Graduation project

Hematocrite and Vascular Access Blood Flow Monitoring

Project Team

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Palestine Polytechnic University

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Electrical Engineering Department

Hebron – Palestine

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By the guidance of our supervisor, and by all members in the examining committee, this project delivered to department of electrical engineering in the college of engineering, to be as a partial fulfillment of the requirement of the department for the degree of B.Sc.

Supervisors Signature

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Testing Committee Signature

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I

جامعة بوليتكنك فلسطين

كلية الهندسة والتكنولوجيا

دائرة الهندسة الكهربائية

الخليل ــ فلسطين

أسماء الطلبة

معتز أبو سنينة   يوسف سرغلي

فادي أبو صبح   بهاء الفقيه

بناء على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة , تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية , وذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة الأجهزة الطبية .

توقيع المشرفين

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توقيع اللجنة الممتحنة

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توقيع رئيس الدائرة

Abstract:

It is known that an increase or decrease of fluid in the blood may cause a defect in some of the body function. Hematocrite is and indicator of the fluid. The measurement of access blood flow rate helps nursing staff in the dialysis unit to adjust the speed of the peristaltic pump and recirculation ratio which helps to predict the incidence of thrombosis and stenosis at this access.

This project aims to design and implement a system for measuring the Hematocrite (HCT) percentage in the blood using the optical method. The idea is to use two LEDs with different wavelengths, one transmits visible beam and the other transmits infrared beam. Then, the system calculates the value of light transmittance for each wavelength. Comparing the light transmittance between the wavelengths, it is possible to obtain an estimate of the HCT percentage. This can be used to calculate the blood plasma volume. Further, the system is capable of measuring vascular access blood flow rate and recirculation ratio in patient access. This is achieved by using a technology and based on the temperature difference between the blood in the artery and the blood in the vein.

الملخص :-

من المعروف ان زيادة أو نقصان السوائل في الدم يسبب خلل في عمل بعض وظائف الجسم ,و لمعرفة اذا كانت السوائل ضمن المدى الطبيعي نستخدم قياس الهيماتوكرت (نسبة حجم خلايا الدم الحمراء الى الحجم الكلي للدم) حيث انه اذا زادت نسبة السوائل في الدم فان قيمة الهيماتوكريت تقل واذا قلت نسبة السوائل في الدم فان قيمة الهيماتوكريت تزداد, وأيضا قياس تدفق الدم الجاري في الوصلة الصناعية يساعد الطاقم المسؤل في وحدة غسيل الكلى على ضبط سرعة مضخة سحب الدم ونسبة الترشيح تساعد في التنبؤ بحدوث تجلطات و تضيقات في هذه الوصلة .

يهدف هذا المشروع إلى قياس عدة معاملات, أولا قياس نسبة الهيماتوكرت في الدم بإستخدم الطريقة الضوئية وتتم عن طريق استخدام مصدرين من ثنائي الباعث الضوئي ذو طولين موجبين احدهما يصدر أشعة مرئية والأخر يصدر أشعة تحت الحمراء وبحساب قيمة اختراق الضوء لكل طول موجي وإجراء مقارنة اختراق الضوء بين الطولين الموجبين نحصل على قيمة الهيماتوكرت ومن خلالها نقوم بحساب حجم بلازما الدم . ثانيا حساب معدل تدفق الدم ونسبة إعادة الدوران (access recirculation ratio) في الوصلة الشريانية الوريدية اعتمادا على فرق درجة الحرارة الدم في خط الوريد وخط الشريان .

إلى الذيـن يحملون شعلـة الفكر وهـاجـة ، ومـصابيـح الثقافـة وضـاءة ، فيبـددون بشعاعهـا ظلمـة ليالينا، ويعبـدون بنورهـا طـريـق نهارنـا .

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مقتـد برسـول الرحمـة والخيـر .

إلى كـل مربٍ سائـر في درب الهـدى ......

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إلى هؤلاء جميعـا... نهدي هذه الدراسـة.

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Abbreviations

ESRD: End-Stage Renal Disease

PD: Peritoneal Dialysis

HD: Hemodialysis.

ESRF: End-Stage Renal Failure

RC-AVF: Radiocephalic Arteriovenous Fistula

AVF: Arteriovenous Fistula

AVG: Arteriovenous Graft

IH: Intimal Hyperplasia

RBC: Red Blood Cells

WBC: White Blood Cells

HCT: Hematocrit

AR: Access Recirculation

Q_A**:** Access flow rate

Q_B **:** extracorporeal blood pump speed in ml/min

Q_S: Shunt blood flow rate

CPR: Cardiopulmonary Recirculation

Q_{SYS}: Systemic flow rate

BV: Blood Volume

BTM: blood temperature monitor

T_{ART} : Arterial temperature

T_{vein} : Vein temperature

TGM: Temperature Gradients Method

PCV: Packed Cell Volume

PV: plasma volume

VR: total volume of RBCs**.**

A: Absorbance

I: Intensity of transmitted light

I_0: Intensity of incident light

T: Transmittance

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Chapter one

Introduction

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1.1 Project Overview

Vascular access problems are responsible for a considerable amount of morbidity inpatients on HD (hemodialysis). Access dysfunction accounts for approximately 25% of hospitalizations, with consequent major healthcare costs. Dysfunction of the vascular access limits efficient HD treatment and may result in under dialysis and in consequence to increased morbidity and mortality, Logically, strategies to prevent access failure are of the most importance, Though guidelines recommend access surveillance programs, preferably based on access flow monitoring, also, Blood Hematocrite measures the volume of red blood cells compared to the total blood volume, The normal Hematocrite for men is 40 to 54%; and for women it is 36 to 48%. During hemodialysis therapy, a large amount of water is removed from the patient's blood in a short time. As water is removed, the circulating serum proteins become more concentrated ,determination of Hematocrite, on a periodic or continuous monitoring is essential for patients to give the value of fluid that must removed or added to the blood.

This project describes and evaluates temperature and optical methods for measuring access blood flow rate and Hematocrite during hemodialysis treatment.

1.2 Project objectives

1. To measure the blood flow rate in the vascular access of the patient in HD hemodialysis treatment then calculate the recirculation ratio in the vascular access.

2. Measure the Hematocrite percentage by using optical method and calculate the plasma volume from it to help patient when fluids replacement occur.

3. Check if the patient has stenosis or thrombosis in patient vascular access blood.

1.3 Literature Review

- **Vascular Access flow rate:**

There are two previous methods for measuring vascular access flow rate:

[1] Ultrasound Dilution:

Flow in peripheral arteriovenous fistulas and grafts were examined using an indicator dilution technique while the patient's blood lines were reversed. The indicator was a bolus of normal saline detected by an ultrasound flow sensor clamped onto the patient's blood line. The ultrasound sensor measured blood flow in the tubing using an established transit-time method and simultaneously detected saline dilution of the blood from changes in the average cross sectional velocity of an ultrasound beam that illuminated the blood flowing through the tubing

[2] Thermodilution method:

It uses BTM sensor as indicator through dialysate temperature to heat up or cool down the returning blood to the patient. Temperature is registered by two temperature sensors which are placed around the venous and arterial bloodline, the change in temperature will be registered by the sensor placed around the venous bloodline, At the end of the measurement the difference between the venous and arterial bloodline temperatures is displayed then we calculated the access flow from it.

- **Hematocrite:**

Several methods have been proposed for Hematocrite measurements:

[1] Blood sample:

The packed cell volume (PCV) or Hematocrite can be determined
by centrifuging heparinized blood in a capillary tube . This separates the blood into layers. The
volume of packed red blood cells divided by the total volume of the blood sample gives the PCV.

[2] Automated analyzer:

With modern lab equipment, the hematocrit is calculated by an automated analyzer and not
directly measured. It is determined by multiplying the red cell count by the mean cell volume.

[3] Ultrasound method

They determined the value of hematocrit by monitoring changes in ultrasound wave velocity
propagation in plasma as a function of RBC's concentration.

[4] Impedance spectroscopy methods:

The sensor is based on electrical impedance spectroscopy and allows HCT-measurement
inside standard plastic tubing without the requirement to open the existing external blood circulation
system.

1.4Time Schedule

Table 1.1 shows the activities that done in the project, and the time for each one.

Table 1.1: Activities Planning

Weeks / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
System Definition	■	■	■	■												
System Analysis					■	■	■	■								
System Design									■	■	■	■	■			
Presentation Preparing														■	■	■
Documentation				■	■	■	■	■	■	■	■	■	■	■		

1.5 Chapters Contents

Chapter Two: physiological background for patient vascular access and blood structure and kidney structure also hemodialysis machine.

Chapter Three: previous methods for measuring vascular access flow rate,Hematocrite, calculate recirculation ratio and plasma volume in addition to a new method for these parameters (by extracorporeal temperature for vascular access flow and LED light with multiple wavelengths for measuring HCT percentage).

Chapter Four: contains HD Flow diagram, general block diagram for project, and conditioning circuits.

Chapter Five: contains Arduino controller, and general flow chart for project.

Chapter Two

Physiological background

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2.1 Introduction

A healthy kidney is responsible for a continuous balance of the milieu interior through volume and electrolyte control, excretion of waste products, maintenance of the acid/base balance, and production of hormones. In patients with ESRD (end-stage renal disease) these functions are impaired. Renal hormonal functions can, for the larger part, be substituted through medication; the other functions have to be substituted through renal replacement therapy. Besides transplantation, the two major treatment modalities are PD (peritoneal dialysis) and HD (Hemodialysis).[1.pp.12]

2.2 Principles of Hemodialysis

HD machine is one of the most important medical devices that perform renal replacement therapy when someone has ESRF (end-stage renal failure); the machine removes waste products and metabolism from the blood. The HD machine could not replace natural kidney that our God give it to us, and it is classified just as supporting or helping machine, while it performs of 60 -70% from filtration of natural kidney. In HD machine, there are two basic parts that simulate the natural organs in the human body, the blood pump or peristaltic pump simulate the heart pump, it is used to pull blood from the artery. The second part is dialyzer that performs filtering operation which simulates the nephrons in natural kidney. If we make comparison between natural kidney and the artificial kidney.[1.pp.12]

2.3 Types of vascular access

The vascular access is often referred to as being the Achilles heel of HD: In order to achieve efficient cleaning, the blood has to be drained from the patient with an average of 300 to 400 ml/min, resulting in a total of 70 to 90 liters of blood passing the artificial kidney during one HD treatment. It is evident that HD requires a safe, reliable, high efficient, multiple accessible vascular access that offers a high flow.[1.pp.13]

2.3.1 Radio cephalic fistula

The RC-AVF (radio cephalic arteriovenous fistula) at the wrist is the recommended first choice for Hemodialysis access, the created low resistance causes an increase in flow through the artery and the vein, the vein diameter enlarges, and the vein vessel wall thickens. This vascular access is less sensitive for infection because of the subcutaneous position. It has a relatively low complication rate and a long life expectancy, has minor impact on patients daily life, is easy to cannulate for each HD treatment (efficient and multiple accessible), and generates a high flow.[1.pp.13]

2.3.2 Brachial-cubical, cephalic and basilic fistula

Upper arm fistulae are an important alternative for compromised patients. When peripheral vessels are too tiny and diseased for the creation of a radio cephalic fistula, upper arm AVF (arteriovenous fistula) may be indicated. The brachial artery is either anastomosed to the cubital, cephalic or basilic vein.[1. pp. 14]

2.3.3 Arteriovenous graft

An arteriovenous graft can be of biologic or synthetic material; however, synthetic grafts are utilized most frequently. The graft material is implanted subcutaneously into either the fore or upper arm, but the chest or leg area may be used as well. An AVG (arteriovenous graft) is anastomosed to an artery and a vein. It can be used within two weeks after implantation and is easy to cannulate. However, AVG stenosis formation (mostly at the graft-vein anastomoses) will lead to thrombotic occlusion within 12 to 24 months24. IH (Intimal hyperplasia) with smooth muscle cell migration and proliferation and matrix deposition is the major cause for stenosis formation and thrombosis. The etiology of IH is unknown, however, high shear stress due to the unnatural high flow causing turbulent instead of laminar flow, will denudate the endothelial layer, resulting in platelet adhesion and initiation of a cascade of proteins that stimulate the smooth muscle cells to proliferate and migrate. Due to the high thrombosis incidence the AVG is considered second choice for vascular access. [1. pp.14].

2.4 Vascular Access failure

Vascular access problems are responsible for a considerable amount of morbidity in patients on HD. Access dysfunction accounts for approximately 25% of hospitalizations, with consequent major healthcare costs40. Dysfunction of the vascular access limits efficient HD treatment and may result in under dialysis and in consequence to increased morbidity and mortality.[1. PP.15]

2.5 Blood Composition

The blood is the familiar red fluid in the body that contains white and red blood cells, platelets, proteins, and other elements. The blood is transported throughout the body by the system. Blood serves three main purposes in our bodies. First, it is a transport system. Blood delivers oxygen and nutrients, transports hormones and enzymes, and delivers waste products to be excreted. Second, blood helps regulate our pH, as well as our temperature. Finally, products in our blood protect us against disease and also provide clotting agents to stop bleeding. Blood consist of two main components: [2.PP.17-21]

- Plasma, which is a clear extracellular fluid.
- Formed elements, which are made up of the blood cells and platelets.

2.5.1 Plasma

Plasma is a pale-yellowish, watery solution that suspends all of the other parts of the blood. It makes up about 55% of the total volume of our blood. Plasma itself is made up of 91.5% water. It acts as a solvent for important proteins, nutrients, electrolytes, gases, and other substances essential to life.

Plasma is made mostly of water. This allows our blood to flow freely through our blood vessels, transporting a variety of substances throughout our entire body. We can think of plasma as

the river upon which particles can travel and be delivered where needed. Red blood cells, white blood cells, and platelets are carried in the plasma, transporting oxygen, providing an immune response, and delivering clotting agents when we have a cut. [2.PP.23]

2.5.2 Red blood cells (RBC's)

Red cells, or erythrocytes, are relatively large microscopic cells without nuclei.

Red cells normally make up 40-50% of the total blood volume. They transport oxygen from the lungs to all of the living tissues of the body and carry away carbon dioxide. [2.PP.33]

2.5.3 White blood cells (WBC's)

White cells, or leukocytes , it makes a very small part of blood's volume--normally only about 1% in healthy people Some white cells (called lymphocytes) are the first responders for our immune system. They seek out, identify, and bind to alien protein on bacteria, viruses, and fungi so that they can be removed. Other white cells (called granulocytes and macrophages) then arrive to surround and destroy the alien cells. They also have the function of getting rid of dead or dying blood cells as well as foreign matter such as dust and asbestos. [2.PP.39]

2.5.4 Platelets

Platelets ,or Thrombocytes, are cell fragments without nuclei that work with blood clotting chemicals at the site of wounds. They do this by adhering to the walls of blood vessels, thereby plugging the rupture in the vascular wall. They also can release coagulating chemicals which cause clots to form in the blood that can plug up narrowed blood vessels. [2.PP.52]

2.6Hematocrit

The Hematocrit is the proportion, by volume, of the blood that consists of red blood cells. The HCT (Hematocrit) is expressed as a percentage. [3]

2.6.1 Monitoring of Hematocrit (HCT)

Monitoring Hematocrit is of importance in several clinical applications:

- Monitoring of Hematocrit is essential during dialysis procedure where microfiltration of the blood can lead to inadvertent removal of red blood cells from plasma and thus to reduction of Hematocrit. Rapid determination of Hematocrit is also essential in emergency rooms environment and during open-heart surgery.[3]

- Determining Hemodialysis efficiency.
- Diagnoses diseases by Hematocrit value.

