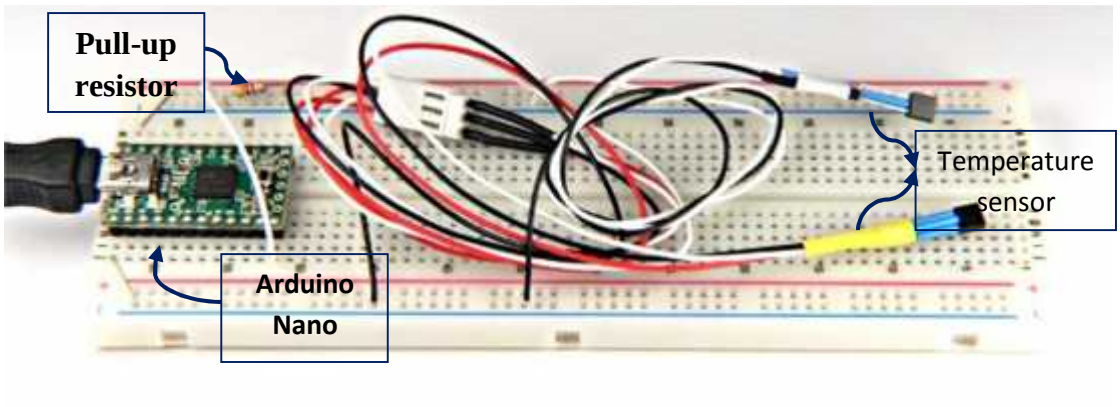


Figure (5.2): Temperature Sensor Circuit.

After programming the sensor, it is fixed on the mask and connected to the Arduino mega to measure the temperature of patient's breath as discussed in the previous chapter.

5.1.2 CO_2 Detector Circuit:

The CO_2 circuit consists of CO_2 sensor and processing circuit. The CO_2 sensor is located in the mask to be close to patient's breath, where the processing circuit is located in the system box. It composed of filtration and amplification circuits as illustrated in figure (5.3).

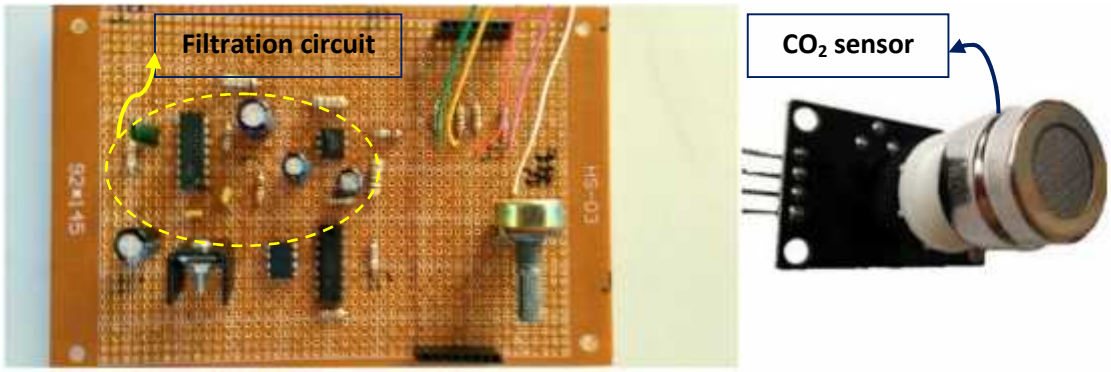


Figure (5.3): CO_2 Detector Circuit.

5.1.3 Heart Rate Measurement Circuit:

The heart rate circuit shown in figure (5.4) consists of two main parts, sensing part and processing part. The sensing part composed of infrared LED and photodetector in addition to their coating (HRM-2511E), it is made of a rubber material to isolate the light from the surrounding environment in order to give better readings. The processing circuit consists of multiple stages to amplify and filter the sensor output signal.

