Design and Implementation of a Wearable Artificial Kidney Prototype for Home Dialysis

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Submitted to the College of Engineering
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Palestine Polytechnic University
College of Engineering
Electrical Engineering Department
Hebron-Palestine

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Project Team

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By the Guidance Of project's supervisor, and by all members in the testing committee, this project delivered to department of electrical engineering in the college of engineering and technology, to be as a partial fulfillment of the requirement of the department for the degree of B.Sc

Project Supervisor Signature

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جامعة بوليتكنيك فلسطين

كـــلـيـة الهنـدســة

دائرة الهندسة الكهربائية

فلسطين-الخليل

أسماء الطلبة

انوار ابو خريبة　　　　هيا سلهب　　　　رغده جعبري

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.

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❀ إلى من كلله الله بالهيبة والوقار... واحمل اسمه بكل افتخار .... إلى البدر الساطع

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والقهر بالإصرار..................................... والدي العزيز

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كل حدب وصوب ....فسلك بها سبل النجاة ....حتى أوصلها بجهده وعلمه إلى

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زرع الابتسامة على وجهي في أصعب الظروف .... أحبائي وأصدقائي

فريق المشروع : هيا سلهب & رغده جعبري & أنوار أبو خربة

Abstract

Hemodialysis is a life-preserving treatment for hundreds of thousands of patients with kidney failure. But the standard schedule of in-center HD three times a week is, at best, inconvenient, and at worst, hard on the heart. So home dialysis is the best solution.

Home HD lets the patient set the schedule, the patient can choose treatment times taking in consideration his\her other life activities, so the patient will overcome the difficulties of hemodialysis in the hospital. As known, HD department is always overcrowded by patients , the patient needs to wait for long time, the difficulties of the transportation to reach the hospital, and the most important point is the high level of decontamination this can avoid the patient from infection" the device only for one person".

The wearable artificial kidney prototype is a minimized dialysis machine. The patient have to enter only the target weight to be removed then the system process it and calculate all other parameters automatically. The system consists of two circuits the blood circuit and the dialysate circuit, blood filtration will be done in the dialyzer, before returning the filtered blood to the patient the system will monitor several parameters such as the temperature, pressure, flow, and air bubbles using an advanced microcontroller and a number of sensors. The artificial kidney equipped with visible and audible alarm system to aware the patients if there is any problem.

Recently the wearable artificial kidney depends on many technologies such as a sediment filter which require approximately 5 gallons of water and it just removes the large particles from blood, so there is a need for another small filter, the other technology used is the silicon membranes "nano dimensions" "Silicon Valley Technology" which costs a lot, so the prototype provides the alternative in term of efficiency and price.

ملخص المشروع

الغسيل الكلوي هي عملية للحفاظ على حياة المرضى الذين يعانون من الفشل الكلوي. وتشير الدراسات إلى أن أكثر من ٢.٥ مليون شخص تلقوا علاجاً بالغسيل الكلوي عام ٢٠١٠ وتوقع القائمون على الدراسة أن يكون عدد المصابين بالفشل الكلوي حول العالم ٥.٤ مليون شخص بحلول عام ٢٠٣٠ معظمهم في البلدان النامية بآسيا وإفريقيا. ورغم أهمية هذه العملية إلا أن المرضى يعانون من العديد من المشاكل خلالها حيث أن الجدول الزمني للغسيل الكلوي في المستشفى في أفضل ظروفه غير مريح ومرهق للمريض، لذلك فإن الغسيل الكلوي المنزلي هو الحل الأفضل حيث أن الغسيل الكلوي المنزلي يتيح للمريض أن يتحكم بالجدول الزمني لجلسة الغسيل، فبإمكانه اختيار أوقات العلاج التي تتناسب مع نشاطاته اليومية المختلفة، وبالتالي فأنه سيتغلب على مشكلة الانتظار لفترة زمنية طويلة نظرا لازدحام قسم الغسيل بالمرضى، بالإضافة إلى التخلص من صعوبة التنقل والمواصلات والمرافقين في حالات كبار السن والأطفال. ومن أهم مشاكل غسيل الكلى أيضاً الإصابة بالعدوى الفيروسية للأمراض التي تنتقل عبر الدم كون الجهاز يستخدم لأكثر من مريض، فجهاز الغسيل المنزلي يضمن الخصوصية ودرجات عالية من التعقيم.