Low Hematocrit may be related to anemia, destruction of red blood cells, leukemia, over hydration, Malnutrition, Nutritional deficiencies of iron, folate, vitamin B12, and vitamin B6

High Hematocrit may be related to Congenital heart disease , Failure of the right side of the heart , Dehydration , Abnormal increase in red blood cells ,Low blood oxygen levels (hypoxia) , Scarring or thickening of the lungs (pulmonary fibrosis) , Bone marrow disease that causes abnormal increase in RBCs (polycythemia Vera) . [3]

2.7 Access Recirculation ratio

Recirculation is a collective term describing any combination of factors causing a proportion of dialyzed blood returning from the dialysis machine to bypass the patient's systemic circulation and to be re-dialyzed. Knowledge of the different forms of recirculation has important implications in the interpretation of recirculation data. AR (Access recirculation) can occur in any method of vascular access. The most basic form of AR can arise in the arterial-venous access (fistula or graft) and is the best illustrated with a simple example. In Figure (2.1) the Fistula is supplied with aQ_A (access flow rate) of 300 ml/min. Blood is drawn from the arterial needle and returned to the fistula downstream via the venous needle. The term shunt used to describe the section of blood vessel between the arterial and venous needle. The value and direction of Q_S (shunt blood flow rate) depends on the access recirculation. As shown in Fig.(2.1.A), in the absence of access recirculation ($Q_A > Q_B$) the shunt blood flow rate (Q_S) is in the forward direction, but when blood flow rate (Q_B) exceeds the available access flow rate (Q_A) as shown in Fig.(2.1.B), flow through the shunt (Q_S) is reversed and access recirculation occurs. Providing the blood flow rate in the extracorporeal circuit (Q_B) is less than Q_A, and then the blood flows in the 'forward' direction through the shunt. Therefore, the shunt flow rate (Q_S) is simply

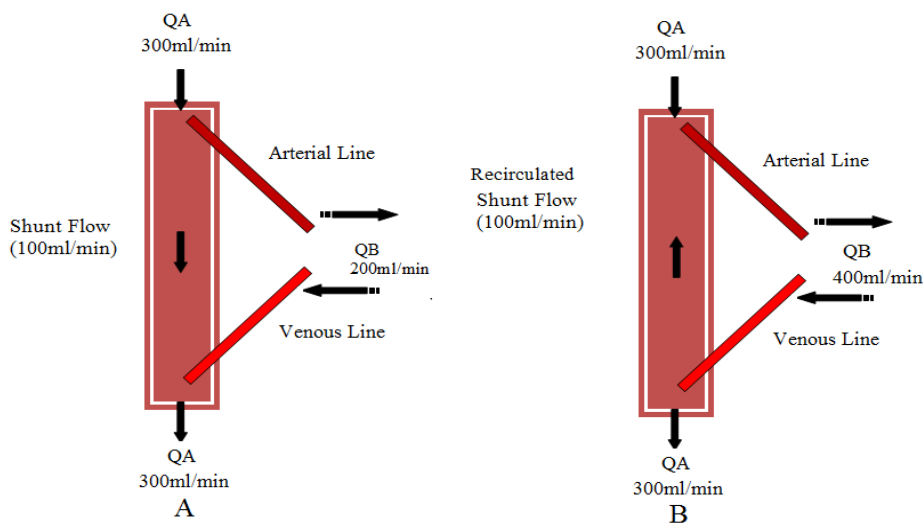$$Q_S = Q_A - Q_B \qquad \text{Equation (2.1)}$$

Figure (2.1): the value and direction of shunt blood flow rate

But if the blood pump demands more flow than the supplied by access (i.e. $Q_B > Q_A$), then the direction of shunt is reversed as shown in Fig. (2.1). Again, the shunt flow must be the difference between Q_A and Q_B (i.e. 100 ml/min). In other words, a proportion of the blood flow rate from the venous needle is drawn back to the arterial needle causing recirculation.[1.pp.60]

$$AR = \frac{Q_B - Q_A}{Q_B} \quad \text{Equation (2.2)}$$

While the fraction of blood which is recirculated, the access recirculation is expressed as normally, access flow rate, Q_A in the arterial-venous access are above 700 ml/min, considerably in excess of the maximum extracorporeal blood flow rate used for dialysis. Therefore, the presence of AR recirculation is usually indicative of stenosis, reducing flow in the access. But we must know that the CPR (cardiopulmonary recirculation) is always present in the arterial-venous access.

Figure (2.2) shows a simplified schematic of the circulatory system, an arterial-venous fistula and an extracorporeal circuit. This Figure illustrates the condition when the extracorporeal blood flow rate (Q_B) is less than the access flow rate (Q_A). The bold figures represent the blood flow rates in the respective limbs of the circuit and the italic figure indicates the flow rates of the dialyzed blood. For simplicity, it is assumed that all of the blood returning from the venous needle has been completely cleared of solute. The ventricles of the heart and the pulmonary vessels of the lungs may be regarded collectively as the cardiopulmonary circulation.
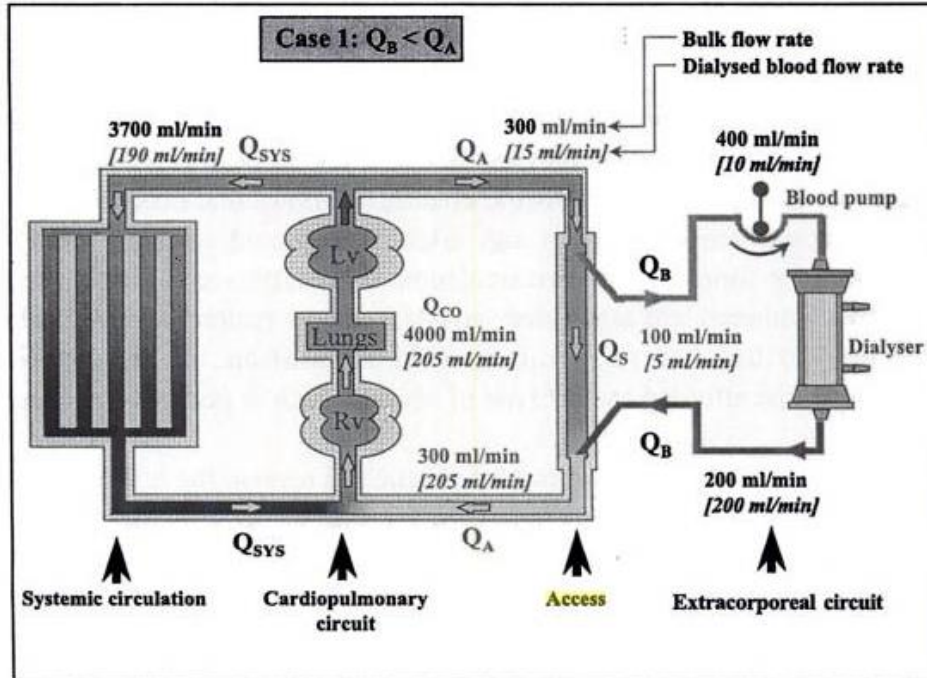
Figure (2.2):simplified schematic of the circulatory system

In normal subject, blood returning from systemic circulation passes through the cardio-pulmonary circulation in a single path. But the creation of a fistula provides a second path through which blood may be returned to the cardio-pulmonary circulation. So the cardiac output divided into two parts: Q_{SYS} (Systemic flow rate) and Q_A. This means that a component of cardiac output containing dialyzed blood is diverted to the arterial end of fistula to be re-dialyzed. If the blood flow rate Q_B in the extracorporeal circuit is less than the available Q_A, then only CPR occurs. That means, there is always a fraction of dialyzed blood which continuously circulates through the fistula and cardiopulmonary circuit, not entering either the systemic circulation or the extracorporeal circuit. If $Q_B > Q_A$, total recirculation ratio will be found (CPR+AR). CPR can be classifying from AR if the value of total recirculation ratio is equal or less than 12% [24].But there are other invasive methods for measuring access recirculation by taking blood samples from patient and measure the urea concentration in these samples and then apply equation.[1.pp.61]

$$R = \left(\frac{S - A}{S - V} \right) \times 100 \text{ Equation (2.3)}$$

Where: **S** is the blood urea nitrogen concentration in peripheral blood sample.

   A is the blood urea nitrogen concentration in arterial blood sample.

   V is the blood urea nitrogen concentration in vein blood sample.

2.8Plasma volume

During hemodialysis   The percentage of increase in Hematocrit during volume removal estimates the percentage of decrease in blood volume accurately , Hemodialysis treatment, besides removing toxic substances and metabolites, also eliminates surplus body water from the blood and from over hydrated tissues, as the circulating plasma volume is only 5% of body weight when the Hematocrit is ~30%, the ultra-filtered water removed in a single dialysis session, may, in some cases, exceed the total circulating plasma volume. To preserve BV (Blood Volume).[4]

$$\text{Plasma Volume (mL)} = (1 - \text{HCT})(b + cW) \qquad\qquad \text{Equation (2.4)}$$

HCT: Hematocrit value, expressed as a fraction from 0to 1 (not a percent).

B: a constant of 1530 for males, 864 for females

C: a constant of 41 for males, 47.9 for females

W: dry weight in Kg

Literature Review

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3.2Flow access monitor by using saline dilution method

3.2.1 Drawbacks

3.3 Flow access monitor by using thermo dilution method

3.3.1 Drawbacks

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3.9LED light with multiple wave length

3.9.1 Reasons for chosen this method

3.1 Introduction

Adequacy of dialysis refers to how well we remove toxins and waste products from the patient's blood. But the Clinical Practice Guideline on Adequacy of Hemodialysis defined adequate hemodialysis as the recommended quantity of hemodialysis delivered which is required for adequate treatment of ESRD such that patients receive full benefit of hemodialysis therapy.

A. *Access flow rate and recirculation ratio previous measuring methods:*

3.2 Flow access monitor by using saline dilution method

Measuring access flow using saline dilution, a bolus of isotonic saline (indicator) is administrated into the venous bubble trap after line reversal. Two ultrasound dilution sensors are clamped onto the bloodlines, one on the arterial and one on the venous bloodline. The venous saline dilution sensor will first sense the diluted blood used as a reference value to calculate the actual recirculation (R) of saline entering the arterial line. Besides sensing dilution, the ultrasound sensors simultaneously measure blood flow in the bloodlines (Qb). Qa can now be calculated with the formula. [1.pp.55]

$$Qa = Qb * (\frac{1-R}{R}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{Equation (3.1)}$$

This method is based on reversed line position. The Purpose of reversed line position is to enable delivery of indicator into the venous dialyzer line upstream of the access, and then to be able to sample downstream of the access (after the indicator has mixed) in the arterial line.[1.pp.56]

Measuring access flow with the use of the Transonic HD01, a bolus of isotonic saline(indicator) is administrated in the venous bubble trap after line reversal. The administration time has to be less than six seconds to prevent cardiopulmonary recirculation. Two ultrasound dilution sensors are clamped onto the bloodlines, one on the arterial and one on the venous bloodline. The venous saline dilution sensor will first sense the diluted blood (ultrasound velocity

blood: 1560-1590 m/s, isotonic saline 0,9%:1533 m/s), which is a reference value to calculate the actual recirculation, which is what is left of the dilution in the arterial line, after passing the access.[1.pp.54].
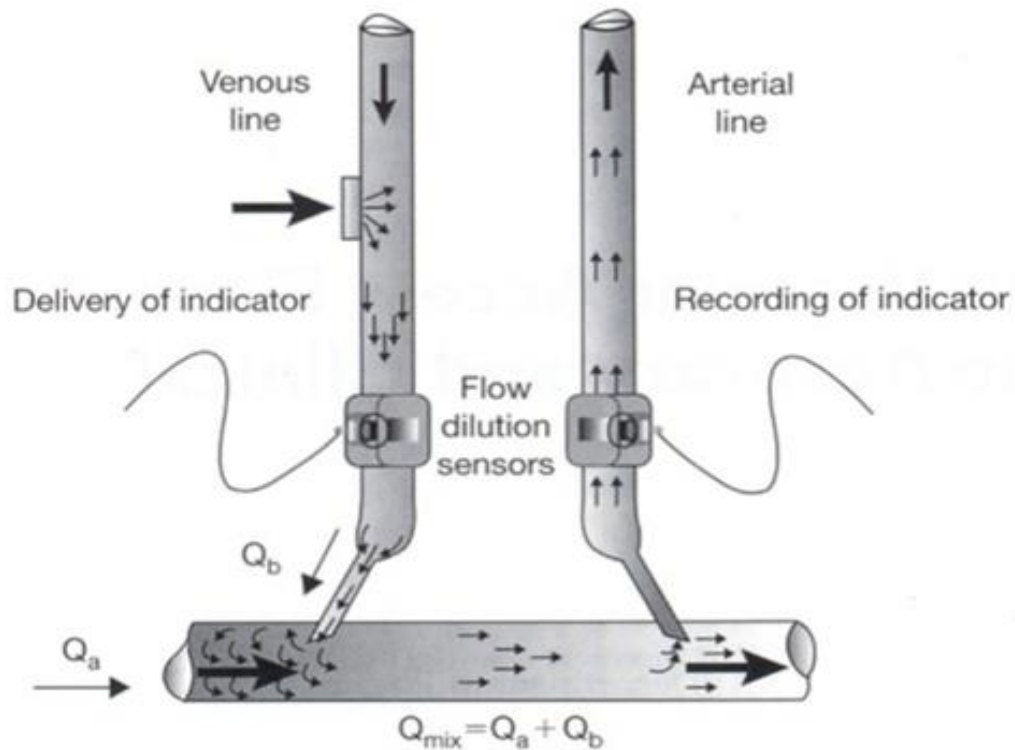
Figure (3.1):flow access using saline dilution method

Besides sensing dilution, the saline dilution sensors simultaneously measure blood flow in the bloodlines. The obtained recirculation fraction (R) and measured extracorporeal blood flow (Qb) provide the possibility to calculate access flow (Qa) according to equation (3.1).

Recirculation measurement with the saline dilution technique is performed with normal extracorporeal line position. The administered bolus of isotonic saline in the venous bubble trap will

disappear upstream of the access. However, when vascular access recirculation appears a fraction of the administered saline will be sensed in the arterial line.[1.pp.55]