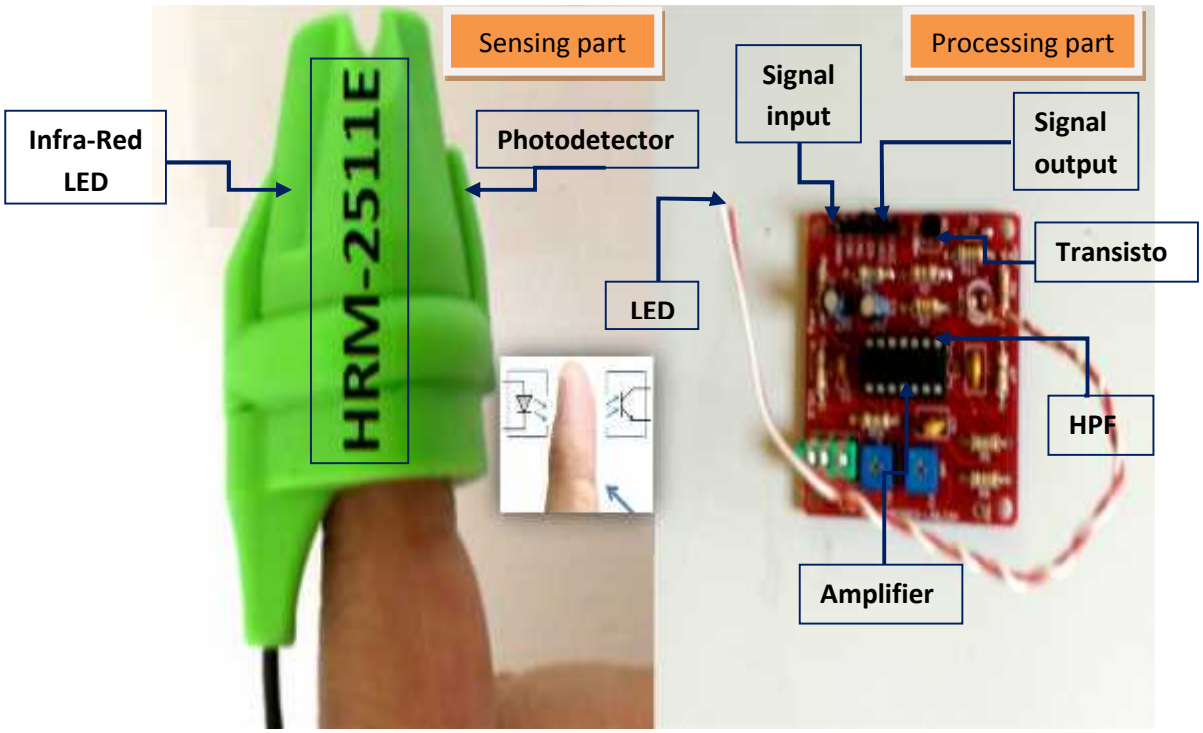


Figure (5.4): Heart Rate Measurement Circuit.

5.1.4 Controller Connections

As mentioned in the previous chapter, the Arduino Mega is the brain of the project, so all of above circuits, LCD, LEDs, Arduino Uno and buzzer are connected to it. This section will show these connections in the following figure (5.5).

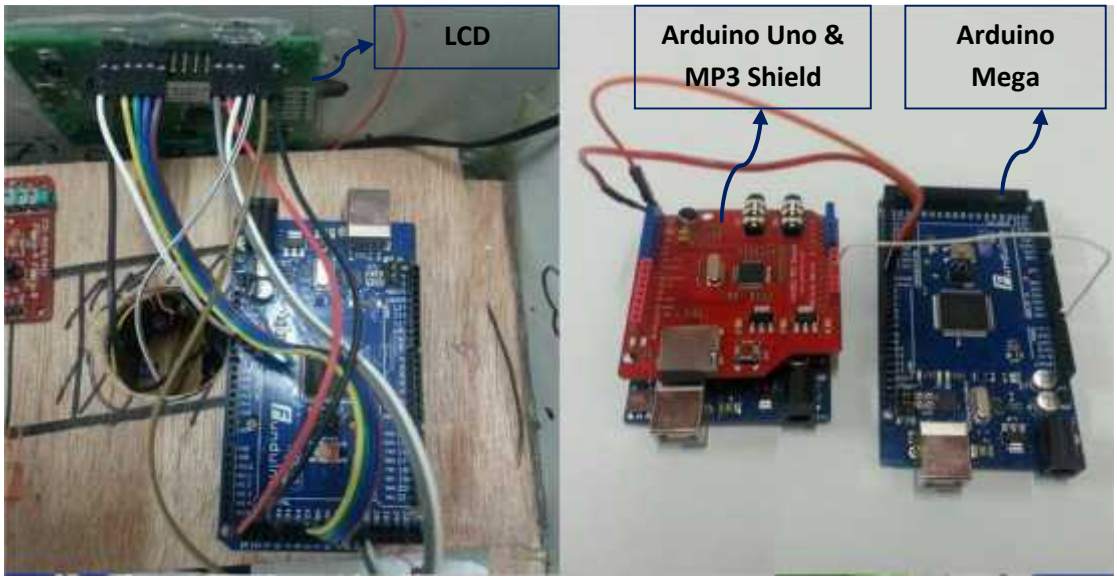


Figure (5.5): Controller Connections.