الكلية الاصطناعية عبارة عن جهاز غسيل كلوي مصغر ومحمول ويمكن إرتداؤه على شكل سترة. حيث يقوم لمريض بإدخال الوزن المطلوب خسارته وسيقوم النظام بتحليل كافة المعلومات المطلوبة أوتوماتيكيا من خلال المتحكم الدقيق. يتكون النظام من دائرتين: دائرة الدم ودائرة المحلول الذي يستخدم للغسيل. حيث سيتم تصفية الدم باستخدام فلتر يقوم بإزالة الشوائب والأملاح والسوائل الزائدة والمواد السامة من الدم ويتم عرض أغلب العلامات الحيوية التي تتعلق بعملية غسيل الكلى باستخدام متحكم دقيق وعدد من المجسات. الكلية مزودة بنظام إنذار مرئي ومسموع يحذر المريض في حال حدوث أي مشكلة كانخفاض الضغط أو وجود فقاعات هواء في مجرى الدم أوفي حال وجود تسرب للدم إلى دائرة المحلول.

أصبحت مؤخرا الكلية الصناعية عالميا تعتمد على عدة تقنيات مثل فلتر تصفية الرواسب الذي يحتاج إلى ٥ غالونات ماء ويزيل الجزيئات الكبيرة فقط من الدم، ولكن هنالك حاجة لإزالة الجزيئات الصغيرة، والتقنية الأخرى تعتمد على استخدام السليكون المصنع كأغشية ذات أحجام صغيره جدا لكنها مكلفة، لذلك فان النموذج يوفر البديل من حيث الكفاءة والسعر.

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Glossary

Abbreviation	Meaning
AV	**Arteriovenous**
ESRD	**End Stage Renal Disease**
HD	**Hemodialysis**
HHD	**Home Hemodialysis**
MC	**Microcontroller**
PD	**Peritoneal Dialysis**
RO	**Reverse Osmosis**
UF	**Ultra Filtration**

Terminology

Word	Meaning
Hemodialysis	غسيل كلوي
Rinse	مرحلة التنظيف
Renal Failure	فشل كلوي
Nephron	الوحدة البنائية الأساسية في الكلية
Priming	مرحلة التخضير للغسيل
Vertebrate Animals	حيوانات فقارية

CHAPTER ONE

INTRODUCTION

1.1 Project Overview

1.2 Project Objectives

1.3 Literature Review

1.4 Project Importance

1.5 Economical Study

1.6 Task Time Schedule

1.7 Project Content

1.1 Project Overview

Normal human beings have two kidneys, a healthy kidney is basically a filtering system removes waste product and excess fluids from the blood in the form of urine.

Renal failure (also kidney failure or renal insufficiency) is a medical condition in which the kidneys fail to adequately filter waste products and excess fluids from the blood, this occur due to several factors and causes some symptoms, when this happened hemodialysis must be performed.

Hemodialysis (HD) is a life-preserving treatment for hundreds of thousands of patients with kidney failure. But the standard schedule of in-center HD three times a week is, at best, inconvenient, and at worst, hard on the heart. So home dialysis is the best solution.

Home HD lets the patient set the schedule, The patient can choose treatment times taking in consideration his/her other life activities, so the patient will overcome the difficulties of hemodialysis in the hospital. As known, HD department is always overcrowded by patients , the patient needs to wait for long time, the difficulties of the transportation to reach the hospital, and the most important point is the high level of decontamination this can avoid the patient from infection because the device only for one person.

The wearable artificial kidney prototype is a minimized dialysis machine, the patient have to enter only the target weight to be removed then the system process it and calculate all other parameters automatically. The system consists of two circuits the blood circuit and the dialysate circuit, blood filtration will be done in the dialyzer, before returning the filtered blood to the patient the system will control several parameters such as the temperature, pressure, flow, and air bubbles using an advanced microcontroller and a number of sensors. The artificial kidney is equipped with an audible and visible alarm system warns the patient if there is any problem.

1.2 Project Objectives:

The main objective of the project is to design a wearable artificial kidney prototype to filter the blood from waste products and excess fluids at home, the system will be controlled using a microcontroller.

The Project Objectives Can Be Summarized In The Followings:

1) Design a flow control sections for blood and dialysate solution.
2) Implement an air bubble detection module.
3) Design a temperature measurement circuit for dialysate solution.
4) Design a measurement circuit for the pressure .
5) Implement a blood leak detection module.
6) Wearable and Automatic prototype.
7) Design and implantation of a visible and audible alarm.