3.2.1 Drawbacks: The insertion of saline dilution cause thrombosis

3.3 flow access monitor by using thermo dilution method

The BTM (Blood temperature monitor) uses temperature as indicator through dialysate temperature to heat up or cool down the returning blood to the patient. Temperature is by two temperature sensors which are placed around the venous and arterial bloodline, both located one meter from the access. When the blood temperature downstream the artificial kidney drops or raises the change in temperature will be registered by the sensor placed around the venous bloodline. This same temperature change will affect the temperature of the central blood volume when it enters the patient's bloodstream. Through cardiopulmonary recirculation the extracorporeal induced temperature change will be sensed by the temperature sensor clamped around the arterial blood line (Figure 3.2.). At the end of the measurement the difference between the venous and arterial bloodline temperatures is displayed on the BTM monitor as a relative value and stands for the temperature recirculation RBTM,x(reversed blood temperature monitor), caused by cardiopulmonary recirculation. The relative recirculation value obtained by executing this measurement with reversed bloodlines RBTM,x, includes both the recirculation over the access and the cardiopulmonary recirculation, due to measurement time which takes approximately five minutes and is technique dependent. To separate the cardiopulmonary induced temperature recirculation from the recirculation fraction over the access, the ratio of access flow to cardiac output has to be defined using the "double recirculation technique"9 and stands for the actual cardiopulmonary recirculation.[1.pp.55]
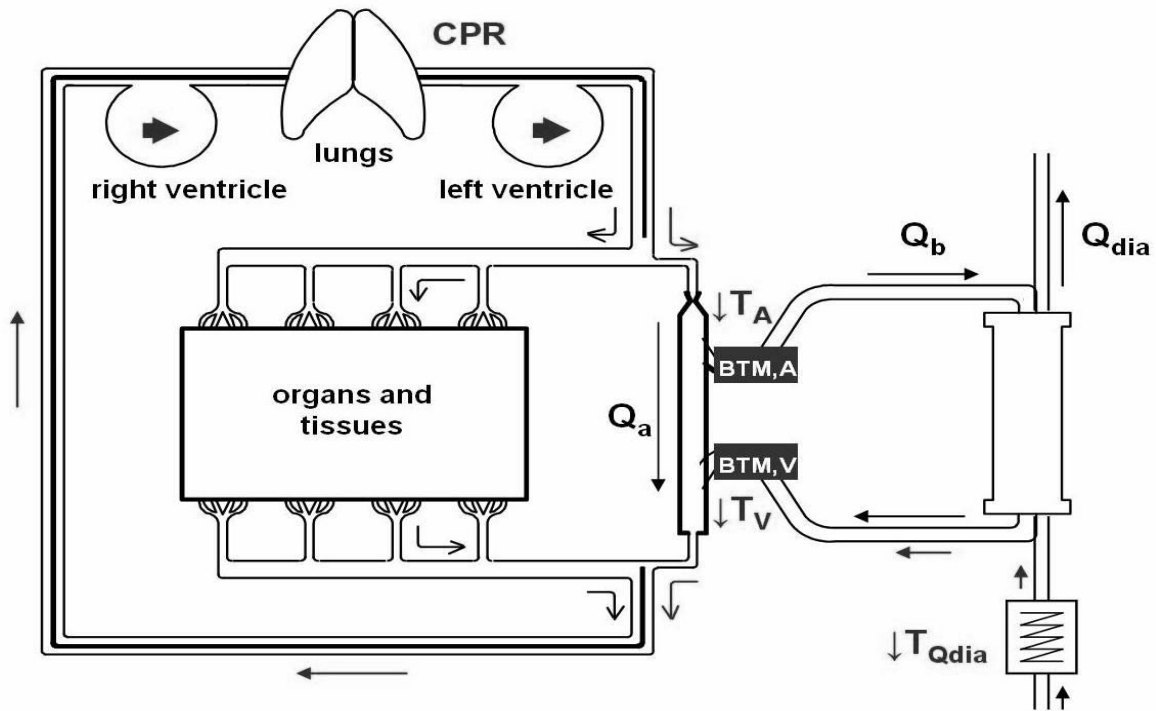
Figure (3.2).The location of temperature sensors

$$Qa = \left(Qb, x - \left(\frac{UFR}{60}\right)\right) * \left(\frac{(1-RBTM,x)}{(RBTM,x*\{(1-\left(RBTM,x\frac{(1-RBTM,n)}{RBTM,n(1-RBTM,x)}\right)*\left(\frac{Qb,x-\frac{UFR}{60}}{Qb,n}\right)\}}\right)$$ ....**Equation (3.2)**

Where:

Q*b, n:* Extra corporeal blood flow with normal line position

Qb, x: The extra corporeal blood flow with reversed line position

UFR: Ultra filtration rate

Qa: Extracorporeal pump speed corrected for the arterial pressure.

RBTM, n: Cardiopulmonary recirculation

RBTM, x: The relative recirculation value obtained by with reversed bloodlines

3.3.1 Drawbacks:

The use of this technique takes a large time compared to other ways .

3.4Flow access monitoring by using extracorporeal temperature gradients

When blood lines are reversed, the Tart (arterial temperature) leaving the access is the result of the mixture of access inflow temperature and the temperature of venous line
Blood returning to the access as shown in (Figure 3.3).[1.pp.68]
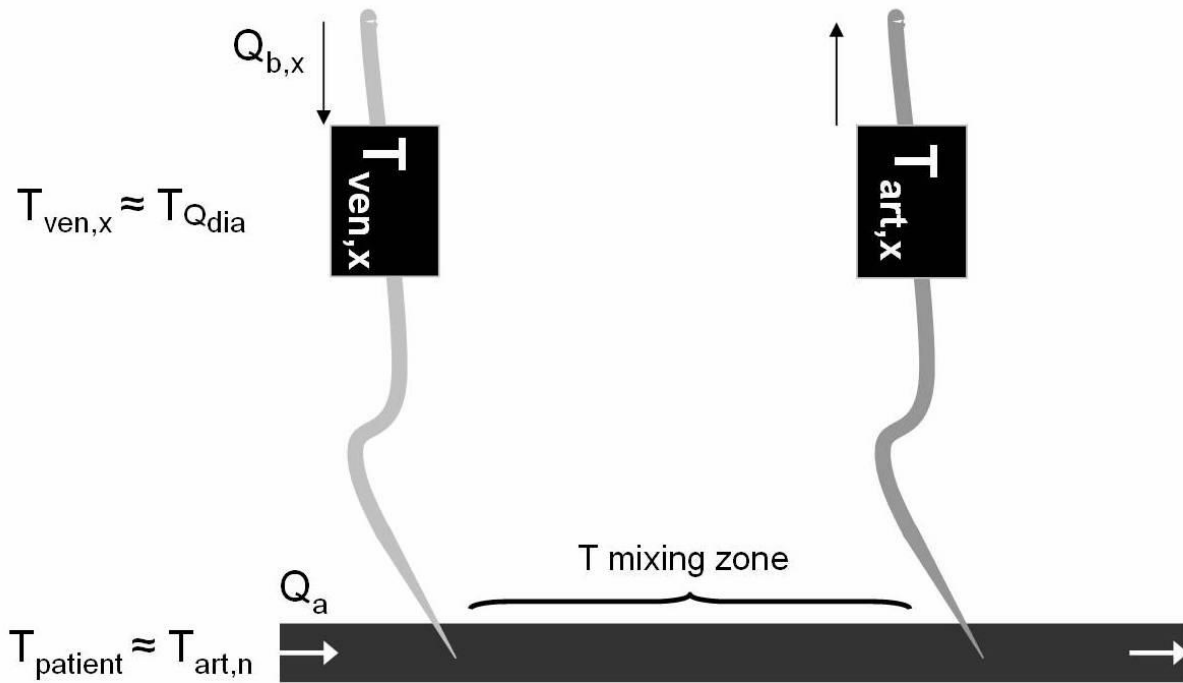

Figure (3.3): Flow access monitoring by using extracorporeal temperature gradients.

$$QA = (QBx - UFR) * \{^{Tart,n}/_{Tven,x}\}.......................................\text{Equation (3.3)}$$

X: indicates the reversal position of the lines

n: indicates the normal position of the lines

The measurement of Qa therefore requires the measurement of arterial and venous line temperatures with correct and reversed placement of blood lines in the presence of arterio-venous temperature gradients. Since arterial and venous temperatures are continuously measured in the current BTM configuration, the measurement of Qa only requires to reverse the arterial and venous line and to measure the step-change in arterial line temperature. [1.pp.69]

3.4.1 The reasons for choose this method

- High correlation of measurements obtained by TGM (Temperature Gradients Method) and saline dilution techniques.

- High reproducibility of subsequent weekly measurements.

- The TGM (temperature gradients method) Qa measurement was quick and simple, as it is no longer required to inject an indicator.

B. *Hematocrit and plasma volume previous measuring methods:*

3.5 Blood sample

The PCV (packed cell volume) or Hematocrit can be determined by centrifuging heparinized blood in a capillary tube (also known as a micro hematocrit tube) at 10,000 RPM for five minutes. This separates the blood into layers. The volume of packed red blood cells divided by the total volume of the blood sample gives the PCV. Since a tube is used, this can be calculated by measuring the lengths of the layers as illustrated in Figure (3.4). [5]
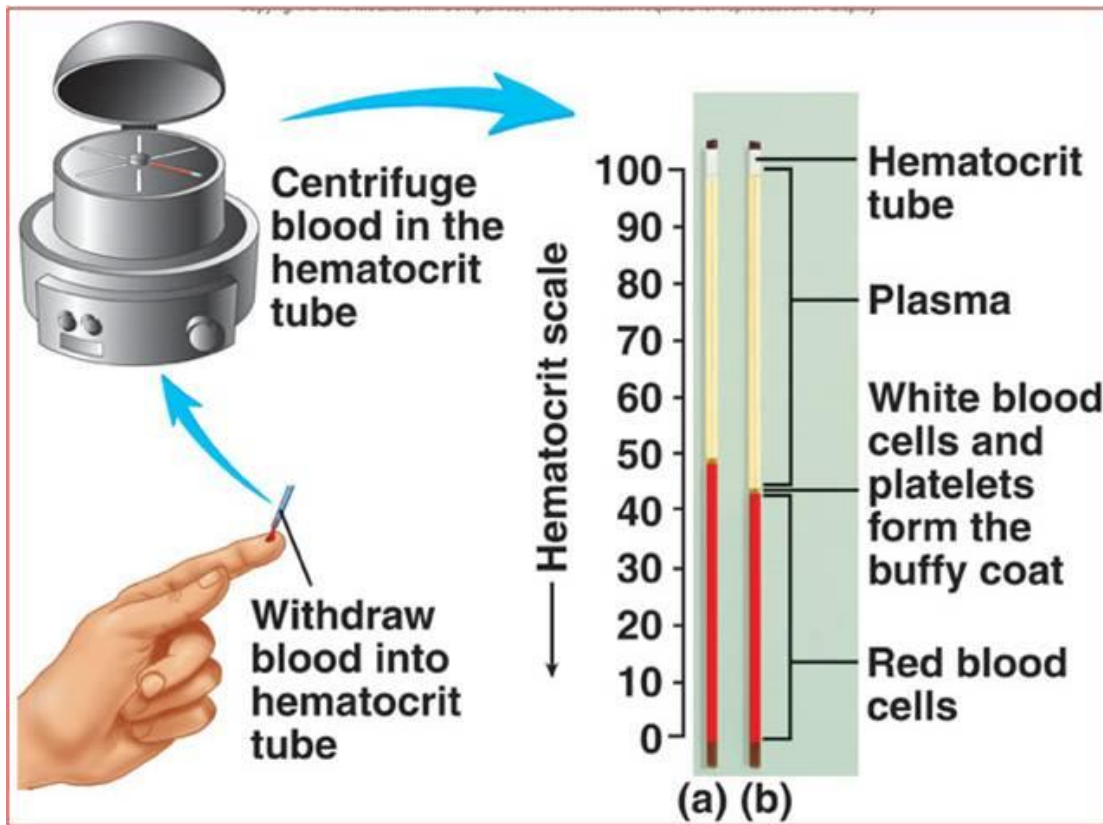
Figure (3.4) Hematocrit measurement by blood sample

3.6 Automated analyzer

With modern lab equipment, the Hematocrit is calculated by an automated analyzer and not directly measured. It is determined by multiplying the red cell count by the mean cell volume. The Hematocrit is slightly more accurate as the PCV includes small amounts of blood plasma trapped between the red cells as shown in figure (3.5). An estimated Hematocrit as a percentage may be derived by tripling the hemoglobin concentration in g/dL and dropping the units. [5]

Figure (3.5): Automated analyzer

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3.7 Ultrasound method

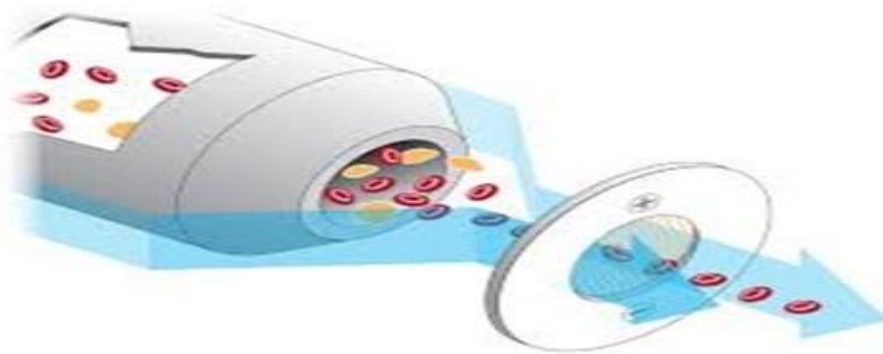They determined the value of Hematocrit by monitoring changes in ultrasound wave velocity propagation in plasma as a function of RBC's concentration. Although they reported good correlation between their measurements and the real value of the Hematocrit, they noted that the uncertainty of the method depended markedly on even minute temperature variations. A Doppler ultrasound method. [6]

The results demonstrated that Hematocrit could be non-invasively determined in the brachial artery to within an error of 5%. However, it was observed that the lateral movement of the vessel induces additional errors. [6]

$$HCT = A \times (\alpha - \alpha 0)$$...Equation (3.4)

Where α is equal to the total acoustic pressure attenuation, and α0 is the acoustic attenuation in plasma and A is a constant determined from the linear regression analysis of
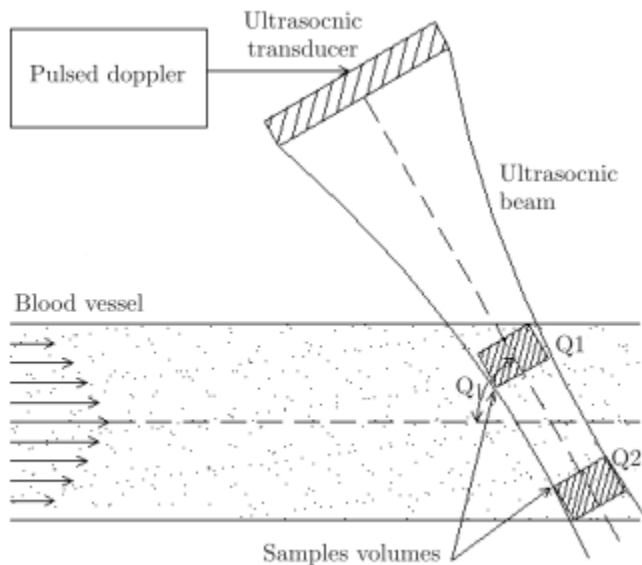The experimental data.[6]

Figure (3.6): Doppler method

Q1, 2 denotes the backscattering coefficient of red blood cells

3.8impedance spectroscopy method

The sensor is based on electrical impedance spectroscopy and allows HCT-measurement inside standard plastic tubing without the requirement to open the existing external blood circulation system. No additional device has to be inserted into the circuit and therefore there is no direct contact between the sensor and the blood. The presented HCT-sensor measures electrical properties of the blood inside the plastic tubing at various frequencies. Since the sensor electrodes are attached to the outer wall of the plastic tubing the sensor measures the properties of the tubing material in addition to the properties of the blood inside the tubing. [7]

$$HCT = (\frac{VR}{VP+VR}) * 100\% \dots\dots\dots\dots\dots\text{Equation (3.5)}$$

$$VR = (\frac{1}{Ri}) \dots\dots\dots\dots\dots\text{Equation (3.6)}$$

$$VP = (\frac{1}{Rp}) \dots\dots\dots\dots\dots\text{Equation (3.7)}$$

$$HCT = \left(\frac{Rp}{Ri+Rp}\right) 100\% \dots\dots\dots\dots\text{Equation (3.8)}$$

Where: **VP** is the plasma volume and **VR:** is the total volume of RBCs**.**

3.9LED light with multiple wave length

An optical method for obtaining Hematocrit values of blood uses the light transmittance properties of blood as a means of acquiring information about the blood sample. An algorithm is used to calculate the Hematocrit value based on the absorbance spectra obtained at wavelengths of 585 nm and 875 nm. These absorbance wavelengths are selected for their insensitivity to the oxygen saturation level of hemoglobin. Additionally, the algorithm has demonstrated insensitivity to plasma and other blood constituent scattering effects. [8.PP.223-226]

$$\%T = \frac{I}{I_0} * 100\% \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation (3.9)}$$

Where:

I_0 is the intensity of incident light, I is the intensity of transmittance light

$$A = 2 - log(T\%) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation (3.10)}$$

A is the absorbance.