5.1.5 Power Supply Circuit:

As mentioned in the previous chapter, the power supply circuit is used to provide the required voltage (5V) to the other circuits and subsystems. Figure (5.6) shows power supply circuit and its components.

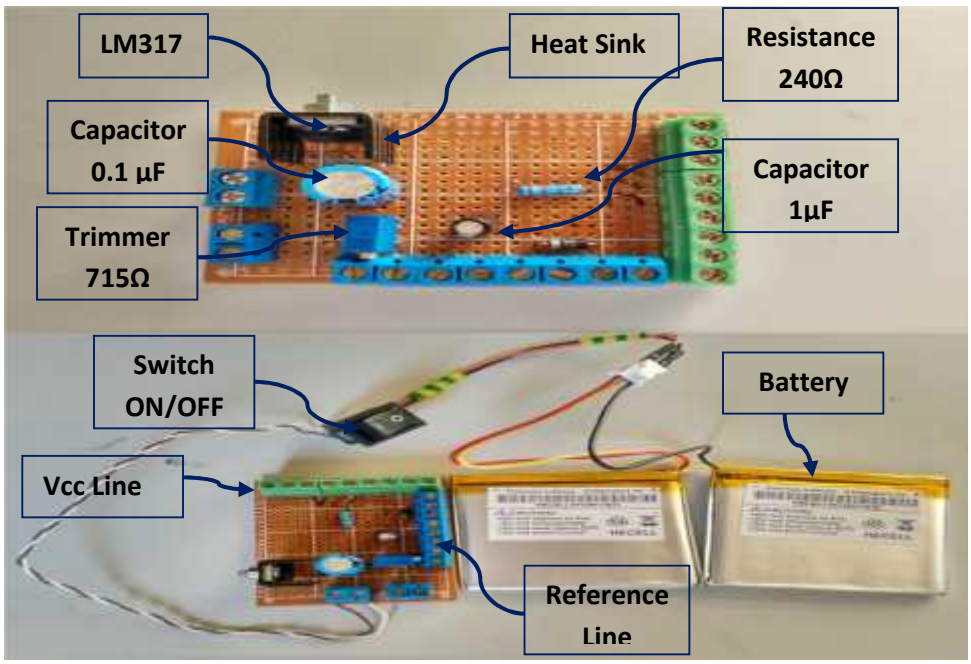


Figure (5.6): Power Supply Circuit.

5.1.6 Overall System Circuit

The overall circuit of the system is shown in the following figure (5.7).