1.3 Literature Review

Studying the following projects gave the idea of the project. The idea of the project has never been proposed before in the Palestine Polytechnic University.

- A research entitled "The future of the artificial kidney: moving towards wearable and miniaturized devices", Department of Nephrology, Dialysis and Transplantation, Ospedale San Bortolo, and International Renal Research Institute of Vicenza (IRRIV), Vicenza, Italy, 2011, by C. RONCO, A. DAVENPORT and V. GURA, Points to a new directions in dialysis research include cheaper treatments, home based therapies and simpler methods of blood purification, this can be achieve by the application of wearable ultrafiltration systems (WUF) and wearable artificial kidneys (WAK).

- An issue entitled "Design and Optimization of A Blood Pump for A Wearable Artificial Kidney Device", Industry Applications, IEEE Transactions, May 3, 2013,written by Miroslav Markovic, Michael Rapin, Marc Correvon, Yves Parried, said that the aim of the European project Nephron+ is the design of a wearable artificial kidney device.
- A research entitled "The design of an optimized portable artificial kidney system using recirculation and regeneration of dialysate", School of Engineering, Coventry University, Bigsby RJ, Rider RJ, Blount GN, Britain,1998.

Recently The wearable artificial kidney depends on many technologies such as a sediment filter which require approximately 5 gallons of water and it just removes the large particles from blood, so there is a need for another small filter, the other technology used is the silicon membranes in nano dimensions "Silicon Valley Technology" which costs a lot, so the project provides the alternative in term of efficiency and price.

1.4 Project Importance

The project is very important, because it serves a large number of end stage renal disease (ESRD) patients by providing a dialysis procedure at home, in addition to a number of some importance as following:

- Making hemodialysis at home is more comfortable for the patient & surrounding people to lead a standard life.
- Minimizing the overcrowding of dialysis department by patients, thus patient does not have to wait for long time (saving patient's time).
- Decrease the rate of infection during the treatment procedure because only one person will use the device.
- Performing the dialysis procedure at home reduces the psychological effects on the patients suffering from sadness and depression.

1.5 Economical Study

This section lists the overall cost of the components that is used in implementing the project. The hardware components are listed in table 1.1

Table1.1 Project Hardware Cost

Component	Quantity	Cost (NIS)
Blood Pump	1	400
Dialysate pump	1	300
Ultrafiltration pump	1	300
Arduino board	1	350
Conductivity cell	1	105
Electrical valve	1	180
LM35	1	7
Tube set	1	50
LCD	1	70
Power system	1	300
Bag	1	12
Wires and terminals	-	110
Plastic body	1	150
Pressure sensor	1	45
Air bubble detector	1	400
Blood leak detector	1	450
Dialyzer	1	40
Transistor	11	43
Resistors	30	6
Potentiometers	15	75
Capacitors	15	10
Diodes	15	10
Buzzer (12V)	1	12
Voltage Regulators	3	15
Amplifiers	4	18
LS7408 AND gate	3	33

Heparin liquid 50ml	50ml	100
Power Switch	1	40
Test boards	2	100
Vest	1	300
Heat sink	6	30
Plastic connectors	8	40
Total	4101 NIS	

1.6 Task Time Schedule

Table1.2 Distribution of tasks Schedule (first semester)

Time (week)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gives Idea																
Collection information																
Design the system																
Analysis Design																
Documentation																

Table 1.3 Distribution of tasks schedule (second semester)

Time (week)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project planning																
Collection of components																
Design the system																
Testing & get results																
Documentation																

1.7 Project Content

The content of the documentation of the project is divided into five chapters, each is briefly explained as following:

Chapter 1: Introduction.

This chapter presents overview, literature review, Project objectives, importance of project, project scheduling, and economical study.

Chapter 2: The Physiology of Renal System and Renal Replacement Therapies.

This chapter includes a background about : The kidney structure, The kidney failure " Reasons and Symptoms", Renal replacement therapies "Transplantation, Peritoneal dialysis, Hemodialysis machine and Patient Cannulation ".

Chapter 3: **Project Conceptual Design and Analysis .**

In this chapter the Project Hardware, Block Diagram of the system were discussed , and Interfaces between stages were introduced.

Chapter 4: **Project Implementation .**

This chapter includes an overview about the principle of operation of each part of the whole system.

Chapter 5: **Testing and Results .**

This chapter presents all results obtained by implementing the project practically, and the final design of the project .