Noise reduction:

When LED off, the measured value is noise thermal and ambient light or any common mode this value must subtracted from results when LED on.

$$I_{finger} = I_{on} - I_{off} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation (3.11)}$$

$$T(\lambda)\% = \frac{I_{finger}}{I_{reference}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation (3.12)}$$

T (λ) % is the percentage of light transmittance passed the finger after normalize, I $_{finger}$ is the light transmittance from LED passed finger to photo detector when the fingertip is in probe, I $_{reference}$ is the light transmittance of LED to photo detector without the fingertip that mean 100% of light transmission (I_0)

$$I = I_0 e^{-\mu x} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation (3.13)}$$

Where μ is called the absorption coefficient and is dependent on energy

$$I_{585=}I_0 e^{-(aHb0+bHb+RBC+Plasma+nail+tissue+pigement)}$$

$$I_{875} = I_0 e^{-(RBC+Plasma+nail+tissue+pigement)}$$

$$T_{585=\frac{I}{I_0}} = e^{-(aHb0+bHb+RBC+Plasma+nail+tissue+pigement)}$$

$$T_{875} = \frac{I}{I_0} = e^{-(RBC+Plasma+nail+tissue+pigement)}$$

$$T_{585}\text{-}T_{875=} \ e^{-(aHb0+bHb)} \quad\text{...} \quad\text{........}\textbf{Equation (3.14)}$$

a, and b are extinction coefficients of oxyhemoglobin and deoxyhemoglobin very small estimated equal to constant k

$$a = b = k\text{..}\textbf{Equation (3.15)}$$

Hematocrit is the sum of oxyhemoglobin and deoxyhemoglobin

$$HCT = Hb_o + Hb\text{...}\textbf{Equation (3.16)}$$

$$T_{585}\text{-}T_{875} = e^{-k(HCT)}$$

$$K\,(Hct) = \ln(T_{585}) - \ln(T_{875}) \quad\text{..}\textbf{Equation (3.17)}$$

$$\Delta T = \ln(T_{585}) - \ln(T_{875}) \quad\text{..}\textbf{Equation (3.18)}$$

$$\mathbf{HCT = \frac{\Delta T}{K}} \text{ ….} \textbf{Equation (3.19)}$$

$$\mathbf{tHB = \left(\frac{g}{dl}\right) = 0.33Hct(\%)} \text{ ….} \textbf{Equation (3.20)}$$

Figure (3.7): LED method

3.9.1 Reasons for chose this method

1. there is no direct contact between the sensor and the blood

2. This method does not cause inflammation or infection because it is not use needles

3. It gives direct results (Online results).

4. Saving time and power

Chapter Four

Hardware Design

4.1 Introduction

4.2 HD Flow Diagram

4.2.1 Blood Circuit

4.2.2 Dialysate Circuit

4.3 Project Block Diagram & Circuits

4.3.1 Temperature sensor

4.3.2 Sensor measurement circuit

4.3.3 Matching circuit

4.3.4 Non-Inverting Operation Amplifier

4.3.5 Transmitters

4.3.6 Constant current source for driving LEDs

4.3.7   Phototransistors

4.3.8 High Pass Filter

4.3.9 Low pass filter

4.4   Project Circuits

4.1 Introduction

This chapter discussed and explains a hardware design of the project, its circuits, and calculation.

4.2 HD Flow Diagram

Figure 4.1, shows Hemodialysis (HD) Flow diagram and the position of temperature sensors that are used in our project, the flow diagram consists from two parts: blood circuit and dialysate circuit.
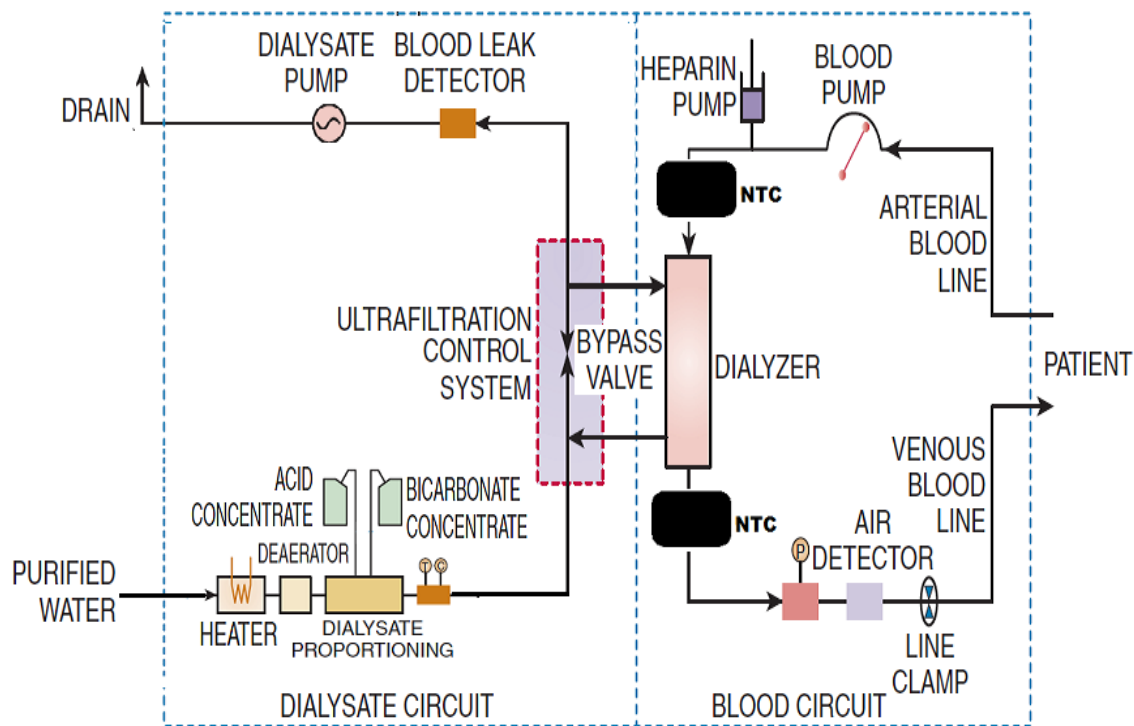

Figure (4.1): HD Flow Diagram

4.2.1 Blood Circuit

The patient's blood is continuously pumped by peristaltic blood pump from an artery, a large vein, or a surgically modified vein to allow high blood flow rates. Its pressure is monitored both upstream and downstream by using pressure sensor. Before the blood enters the dialyzer, heparin is added to prevent clotting. A syringe pump is used to deliver the heparin at a precisely controlled rate.

The blood then enters the dialyzer where it passes across a fiber in dialyzer. These fibers are from semi- permeable membrane but the dialysate solution enters around the fibers in dialyzer. A pressure gradient is maintained across the membrane to ensure the proper flow of compounds out of and into the blood. After cleaning and balancing within the dialysate, the blood is passed through an air trap that contains US sensor to detect if there is any air bubbles in return blood or not, so if it's found the machine activate an air bubbles alarm and the clamp closed before it is returned to the patient and stop the blood pump, as we shown in the previous flow diagram there are two temperature sensors before and after the dialyzer, the main objective of these is to measure the access flow rate of patient.

4.2.2 Dialysate Circuit

Treated water inflows from the RO (Reverse Osmosis) system into the dialysis machine and passes through the heater ,water is heated to body temperature (33°–39°C) ,and it temperature is monitored by a special temperature monitoring device. Air bubbles in purified water removed by deaeration (air degassing pump). Proportioning pump assures proper mixing of heated water with fresh dialysate acid and bicarbonate solution to produce the appropriate dialysate solution. Temperature sensor and conductivity cell monitors dialysate temperature and the conductivity respectively, if there are problem in temperature or conductivity or both of them the dialysate solution passes to drain by activate bypass valve .But when the dialysate temperature and conductivity are correct the dialysate solution passes through the dialyzer.

Conductivity is the amount of electrical current conducted through a dialysate and reflects electrolyte concentration; a constant current is applied across two electrodes 1 cm apart in the dialysate flow. After exchange process complete between blood and dialysate solution the spent dialysate passes through the blood leak detector that detect if there is blood leak in spent dialysate or not. The waste dialysis solution with drawn to drain by the dialysate pump.

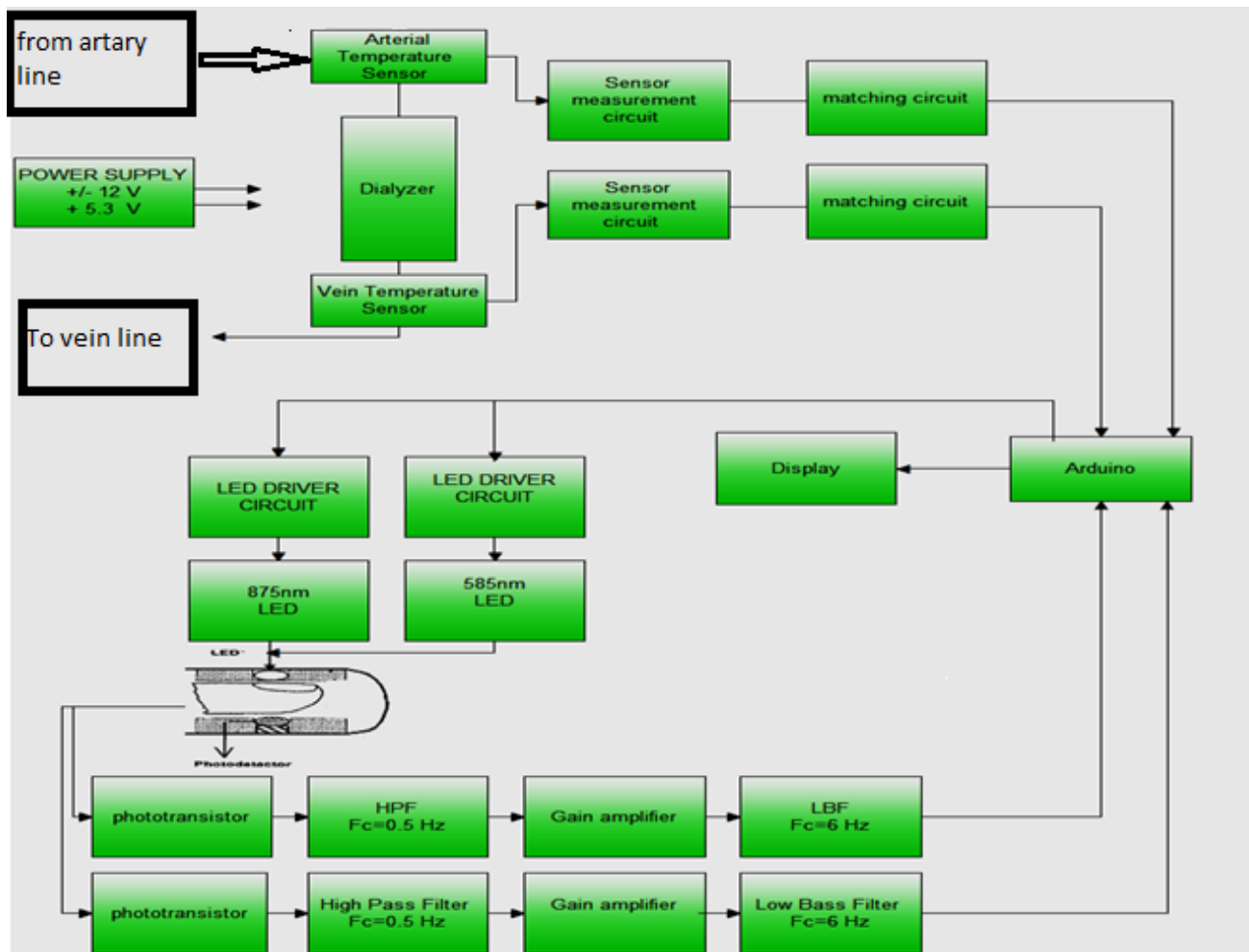## 4.3 Project Block Diagram & Circuits

Figure (4.2): Project Block Diagram

Figure(4.2) shows the project block diagram that consist of two hardware parts ,one for the access blood flow rate measurement that contains arterial and vein circuits to measure the arterial and vein temperature , and the second part of block diagram contains the hardware design that is used to measure the HCT from the patient finger.

4.3.1 Temperature Sensor

A Thermistor is a type of resistor used to measure temperature changes, relying on the change on its resistance with changing temperature. If we assume that the relationship between resistance and temperature is linear (i.e. we make a first-order approximation), then we can say that:

$\varDelta R = k * \varDelta T$ ……………………………………………………………………..……. **Equation (4.1)**

Where:

ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance.

STS-400 skin temperature sensors is one of smith medical products have a thermistor sensor that meets standards of current leakage for minimal likelihood of patient shock or burn. They also feature soft, flexible foam with adhesive for easy placement and removal with little irritation. [9]
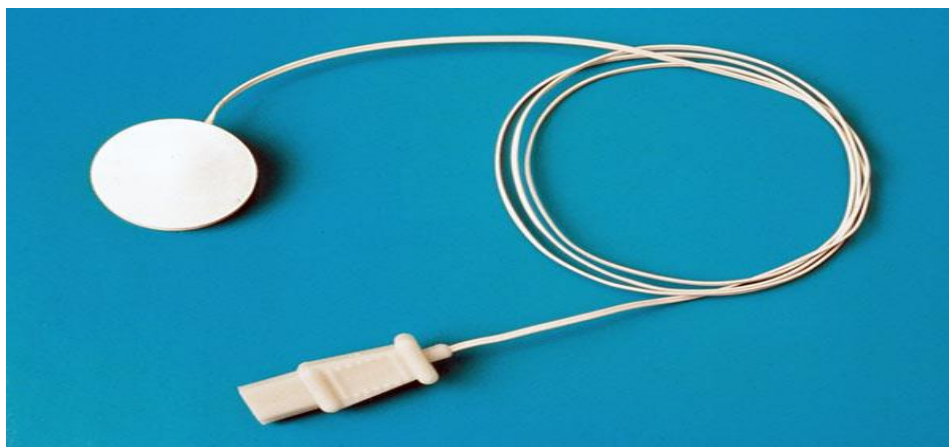

Figure (4.3): NTC Temperature Sensor

To Shaping of the R (T) characteristic by the use of a resistor network, it is possible to modify the R(T) characteristic of a thermistor so that it matches the required form, for example a linear response over a restricted temperature range.

A single fixed resistor R_P placed in parallel with a thermistor gives a S–shape resistance–temperature curve (see Figure 4.4) which is substantially more linear at the temperature range around the inflexion point (R_O, T_O).[10]
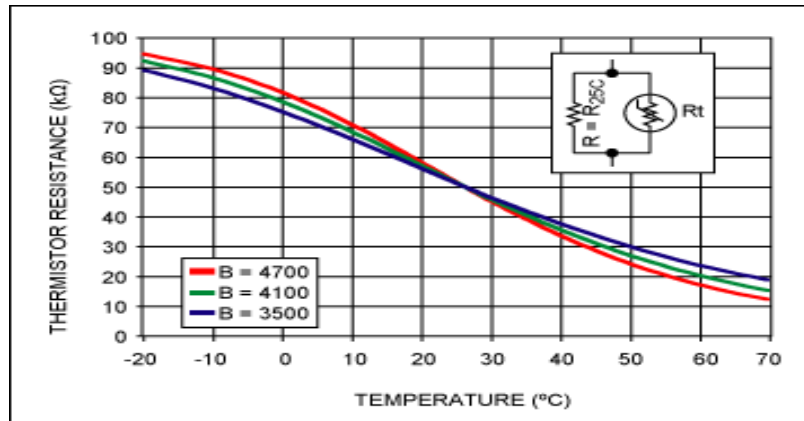

Figure (4.4): Linearization of a Thermistor

It can be calculated that better linearization is obtained when
The fixed resistor value and the mid-range temperature are
Related by the formula:

$$Rp = RTo \; x \; \frac{B - To}{B + 2To} \; \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Equation(4.2)$$

$$B\,(K) \; = \frac{1}{(1/T_1 - 1/T_2)} \times ln\left(\frac{R1}{R2}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Equation(4.3)$$

The best resistance value that placed in parallel with the sensor is 1142 Ω and 1148 Ω.

Note: see the relationship table of the temperature value versus resistance and final output of the circuit in appendix.