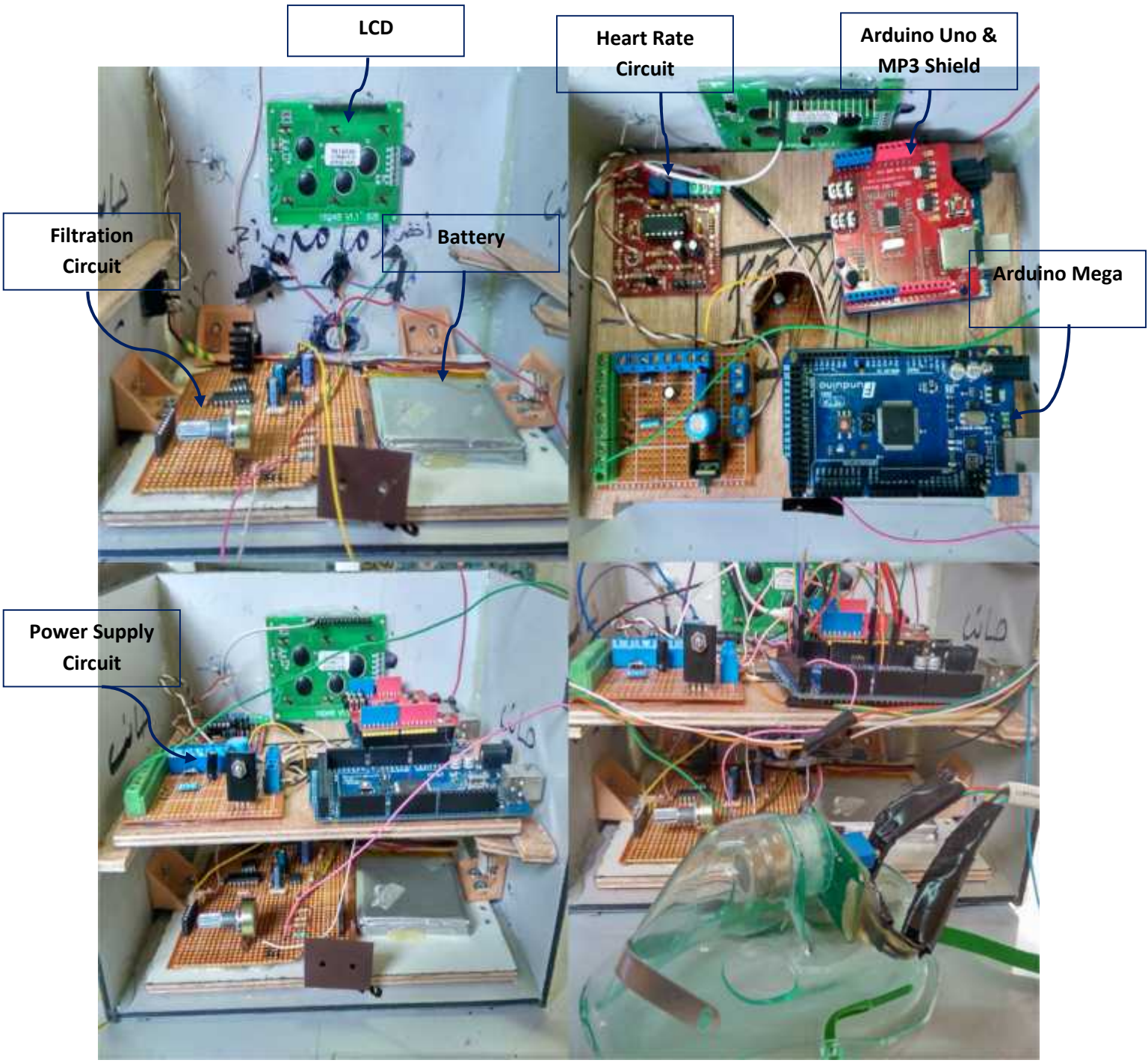


Figure (5.7): Overall System Electrical Circuits.

5.2 Project Testing

According to the project objectives, the system is supposed to provide the user with the heart rate, respiratory rate, and CO_2 concentration readings, and display the results on the LCD screen. Additionally, the system displays the final result of the diagnosis on the LCD screen as shown in figure (5.8). The figure displays the results of diagnosing healthy person. Hence, the green LED is activated.