Chapter 6: **Recommendation, Challenges and Conclusion .**

This chapter includes future improvement of the project, the challenges forced by the project team, and final conclusion about the project.

CHAPTER TWO

THE PHYSIOLOGY OF RENAL SYSTEM AND RENAL REPLACEMENT THERAPIES

2.1 Introduction

The urinary system, also known as the renal system, consists of the two kidneys, ureters, the bladder, and the urethra. Each kidney consists of millions of functional units called nephrons. The purpose of the renal system is to eliminate wastes from the body, regulate blood volume and pressure, control levels of electrolytes and metabolites, and regulate blood pH. The kidneys have extensive blood supply via the renal arteries which leave the kidneys via the renal vein.[1]

There are several functions of the Urinary System:

- Removal of waste product from the body (mainly urea and uric acid)
- Regulation of electrolyte balance (e.g. sodium, potassium and calcium)
- Regulation of acid-base homeostasis
- Controlling blood volume and maintaining blood pressure

In this chapter we will focus on the kidney ,its failure, the symptoms and treatment (**Hemodialysis Machine).**

2.2 The Kidneys Structure

The two kidneys are bean-shaped organs ,each about the size of a fist, that serve several essential regulatory roles in vertebrate animals. They remove excess organic molecules. They are essential in the urinary system and also serve homeostatic functions such as the regulation of electrolytes, maintenance of acid–base balance, and regulation of blood pressure. They serve the body as a natural filter of the blood, and remove water soluble wastes, which are diverted to the urinary bladder.

They are located near the middle of the back, just below the rib cage, one on each side of the spine. Each adult kidney weighs between 125 and 170 grams in males and between 115 and 155 grams in females. The left kidney is usually slightly larger than the right kidney. The kidney is approximately 11–14 cm (4.3–5.5 in) in length, 6 cm (2.4 in) wide and 4 cm (1.6 in) thick. Every day, a person's kidneys process about 200 quarts of blood to sift out about 2 quarts of waste products and extra water.

The wastes and extra water become urine, which flows to the bladder through tubes called ureters. The bladder stores urine until releasing it through urination.

Each kidney is surrounded by membrane know as the renal capsule, each kidney is made up of approximately a million nephrons, each nephron consists of a filtering component called glomerulus and a tubule reabsorbs essential water and chemicals into the blood stream and transports urine from the glomerulus to the ureters.

Urine is formed in the kidneys through a filtration of blood. The urine is then passed through the ureters to the bladder, where it is stored. During urination the urine is passed from the bladder through the urethra to the outside of the body.[2]

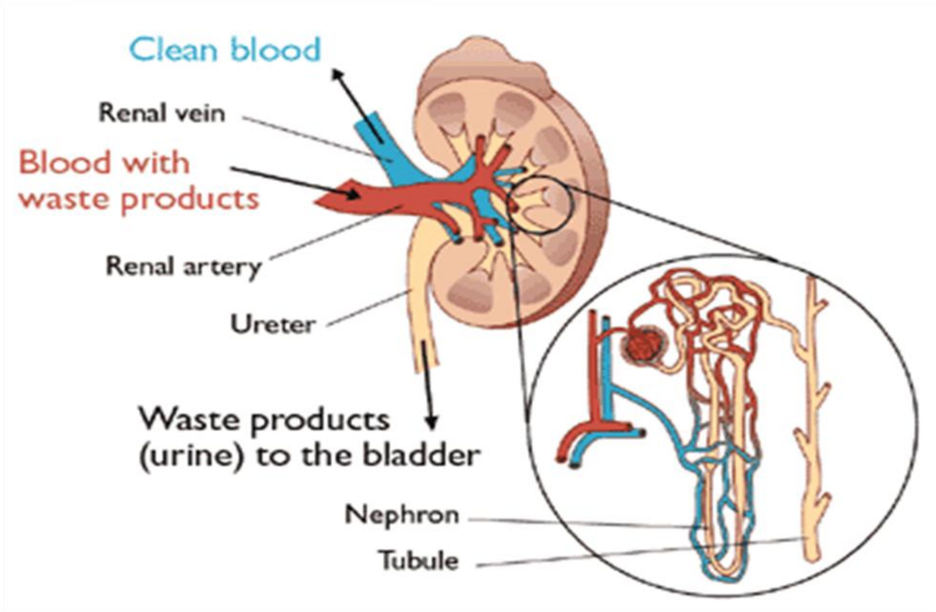


Figure 2.1 : Human Kidney and Nephron

2.3 The Kidney Failure

Definition: **Renal failure** (also **kidney failure** or **renal insufficiency**) is a medical condition in which the kidneys fail to adequately filter waste products from the blood.[3]

Figure 2.2: Kidney Failure.