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Reason For use:

1. High accuracy value when it connected with a parallel resistance 1 Ω / 0.1 C^0
2. Easy to use on HD machine patient circuit.
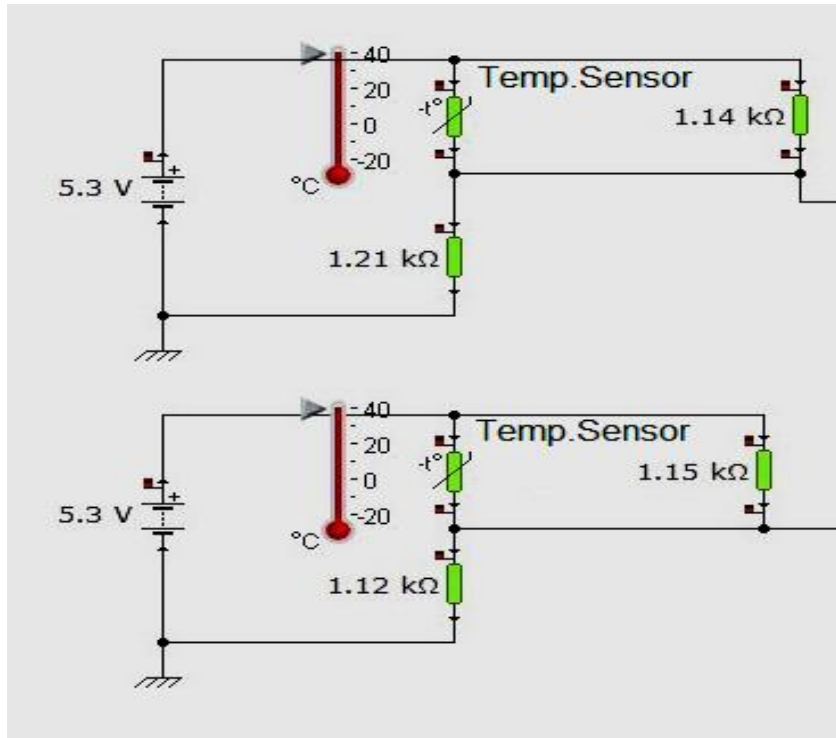
4.3.2 Sensor measurement circuit

Figure (4.5): sensor measurement circuit

Voltage dividers can be used to allow a microcontroller to measure the voltage of a sensor when the temperature is changed, the sensor is wired in series with a known resistance to form a voltage divider and a known voltage is applied across the divider. The microcontroller's analog-to-digital converter is connected to the center tap of the divider by using matching circuit so that it can measure the tap voltage.

Vout=5.3*[eq.resistance/eq.resistance+1.21] for the 1st circuit……………………....**Equation (4.4)**
Vout=5.3*[eq.resistance/eq.resistance+1.12] for the 2nd circuit……………………....**Equation (4.5)**

When the temperature increase by 0.1 C the resistance of the Equivalent resistance will increase approximately by 1 Ω, see the table in appendix.
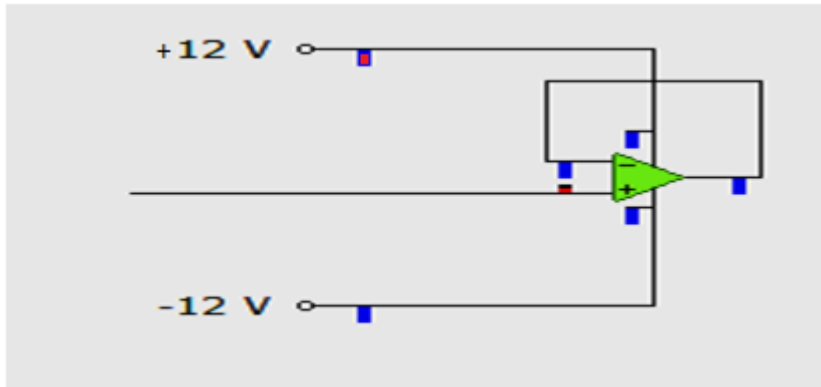
4.3.3 Matching circuit

Figure (4.6): buffer circuit

A voltage buffer amplifier is used to transfer a voltage from a first circuit, having a high output impedance level, to a second circuit with a low input impedance level. The interposed buffer amplifier prevents the second circuit from loading the first circuit unacceptably and interfering with its desired operation.[12]

Vout=Vin……………………………………………………………………………**Equation (4.6)**

4.3.4 Non-Inverting Amplifier

The basic non-inverting amplifier circuit using an op-amp is shown in Figure (4.7). In this circuit the signal is applied to the non-inverting input of the amplifier. However the feedback is taken from the output via a resistor to the inverting input of the operational amplifier where another resistor is taken

to ground. It is the value of these two resistors that govern the gain of the operational amplifier circuit.

Figure (4.7): Non-Inverting amplifier circuit

As the input to the op-amp draws no current this means that the current flowing in the resistors R_1 and R_2 is the same. The voltage at the inverting input is formed from a potential divider consisting of R1 and R2, and as the voltage at both inputs is the same, the voltage at the inverting input must be the same as that at the non-inverting input.

This means that: [13]

$$V_{in=}V_{out}\frac{R_1}{R_1 + R_F}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \textbf{Equation}(\textbf{4.7})$$

Hence the voltage gain of the circuit Av can be taken as:

$$A_v = 1 + \frac{R_f}{R_1}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \textbf{Equation}(\textbf{4.8})$$

For the non-inverting amplifier (in hematocrite measurement):

Gain (A) = 3.6 R_1= 1 kΩ

So R_F =2.6kΩ

4.3.5 Transmitters

Visible LED has wavelength of 585nm is sensitive to hematocrit level , we want to use (LTL-10254W) produced by Lite on, Inc. shown in figure (4.8) b. and near infrared wavelength is 875nm is insensitive to hematocrit , near infrared LED used is (TSHA520) produced by Vishay semiconductors ,shown in figure(4.8) c , these wavelengths are insensitive to oxygen saturation, transmitters will controlled by Arduino as shown in figure (4.9) ,while LED_1 is ON , LED_2 is OFF ,while LED_2 is ON , LED_1 is OFF.

$T_{on} = 2$ min.
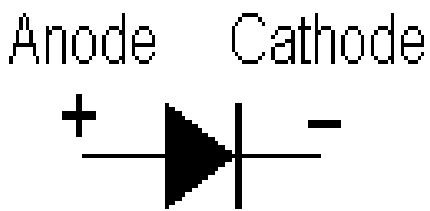
(a)

(b)
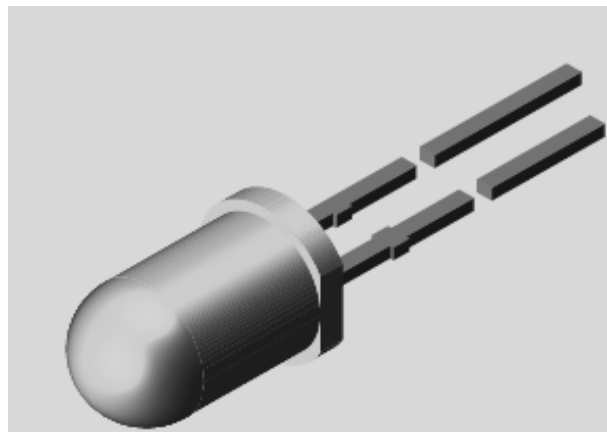
(c)

Figure (4.8): (a) general LED. (b)LTL-10254W LED. (c) TSHA550 LED.
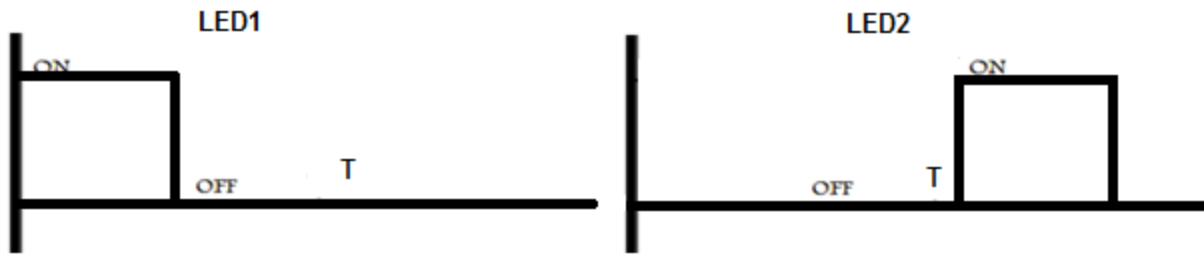
Figure (4.9): Timing Signal for Two LEDs

4.3.6 Constant current source for driving LEDs

A simple potential circuit for achieving this is shown in figure (4.10) in which an op−amp is combined with a bipolar transistor. In this circuit, the negative feedback forces $v_e = v_{in}$. Thus,

Since the collector current is almost equal to the emitter current (I_C is equal to $I_b + I_e$), the LED current is therefore also given by: [14]
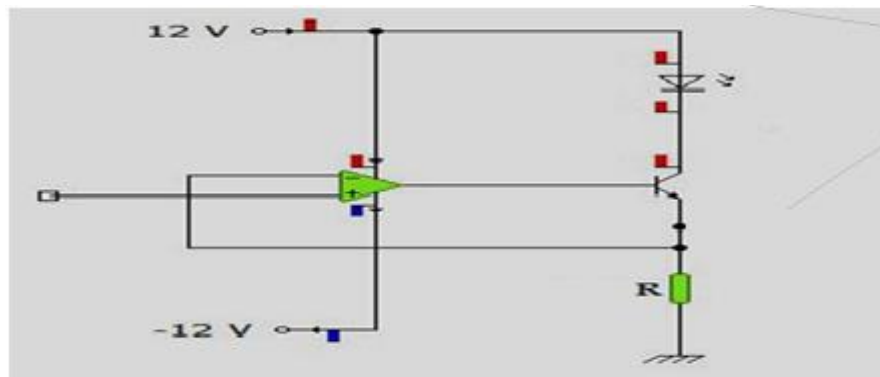
$$I_e = \frac{v_{in} - Vf}{R} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots. \textbf{Equation}(4.9)$$

Figure (4.10): Constant Current Source

$$R = \frac{v_{in} - Vf}{IF}$$

V_F and I_F from datasheet.

For 875nm LED

$I_F = 100mA.$

$V_F=1.5V$

$R_{875nm} = \frac{12V - 1.5V}{100mA}$

$R_{875nm} = 105\Omega$

For 585 nm LED

$I_F = 20mA.$

$VF=2.1V$

$R_{585}nm = \frac{12V - 2.1V}{20mA} = 500\ \Omega$

4.3.7   Phototransistors

It is a type of photo-detector capable of converting light into voltage, the general phototransistor is shown in Figure (4.11) a, we used (BPW40) phototransistor shown in Figure (4.11) b produced by Telefunkin electronics creative technologies for infrared light.
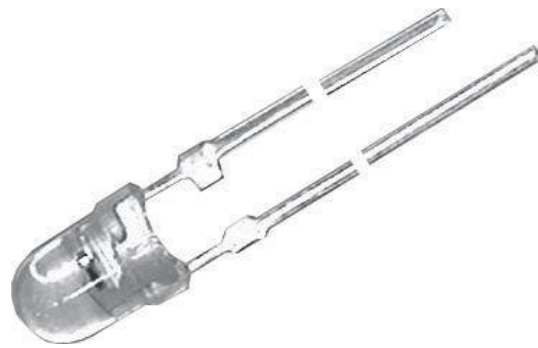
Also we used (TEPT4400) phototransistor shown in Figure (4.11) c produced by Vishay semiconductors for Yellow light.

.
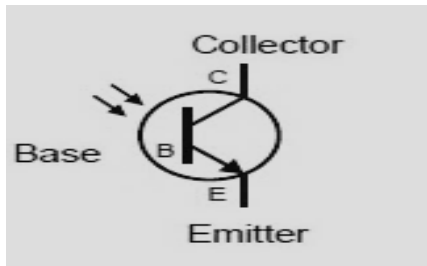
(a)
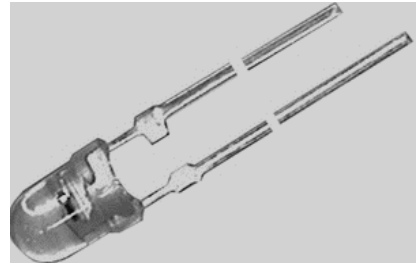
(b)

(c)

Figure (4.11): (a) general phototransistor. (b) BPW40 phototransistor. (c)TEPT4400phototransistor.
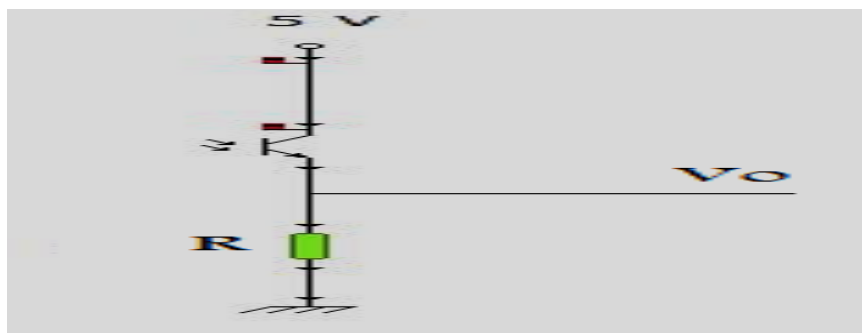

Figure (4.12): Phototransistor Receiver

The phototransistor generates a response proportional to the light received by the component up to a certain light level. When the amount of light surpasses that level, the phototransistor becomes saturated and the output will not increase even as the light level increases. [15]

$$R = \frac{.Vcc - VCE}{Ic} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \textbf{Equation } (\textbf{4.10})$$

For 875nm phototransistor

$V_{CE} = 0.3$V (from datasheet)
Ic $= 1$mA
$R_{875} = 4.7$KΩ

For 585nm phototransistor
$I_{PCE} = 200\mu$A
$R_L = 10$KΩ
Vo max $= 200\mu A \ X \ 10K\Omega = 2$V
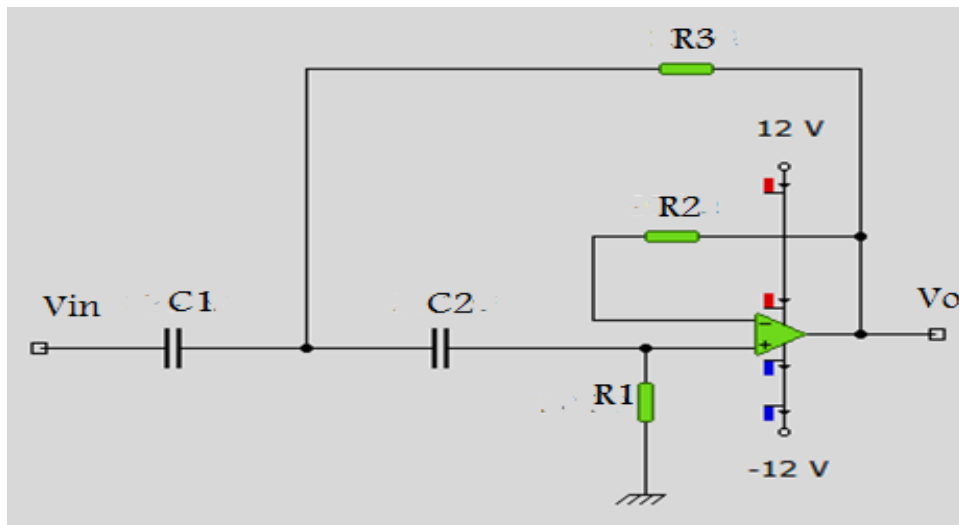
4.3.8 High Pass Filter

Figure (4.13): High Pass Filter

A high pass filter is a circuit that allows frequencies to pass that are than higher than the cutoff frequency. At very low frequencies, the capacitors will have a high reactance and will begin to appear as open circuit's .At high frequencies; the capacitors will have a low reactance and will begin to appear as short circuit. [13.PP.222-226]

$$fc = \frac{1}{2\pi C\sqrt{R1R2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Equation \ (4.11)$$

$C1 = C2 = 10\mu F$

$$Q = \frac{1}{2}\sqrt{\frac{R1}{R2}} = 0.77 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. Equation(4.12)$$

R1=2R2

$$C = \frac{1}{2\pi fc\sqrt{R1R2}}$$

$fc = 0.5Hz$

R3 = R1 = 45KΩ

$R2=22.5KΩ$

4.3.9 Low Pass Filter

This type of low pass filter is unit gain to remove the noise in the signal, Passes only low frequency signals ,the cutoff frequency (f_C) is set at 6 Hz, and can be determined as:
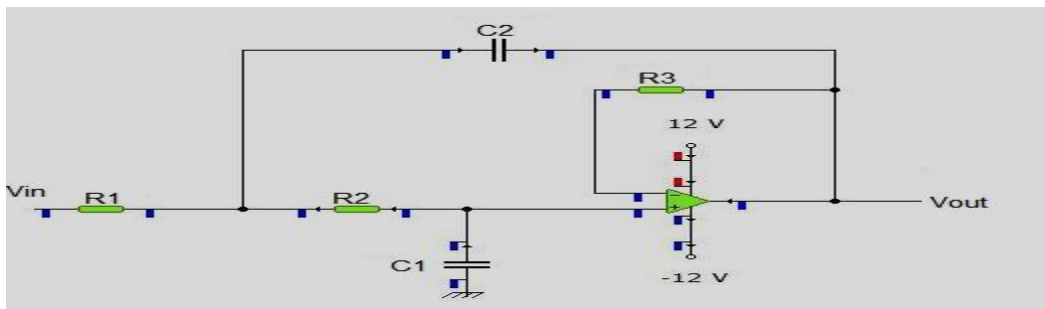
Figure (4.17): Low Pass Filter

The basic low pass sallen key filter can be analyzed for three basic modes of operation: below cutoff, in the area cutoff, and above cutoff. At high frequencies C1 and C2 act as short circuits, shunting the input signal to ground.