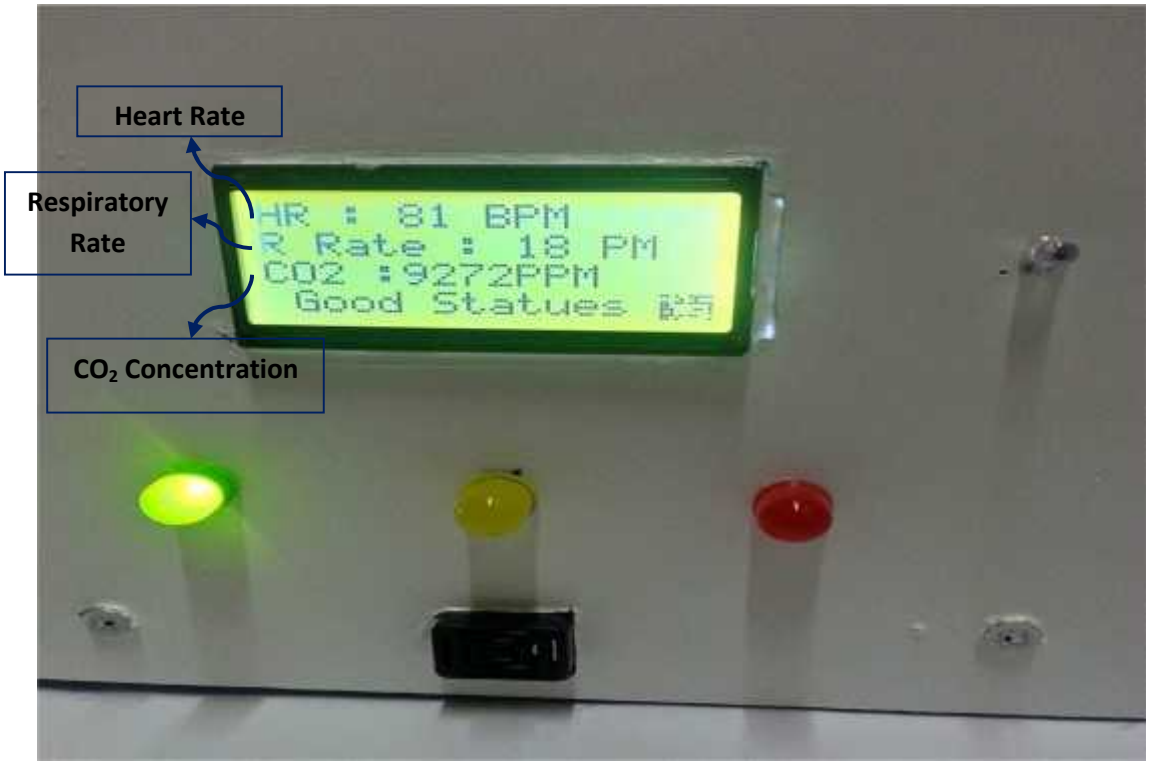


Figure (5.8): Output Readings for normal persons.

Also, the system was tested when there is no contact with patient. The results were displayed as shown in figure (5.9), where respiratory rate and heart rate readings are zero and the CO_2 concentration reading is closely to CO_2 air concentration, therefore the result of diagnosis in this case is emergency case, and red LED and buzzer were activated.

Figure (5.9): Output Readings without person.

Chapter Six
Results and Conclusions

6.1 Results

After the project is installed, its readings are examined on ten persons. The result of all readings is approximately close to the real readings. Table (6.1) shows these readings.

Table (6.1): The Table of the Result.

#	Heart rate (BPM)	Respiratory rate (RPM)	CO_2 concentration (PPM)	Statues of the patient
1	77	14	6703	Good
2	69	15	7558	Good
3	83	21	9635	Good
4	72	16	7852	Good
5	81	17	8569	Good
6	78	19	8264	Good
7	68	14	6882	Good
8	76	17	8783	Good
9	86	18	7892	Good
10	74	15	6775	Good

6.2 Challenges

While designing the system, there are many challenges have been faced, such as:

- Acetone sensor is only available for researchable, and it not allowed commercially.
- Not all required components for this project are available in the Palestinian market; as a result some of main components were purchased from America.
- Some of the project components are expensive.

- The IR sensor of the heart rate is very sensitive for any finger motion.
- The Arduino mega couldn't used for parallel data reading from the sensors.