2.3.1 Signs and Symptoms

Symptoms can vary from person to person. Someone in early stage kidney disease may not feel sick or notice symptoms as they occur.

Symptoms of kidney failure include the following:[4][5]

- High levels of urea in the blood, which can result in:
  - Vomiting and/or diarrhea, which may lead to dehydration.
  - Weight loss.
  - Less frequent urination, or in smaller amounts than usual, with dark colored urine.
  - Blood in the urine.
  - Unusual amounts of urination, usually in large quantities.

- A buildup of phosphates in the blood that diseased kidneys cannot filter out may cause:
  - Bone damage.
  - Nonunion in broken bones.
  - Muscle cramps (caused by low levels of calcium which can be associated with hyperphosphatemia).

- A buildup of potassium in the blood that diseased kidneys cannot filter out may cause:
  - Abnormal heart rhythms.
  - Muscle paralysis.

- Failure of kidneys to remove excess fluid may cause:
  - Swelling of the legs, ankles, feet, face and/or hands.
  - Shortness of breath due to extra fluid on the lungs.

- As the kidneys fail, they produce less erythropoietin, resulting in decreased production of red blood cells, as a result, the blood carries less hemoglobin, a condition known as anemia. This can result in:
  - Feeling tired and/or weak.
  - Memory problems.
  - Dizziness.
  - Low blood pressure.

- Normally, proteins are too large to pass through the kidneys, however, they are able to pass through when the glomeruli are damaged. This does not cause symptoms until extensive kidney damage has occurred,[6] after which symptoms include:

- Foamy or bubbly urine.
- Swelling in the hands, feet, abdomen, or face.

2.3.2 Causes of Kidney Failure

- Diabetes.
- Drug (Heavy dosage).
- Family history.
- High blood pressure.
- Snake bite.
- Unknown factors.

2.4 Renal Replacement Therapies

Renal replacement therapy is a term used to encompass life-supporting treatments for renal failure .It includes: Hemodialysis, Peritoneal Dialysis, and Renal Transplantation. These treatments will not cure chronic kidney disease. In the context of chronic kidney disease, they are to be regarded as life-extending treatments (though if chronic kidney disease is managed well with dialysis).

2.4.1 Transplantation

Kidney transplantation or **renal transplantation** is the organ transplant of a kidney into a patient with end-stage renal disease (ESRD). Kidney transplantation is typically classified as deceased-donor (formerly known as cadaveric) or living-donor transplantation depending on the source of the donor organ, provided that the donor and patient pass the compatibility test.

Problems after a transplant may include: Post operative complication, bleeding, infection, vascular thrombosis and urinary complications.[7]

2.4.2 Peritoneal Dialysis

Peritoneal dialysis (PD) is a treatment for patients with severe chronic kidney disease. The process uses the patient's peritoneum in the abdomen as a membrane across which fluids and dissolved substances (electrolytes, urea, glucose, albumin and other small molecules) are exchanged from the blood. Fluid is introduced through a permanent tube in the abdomen and flushed out. PD is used as an alternative to hemodialysis though it is far less commonly used in many countries, such as the United States. It has comparable risks but is significantly less costly in most parts of the world, with the primary advantage being the ability to undertake treatment without visiting a medical facility. The primary complication of PD is infection due to the presence of a permanent tube in the abdomen.[8]

2.4.3 Hemodialysis Machine

Hemodialysis is the process that involves the removal of chemical substances from the blood by passing it through tubes surrounded by a semi permeable membrane.

Hemodialysis process based on two functions:

- Removal of waste product by Diffusion and Convection. Known as Clearance.
- Removal of excess water by Ultrafiltration.

☒ **Disadvantage of Hemodialysis in Hospital** :

- Patients need to visit the center and spend 5 hours every three times a week.
- Patients can’t able lead a standard life due to the frequent visit to center.
- Infection during the treatment because of the inefficiency of sterilization and cleaning process.
- Expensive.

Due to the disadvantages of the three previous methods it's necessary to find an alternative method for blood filtration such as an artificial kidney performing hemodialysis at home.

2.4.4 Patient Cannulation " Vascular Access"

Vascular access is surgically created vein used to remove and return blood during hemodialysis.