R1=R2

R3=R1+R2

Q=0.707

$$Q = \frac{1}{2}\sqrt{\frac{C2}{C1}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots Equation\ (4.13)$$

C2=2C1

Let C1=1µF

C2=2µF

$$fc = \frac{1}{2\pi R1\sqrt{C1C2}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots Equation(4.14)$$

Fc=6HZ

R1=18.756KΩ

R2=18.756Ω

R3=37.5KΩ

4.4 project circuit

Each temperature sensor (on arterial line and vein line) has the same circuit below to measure the access blood flow rate:
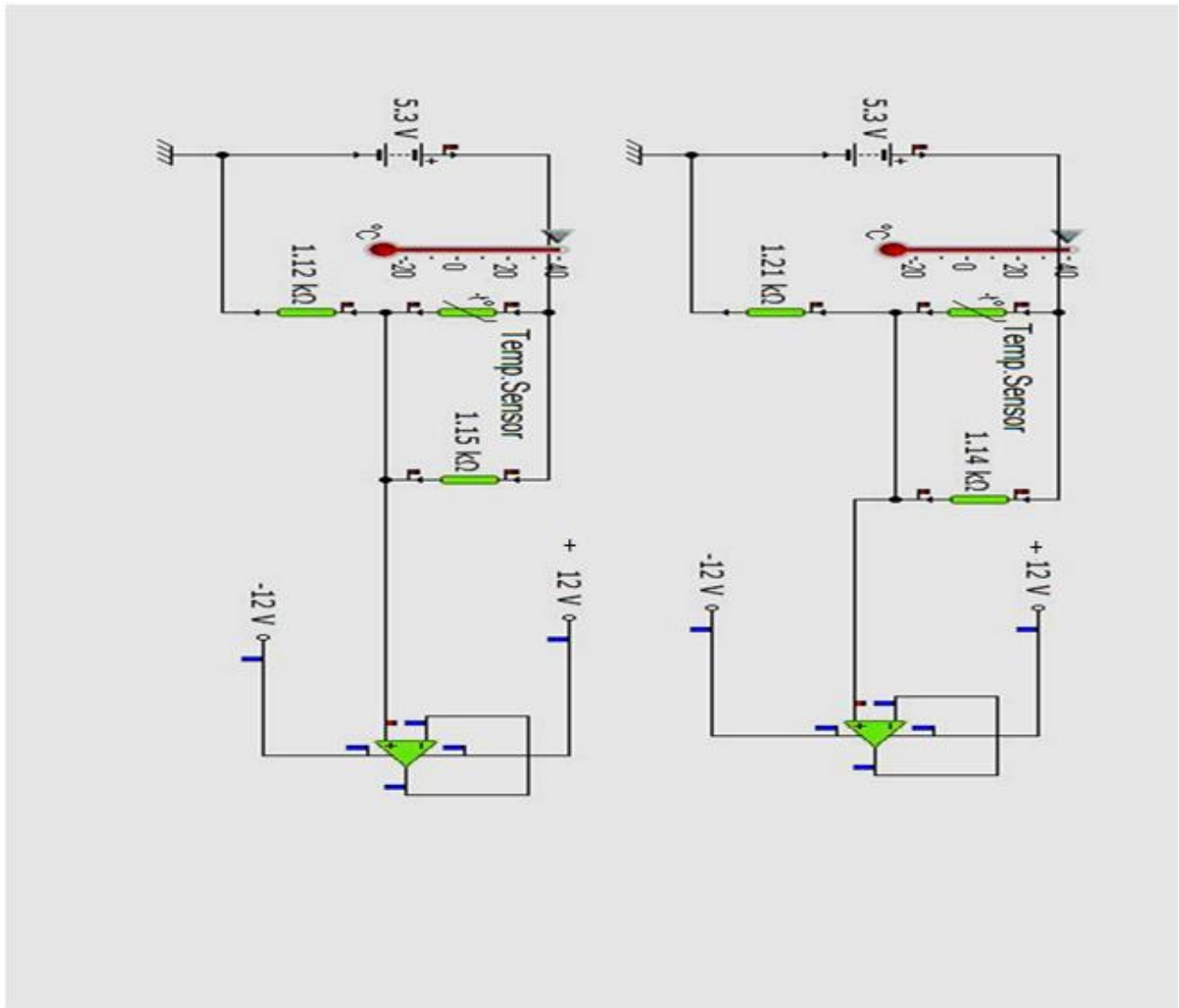

Figure 4.15: Access Blood Flow Circuit

To measure hematocrit, near infrared LED and yellow LED are used , and two receiver are used to detect the signals that comes from each LED when the LED light incident to finger of patient.
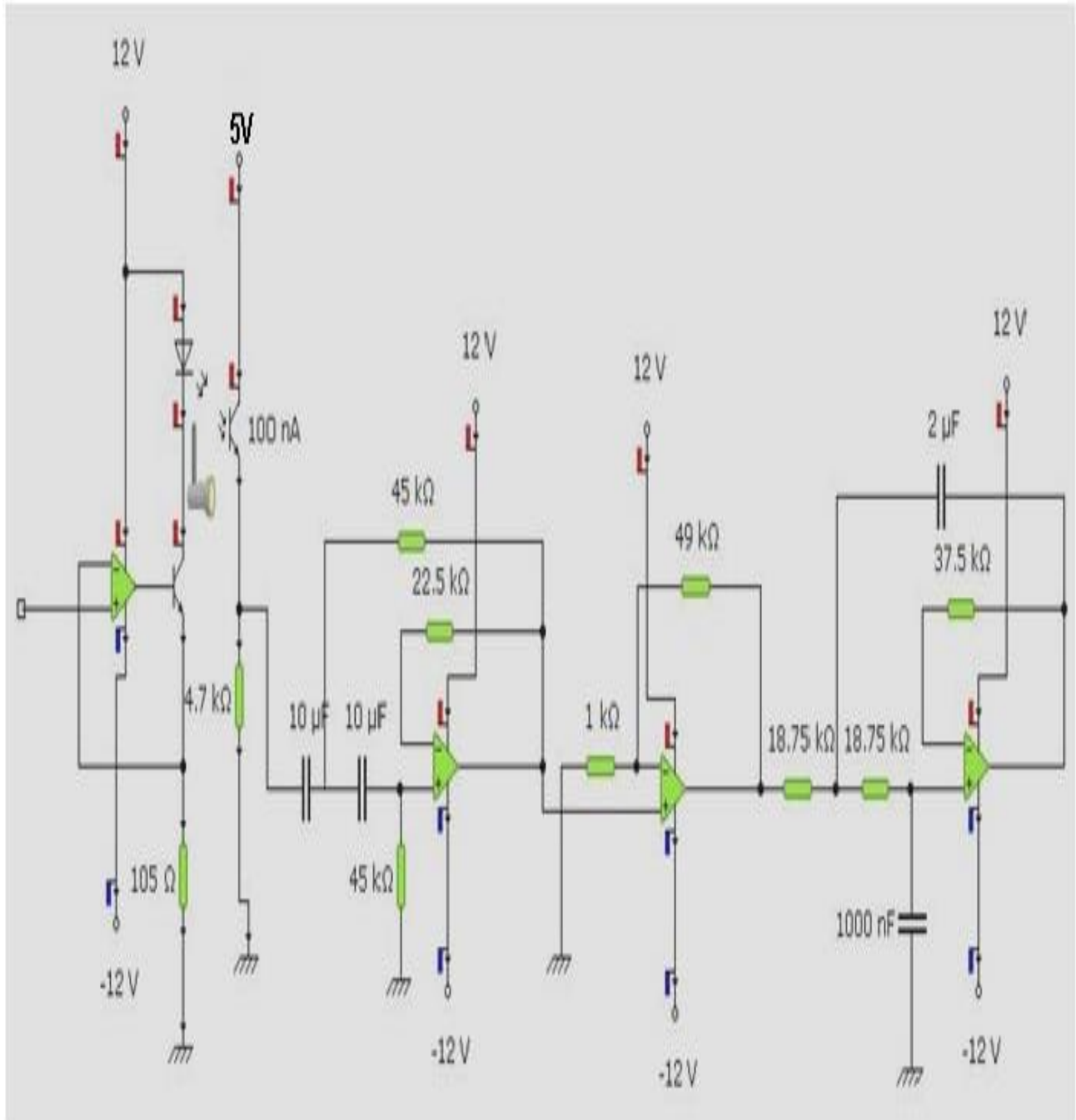

Figure 4.16: Hematocrit Circuit by using IR LED
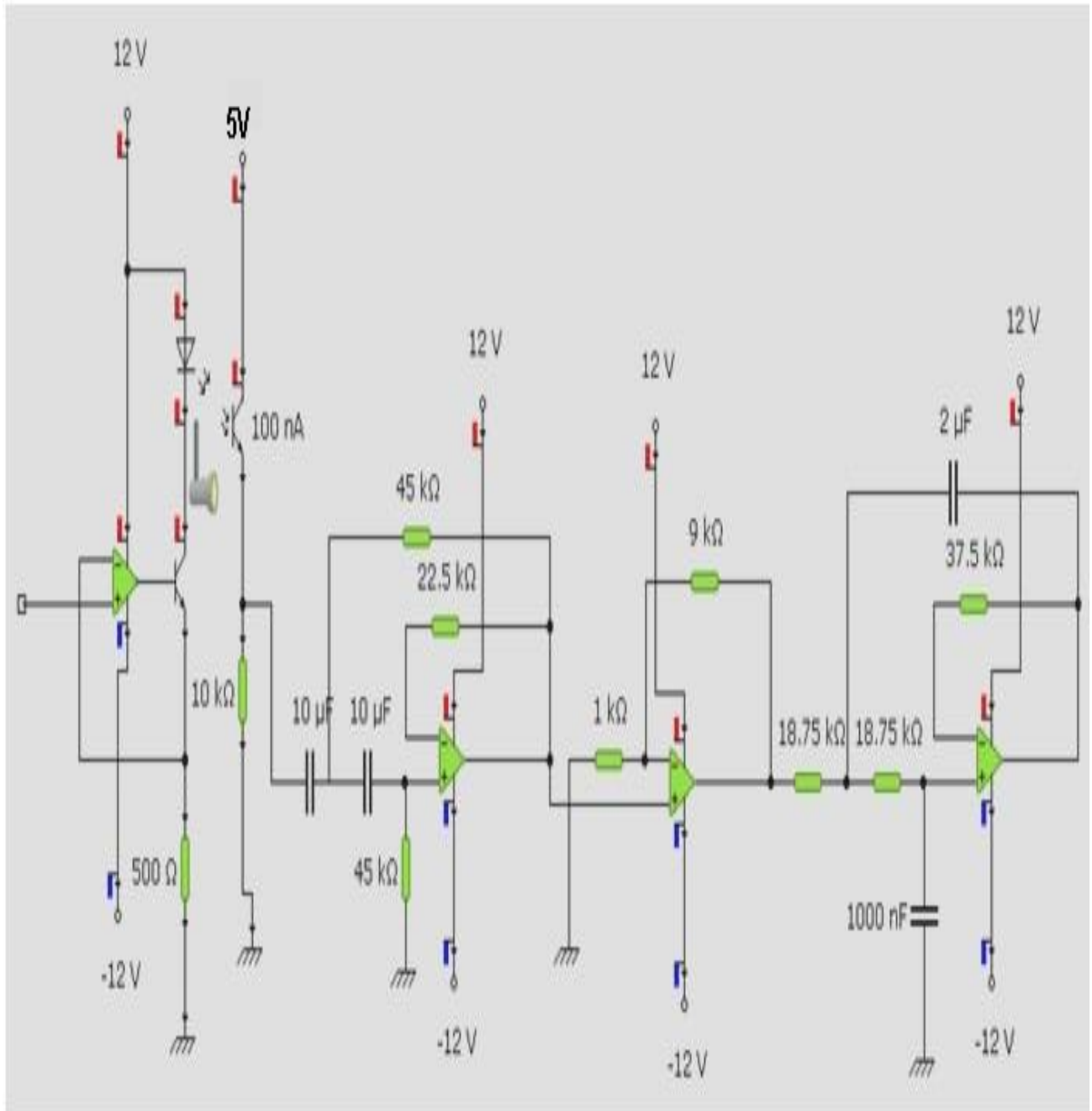
Figure 4.16:Hematocrit Circuit by using yellow LED

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Chapter Five

Software Design

5.1 Introduction

5.2 Arduino Microcontroller

5.2.1   Power

5.2.2   Input and Output

5.2.3   Programming

5.3 Project Flowchart

5.1 Introduction

Our project consists from two parts: Hardware part and software part. In software parts we are used the Arduino Microcontroller.

5.2 Arduino Microcontroller

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language and the Arduino development environment. Arduino projects can be stand-alone or they can communicate with software running on a computer.