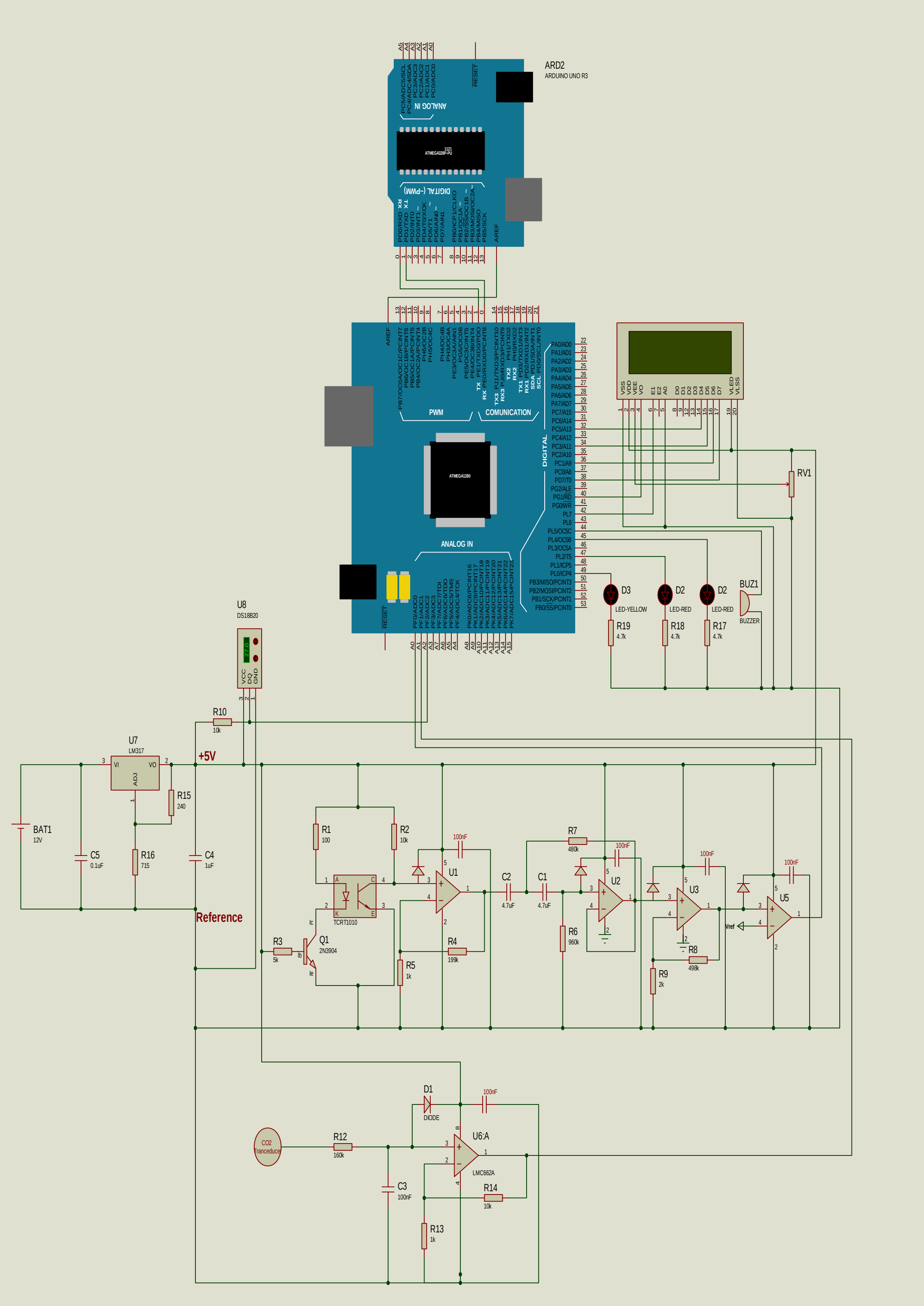
6.3 Conclusions

The CO_2, heart rate, and respiratory rate sensors are used to indicate a very important physiological signs that help diabetes patient and doctors to detect the DKA bout early. After designing, processing, implementing and testing these sensors, the overall system can provide the following features:

- In this project a diagnostic system has been built using a CO_2, heart rate and respiratory rate sensors to detect the DKA.
- A voice commands were used to help the patient who want to use the device.
- The heart rate, Co2 concentration, and respiratory rate sensors are designed to measure continuously.
- The patient can deal with DKA by taken an injection of insulin and potassium.
- The patient can use the device without needing a doctor by following the voice commands.
- The box design was light as possible and combined between beauty and efficiency.

6.4 Recommendations

In this project, the system was designed to detect the DKA bout by detecting a various physiological signs such that CO_2, respiratory and heart rate, but these signs are not sufficient to give the exact total diagnostic, so this project needs more research time to improve its efficiency and some features could be added like acetone sensor when it is available commercially. Also for future works, the telemedicine property and feature can be used to remotely diagnose, treat, and manage the care of DKA patients.


ARD2
ARDUINO UNO R3
ATMEGA328P-PU
ANALOG IN
DIGITAL (~PWM)
ATMEGA1280
PWM
COMUNICATION
ANALOG IN
DIGITAL
U8
DS18B20
RV1
D3
LED-YELLOW
D2
LED-RED
D2
LED-RED
BUZ1
BUZZER
R19
4.7k
R18
4.7k
R17
4.7k
R10
10k
U7
LM317
+5V
R15
240
BAT1
12V
C5
0.1uF
R16
715
C4
1uF
Reference
R1
100
R2
10k
TCRT1010
Q1
2N3904
R3
5k
R4
199k
R5
1k
U1
C2
4.7uF
C1
4.7uF
R7
480k
U2
R6
960k
U3
R8
498k
R9
2k
U5
Vref
100nF
D1
DIODE
CO2 Tranceduce
R12
160k
U6:A
LMC662A
C3
100nF
R14
10k
R13
1k