The Arduino Mega is a microcontroller board .It has 54 digital input/output pins   16 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.[17]

Figure5.1: Mega2560Arduino [17]

5.2.1 Power

The Arduino Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

5.2.2 Input and Output

Each of the 54 digital pins on the Mega can be used as an input or output, using pin Mode (), digital Write (), and digital Read () functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms.[17]

5.2.3 Programming

The Arduino Mega can be programmed with the Arduino software (download). Select "Arduino Uno from the Tools > Board menu (according to the microcontroller on your board). TheArduino Uno comes pre burned with a boot loader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original protocol. [17]
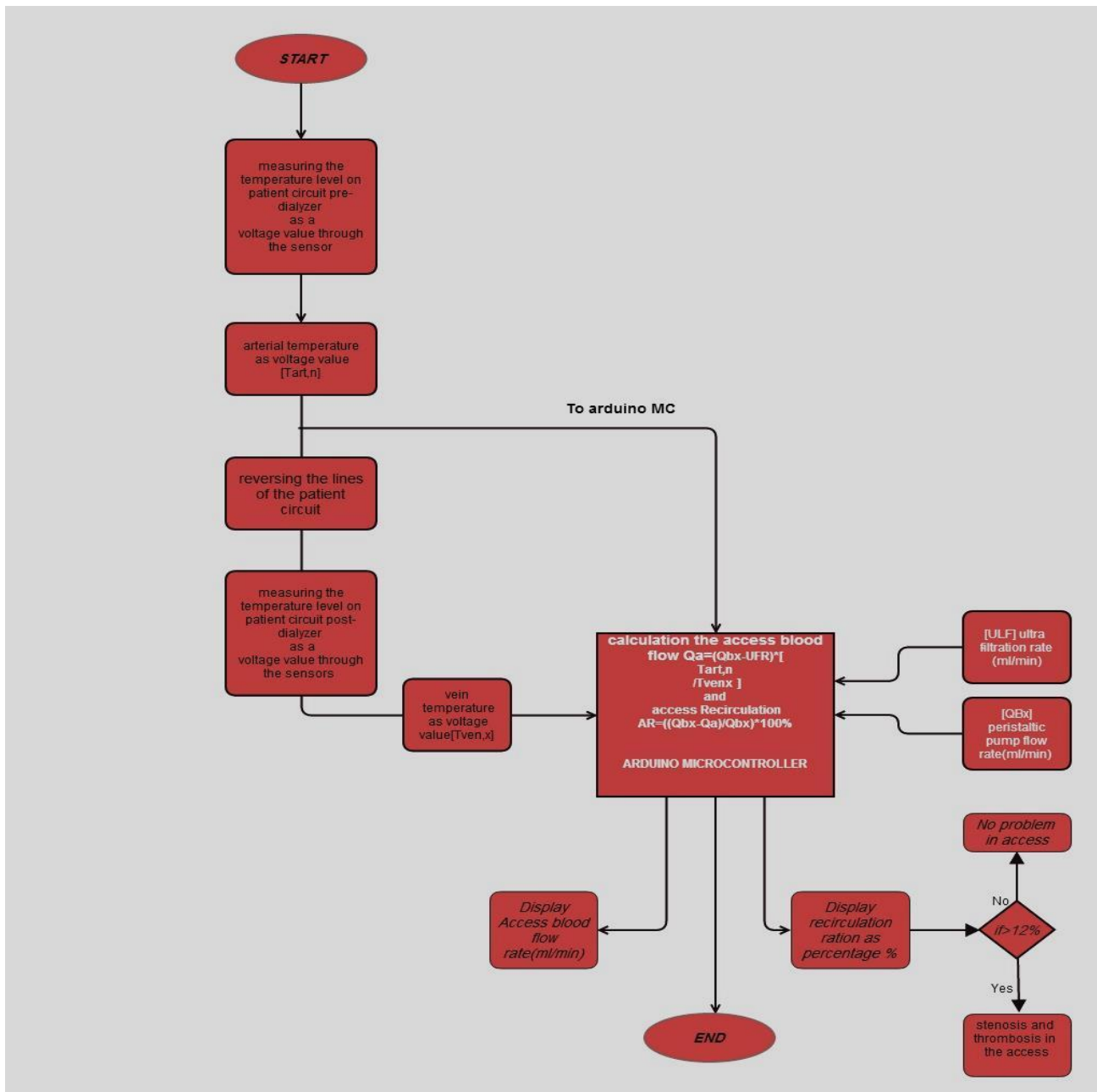
5.3Project Flowchart

Figure 5.2: Flowchart for access blood flow and recirculation ratio measurement

The flow chart consists of two parts. First part for the arterial temperature line and vein temperature line when the lines in normal position, and the second part when the lines in reversal position, first of all we measure the blood arterial temperature through the sensor that's located pre-dialyzer in the normal position, and then measure the blood vein temperature as voltage when the lines of patient circuit in reversed position by the hardware design to get the desired value of voltages that are suitable for the temperature value for the two parts.

Then we entire the ultra-filtration rate [UFR ml/min] and the peristaltic pump flow rate [Qbx ml/min] values to the Arduino Microcontroller to calculate the access blood flow and recirculation ration according to equation (3.3) and equation (2.2) then display the parameters on LCD Display and show the result that depending of the recirculation ratio (if >12% or <12%) if there is stenosis and thrombosis in the access.
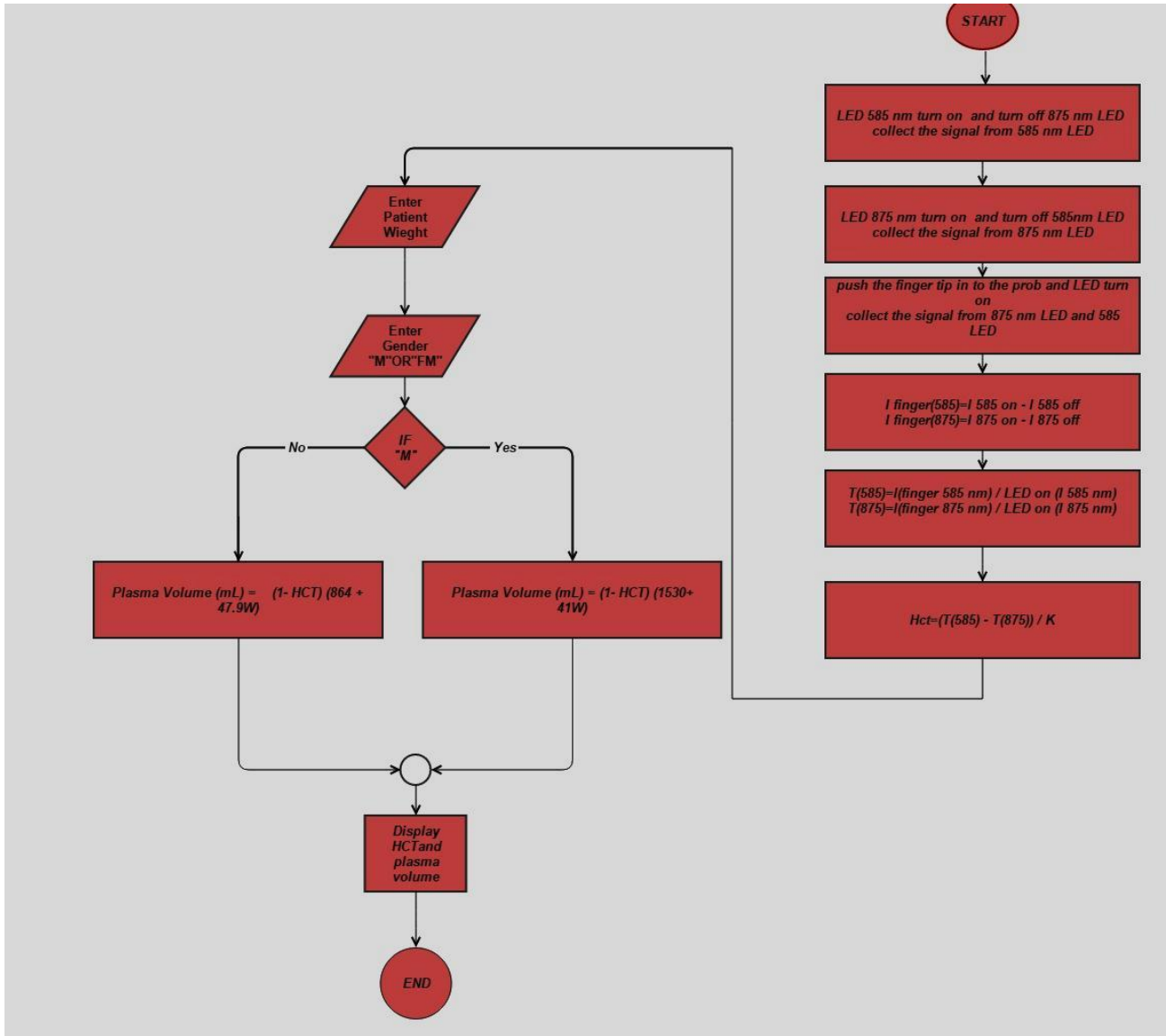
Figure5.3: Flowchart for Hematocrite and Plasma volume measurement

The flow chart consists of two parts. In the first one we ask operator to enter patient weight, and gender (M or F).

We ask the patient push the finger tip, then the system measure the hematocrit in the second part.

According to the gender, the following steps will follow. If ' M ' , we ask operator enter the weight , then the system use plasma volume equation to determine plasma volume and display on LCD the Hematocrit and plasma volume value.

Chapter six

Results and analysis

6.1 Introduction.

6.2 Study design.

6.3 Temperature sensors.

6.4 Pump blood flow rate.

6.5 Patient screen.

6.6 Voltmeter readings.

6.6.1 Voltmeter readings before reversing.

6.6.2 Voltmeter readings after reversing.

6.7 LCD screen.

6.8 Results and analysis.

6.8.1 Analysis.

6.8.2 Results

6.9Conclusion.

6.10Recommendations.

6.1 Introduction

This chapter discussed and explains a results and analysis for the practical project.

6.2 Study Design

This study was designed to make measurement on the hemodialysis machine .it was performed in Hebron at Hebron government hospital.

This experimental measurement taken by a patient that take health care on this hospital and the table below describe information about this patient.

Table (6.1): public information and adjusted parameters

1st patient	
Hospital name	Hebron government hospital
Patient age	28
Sensor type	Temperature sensors
Access type	Shunt fistula
Gender	Male
Ultra filtration rate (ml/h)	868
Pump blood flow rate (ml/min)	300
Dialysate treatment time(min)	180
Machine type	Fresenius B4008
Voltage on arterial line in normal position (V)	4.313
Voltage on Vein line in reversed position (V)	4.296
Vascular access blood flow rate (ml/min)	286.66
Recirculation ratio	4.44%

2ⁿᵈ patient

Hospital name	Hebron government hospital
Patient age	24
Sensor type	Temperature sensors
Access type	Graft
Gender	Male
Ultra filtration rate (ml/h)	800
Pump blood flow rate (ml/min)	260
Dialysate treatment time(min)	150
Machine type	Fresenius 4008 B
Voltage on arterial line in normal position (V)	3.790
Voltage on Vein line in reversed position (V)	4.338
Vascular access blood flow rate (ml/min)	217
Recirculation ratio	16.5%

3ᵗʰ patient

Hospital name	Hebron government hospital
Patient age	55
Sensor type	Temperature sensors
Access type	Shunt fistula
Gender	Male
Ultra filtration rate (ml/h)	714
Pump blood flow rate (ml/min)	240
Dialysate treatment time(min)	180
Machine type	Fresenius 4008 B
Voltage on arterial line in normal position (V)	4.258
Voltage onVein line inreversed position (V)	4.188
Vascular access blood flow rate (ml/min)	232
Recirculation ratio	3.3%

4th patient

Hospital name	Hebron government hospital
Patient age	45
Sensor type	Temperature sensors
Access type	Shunt fistula
Gender	Male
Ultra filtration rate (ml/h)	800
Pump blood flow rate (ml/min)	300
Dialysate treatment time(min)	150
Machine type	Fresenius 4008 B
Voltage on arterial line in normal position (V)	4.410
Voltage onVein line inreversed position (V)	4.355
Vascular access blood flow rate (ml/min)	290
Recirculation ratio	3.3%

6.3 Temperature sensors

The picture below show temperature sensor position on the hemodialysis machine after and before dialyzer.
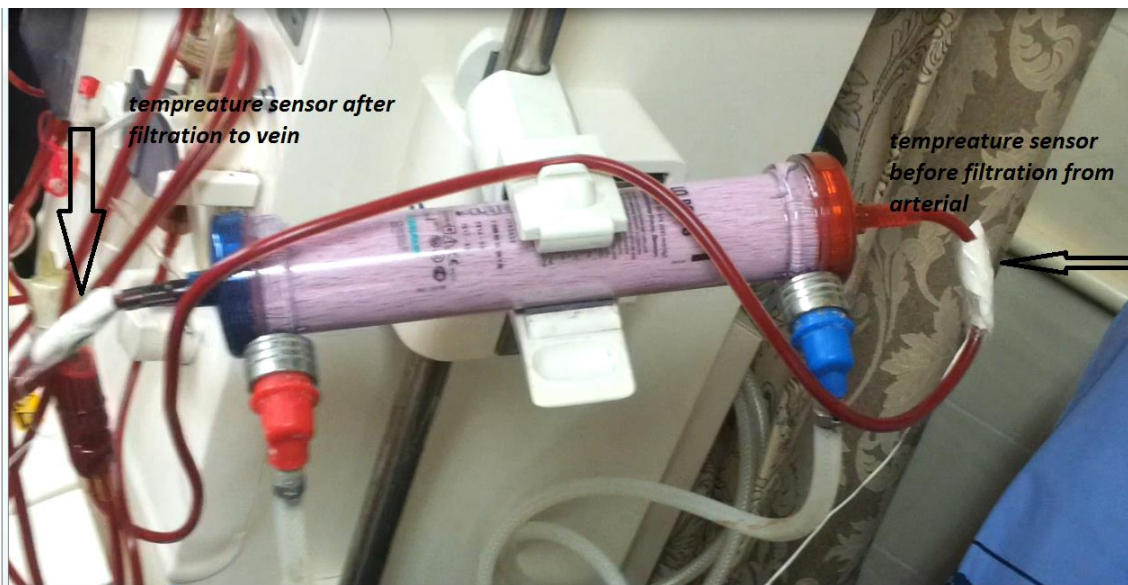

Figure (6.1): temperature sensors position

6.4 pump blood flow rate

A picture below show pump blood flow rate that was set by a nurse staff

Figure (6.2): blood flow rate

6.5 Patient screen.

A picture below show a patient screen that describe ultra-filtration rate

Figure (6.3): Patient screen

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6.6 Voltmeter readings

6.6.1 Voltmeter readings before reversing

This picture represents the value of artery temperature in the normal position of the tubes for all the patients sequently.
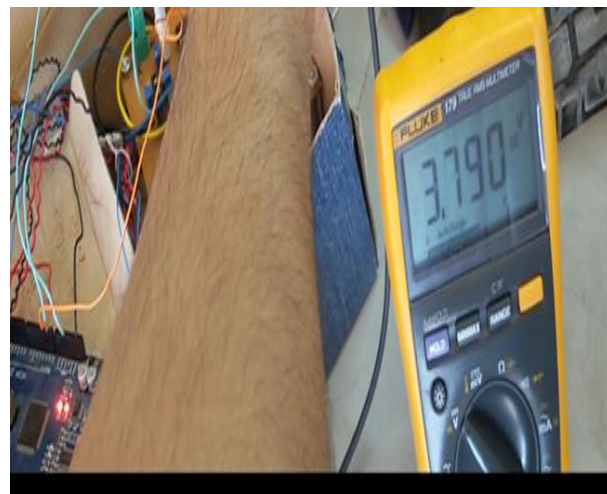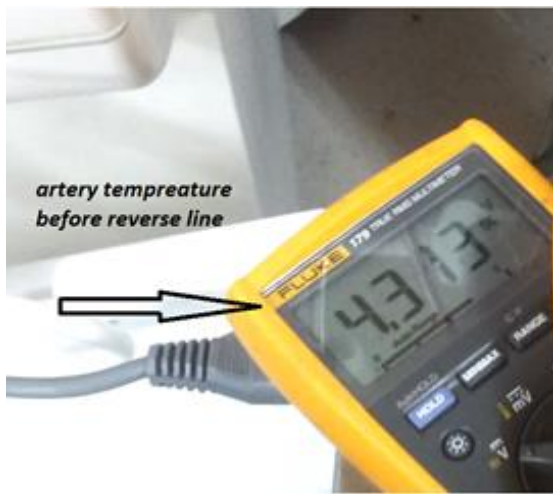

Figure (6.4): Voltmeters readings before reversing

6.6.2 Voltmeter readings after reversing

This picture represents the value of vein temperature value after the lines were reversed for all the patients sequently.
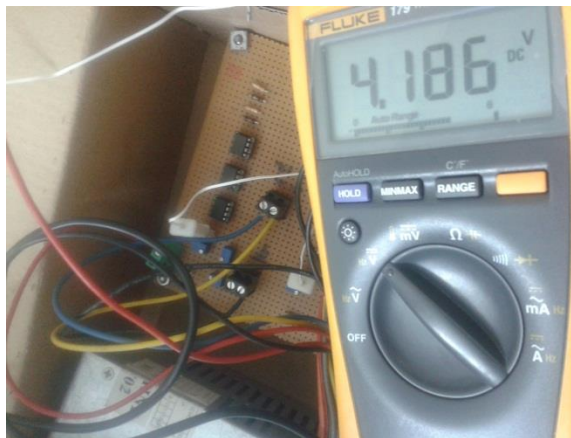

Figure (6.5): Voltmeter readings after reversing

6.7 LCD screen

This picture below show a LCD screen programmed by an Arduino describe the capability of entering the ultra-filtration rate, hematocrit percentage, plasma volume, weight of patient, and gender of patient .
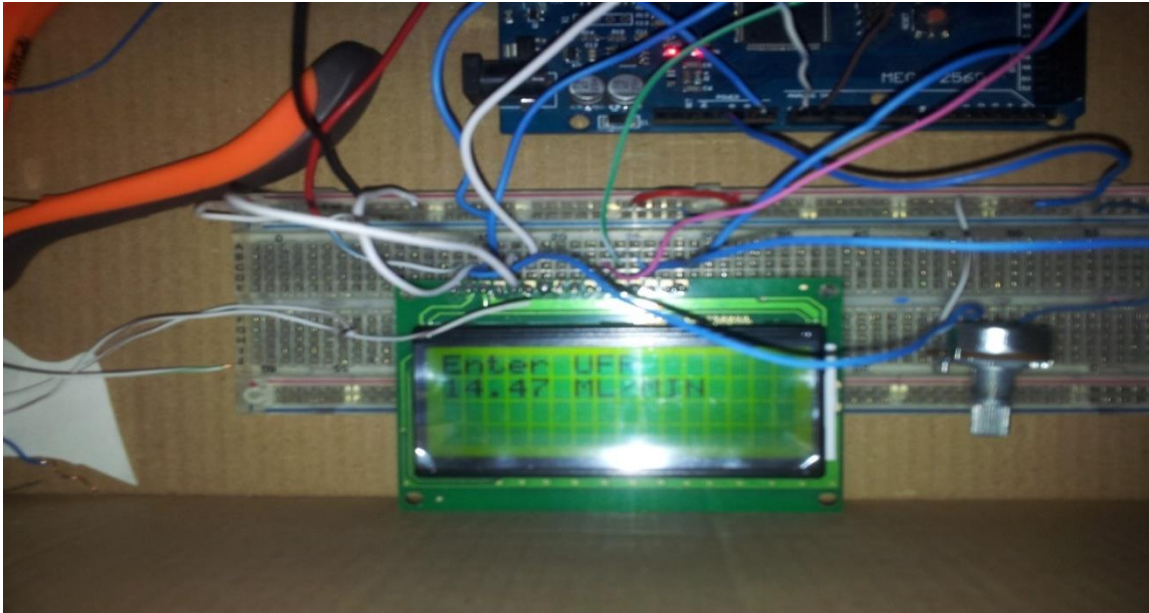

Figure (6.6): UFR rate.

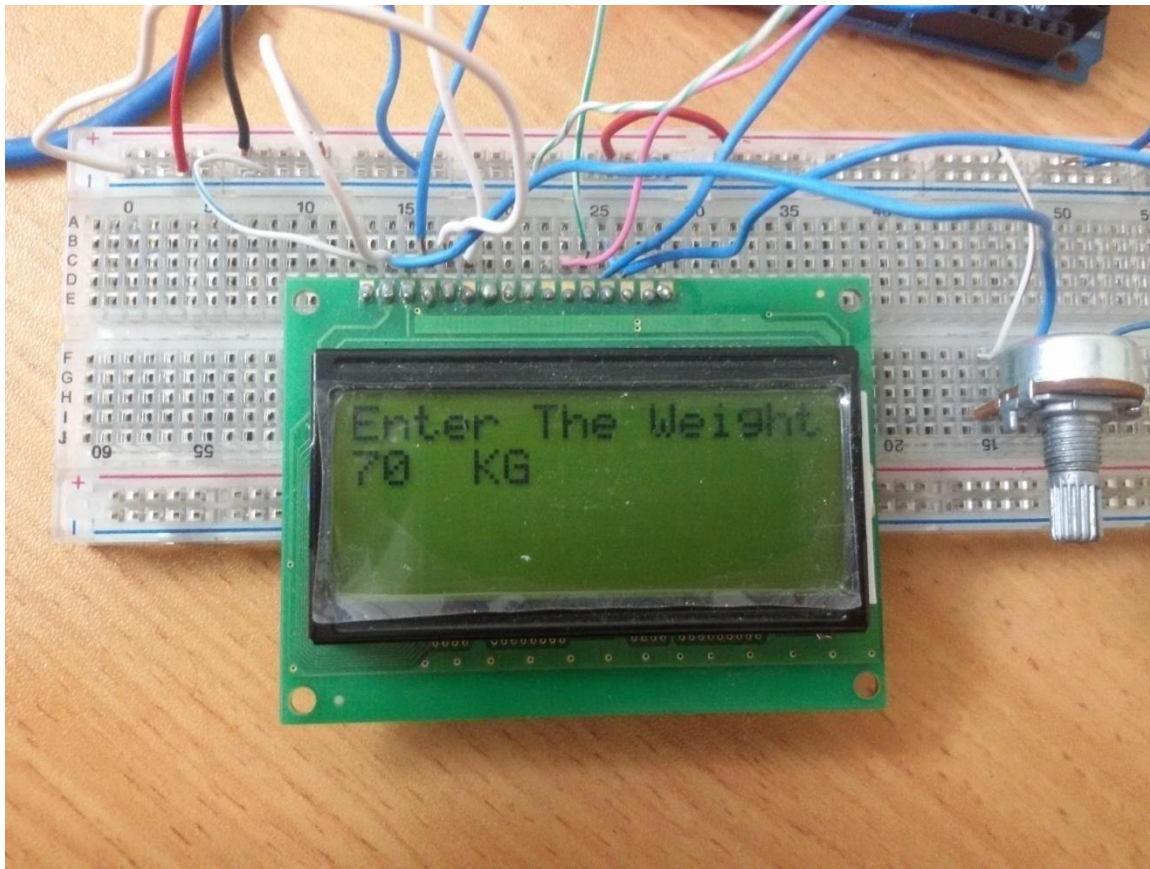Figure (6.7): hematocrit percentage and plasma volume
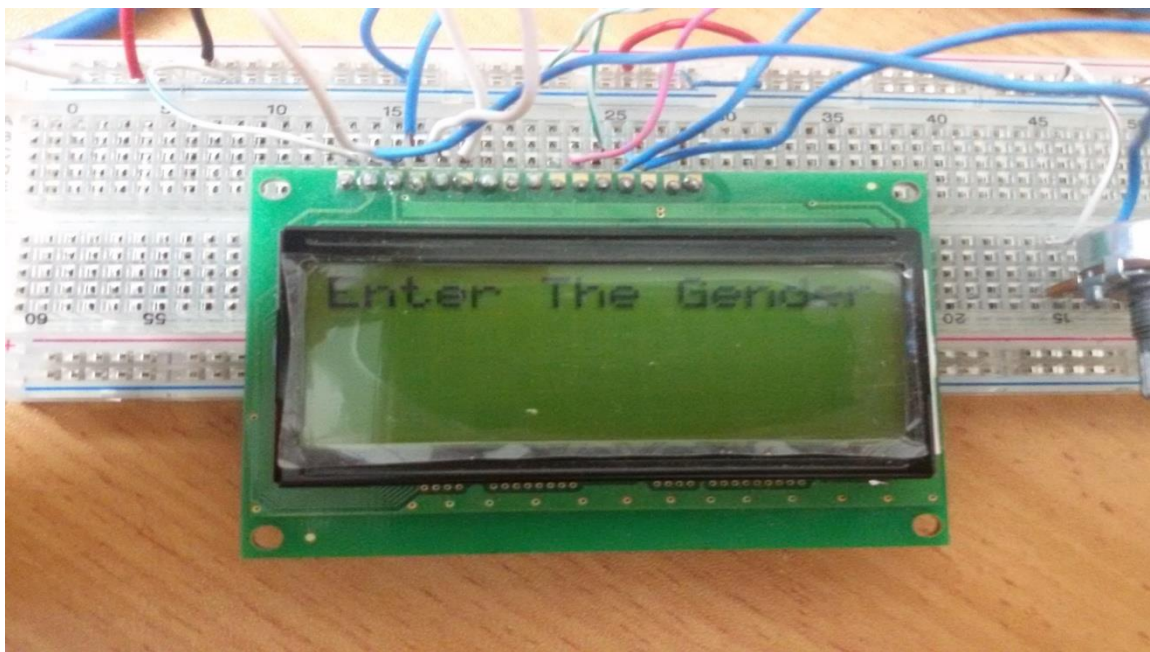
Figure (6.8): patient weight

Figure (6.9):Patient gender

6.8 Results and analysis

6.8.1 Analysis:

In this session, we want to calculate the real blood flow that out of the access for one of patients, after that extracting the recirculation ratio to make a suitable decision about an access condition.

Voltmeters readings:

Tartn=4.313

Tvenx=4.297

Arduino readings:

Tartn= 891 , after transferring the value to voltage   4.37.

Tvenx=911, after transferring the value to voltage 4.46.

Qb=300 ml/min …same Qbx.

UFR=868 ml/h >>> 60 = 14.47 ml/min.

QA= (QBx-UFR)*(Tartn/Tvenx)……………………………………….**equation (6.1).**

QA= (300-14.47)*(4.313/4.297)………………………………………from voltmeters.

    =286.59 ml/min

 QA= (300-14.47)*(891/911)…………………………………………….**from Arduino.**

0.978*285.53=279.25

RR= {(QBx-Qa)/Qbx}*100%..**equation (6.2).**

RR= {(300-286.59)/300}*100%

    =4.47 %< 12%..**from voltmeters.**

RR= {(300-279.25)/300}*100%

    =6.917% <12%..**from Arduino.**

For hematocrite monitoring

We want to measure hematocrite and calculate plasma volume from it

Plasma Volume $(mL) = (1 - HCT)(b + cW)$ ……………………………**equation(6.3)**

B: a constant of 1530 for males, 864 for females

C: a constant of 41 for males, 47.9 for females

W: dry weight in Kg

Case study:

Patient gender	Patient weight (Kg)	HCT %	Plasma volume (ml)
Male	85	48.81	2566.45

6.8.2 Results

Low Pass Filter:

The table and curve below show the characteristics of Low Pass Filter that produce as a practical result of this project.

Table (6.2) :Low Pass Filter results.

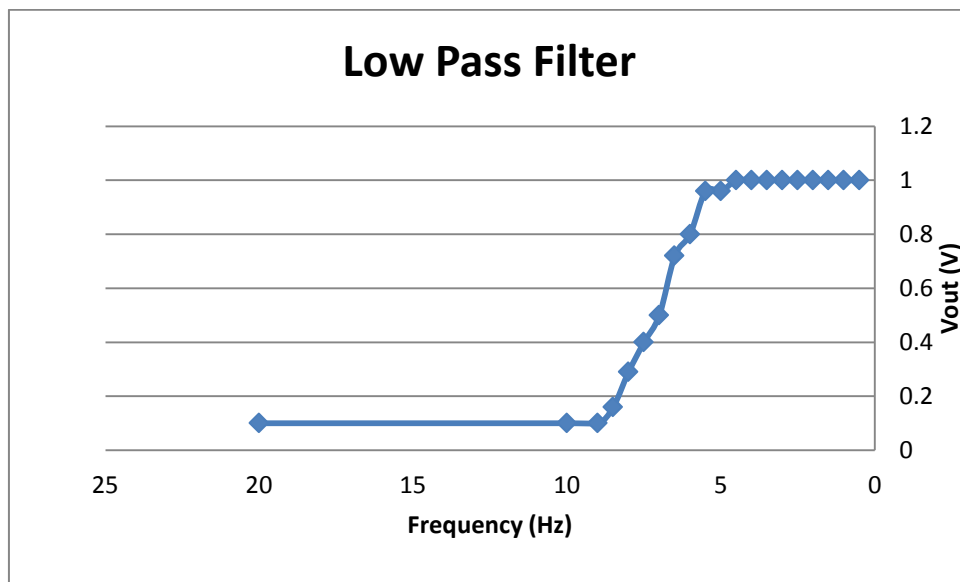| Vin (Vp-p)	Vo(Vp_p)	Frequency (HZ)	Gain
1	1	0.5	1
1	1	1	1
1	1	1.5	1
1	1	2	1
1	1	2.5	1
1	1	3	1
1	1	3.5	1
1	1	4	1
1	1	4.5	1
1	0.960	5	0.960
1	0.960	5.5	0.960
1	0.80	6	0.80
1	0.72	6.5	0.72
1	0.50	7	0.50
1	0.40	7.5	0.40
1	0.29	8	0.29
1	0.16	8.5	0.16
1	0.10	9	0.10
1	0.10	10	0.10
1	0.10	20	0.10

Figure (6.10): Low Pass Filter curve.

High Pass Filter:

The table and figure below show the characteristics of High Pass Filter that we get from practical work of this project.

Table (6.3): High Pass Filter results

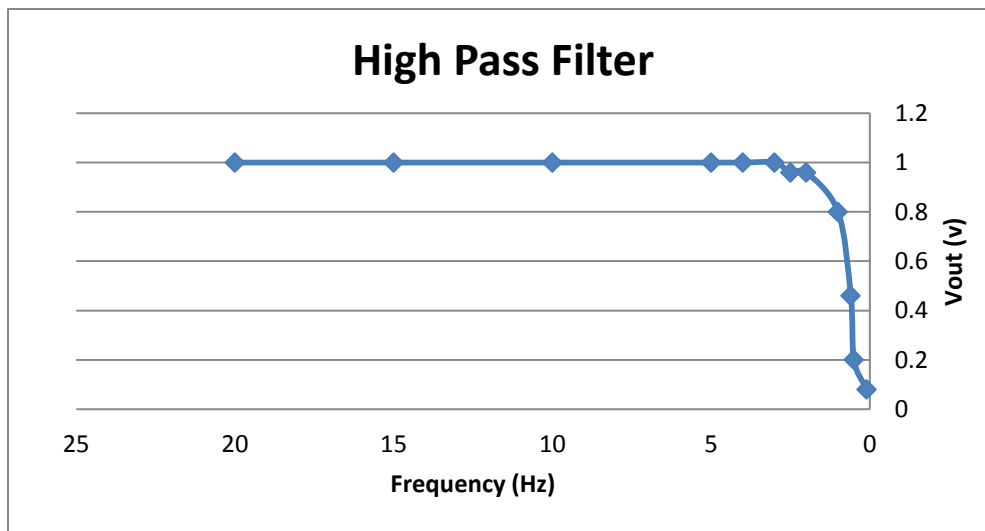| Vin (Vp-p)	Vo(Vp_p)	Frequency (HZ)	Gain
1	0.08	0.1	0.08
1	0.2	0.5	0.2
1	0.46	0.6	0.46
1	0.80	1	0.80
1	0.96	2	0.96
1	0.96	2.5	0.96
1	1	3	1
1	1	4	1
1	1	5	1
1	1	10	1
1	1	15	1
1	1	20	1

Figure (6.11) : High Pass Filter curve

Table (6.4): public information and adjusted parameters

Patient#	HCT% (CBC)	HCT measured	Error %	Patient Weight(Kg)	Patient gender	Plasma volume(ml)
1	37.6	43.72	16.2	70	female	2508
2	47.8	48.81	2.1	85	male	2566.45
3	31.1	35.65	14.6	65	female	2595.95
4	34.2	41.64	21.7	67	female	2523.43
5	38.2	38.64	1.15	71	female	2753.5
6	35.7	40.67	13.9	58	female	2344.29
7	44.6	47.79	7.15	87	male	2666.60
8	35.6	40.67	14.2	55	female	2271
9	40.9	51.86	26.8	75	male	2183.69
10	33.5	37.62	12.3	63	female	2591.19

6.9 Conclusion

1) After comparison between the results by taking different parameters we found approximately same results either by voltage values, and temperatures.

2) Using Extracorporeal temperature gradients method is better than other ways like saline dilution, and thermo dilution.

3) The optical method is affected by ambient light.

4) The optical method is affected by the angle between the transmitter and receiver.

6.10 Recommendation

1) For accurate measurement for vascular access blood flow, Arduino duo should be used because it has a higher resolution than 10 bit than other types

2) To increase the accuracy of the measurement of HCT its better to use low noise operational amplifier.

Appendix A

Appendix B

Appendix C

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