A vascular access lets large amounts of blood flow continuously during hemodialysis treatments to filter as much blood as possible per treatment.

Two types of vascular access designed for long-term use include the arteriovenous (AV) fistula and the AV graft. A third type of vascular access "the venous catheter" is for short-term use.

1) AV Fistula:

An AV fistula is a connection, made by a vascular surgeon, of an artery to a vein. The surgeon usually places an AV fistula in the forearm or upper arm. An AV fistula causes extra pressure and extra blood to flow into the vein, making it grow large and strong. The larger vein provides easy, reliable access to blood vessels. Without this kind of access, regular hemodialysis sessions would not be possible.

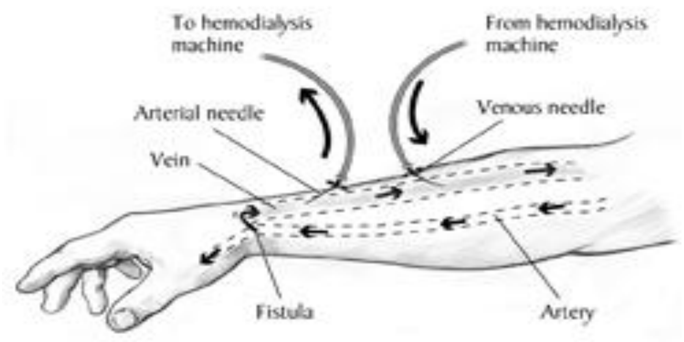


Fig.2.3: AV Fistula

✓ **Features of AV Fistula :**

- provides good blood flow for dialysis
- lasts longer than other types of access
- is less likely to get infected or cause blood clots than other types of access

2) **AV Graft:**

An AV graft is a looped, plastic tube that connects an artery to a vein. A vascular surgeon performs AV graft surgery, much like AV fistula surgery.

An AV graft is more likely than an AV fistula to have problems with infection and clotting.

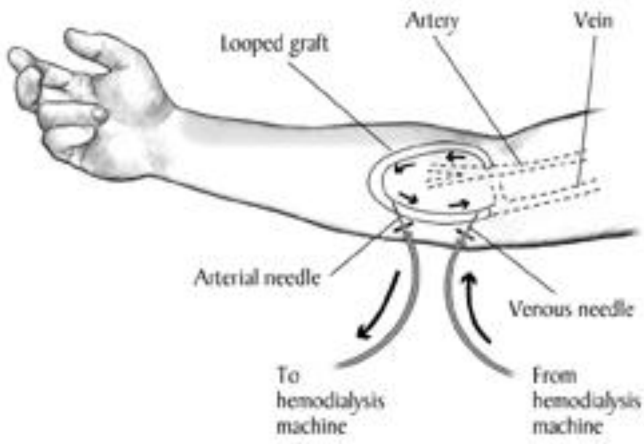


Fig.2.4: AV Graft

CHAPTER THREE

PROJECT CONCEPTUAL DESIGN

3.1 Introduction

In this chapter the project block diagram, hardware components of the system were discussed, and interfaces between stages were introduced. Also it focuses on the features and characteristics of the components to justify the reason of selection.

Several comparisons between many models of one type of component are exist to show preference for use.

3.2 Patient Circuit and Dialysate Circuit

- **The Patient Circuit:**

  The patient's blood is continuously pumped to the dialyzer by peristaltic pump from an artery "a large vein" or a surgically modified vein to allow high blood flow rates. Before the blood enters the dialyzer, heparin is added to prevent clotting. Then when the blood flows through the dialyzer it will pass across it's fibers, while the dialysate solution enters around these fibers a pressure gradient across the fibers membrane will occur, then a proper flow of compounds out of and into the blood will happen.

  After the process of filtering the blood is done in the dialyzer, the blood is passing through several stages of processing before returning it back to the patient. The first stage is an air bubble detection using an ultrasonic sensor to detect if there is any air bubble inside the filtered blood, in the case of the bubble detection the alarm system will be activated and the system is stopped to prevent blood containing bubbles enters the patient body.

  The second stage is pressure monitoring and controlling by a pressure sensor that measures the blood pressure before entering the patient body, if the measured pressure is out of the normal range[350_450]mmHg the system will be stopped preventing the blood flows to the patient body.

- **The Dialysate Circuit:**

Treated water inflows from Reverse Osmosis (RO) system into the dialysate tank to obtain a fixed conductivity of dialysate solution 14 mS/cm that is measured using a conductivity cell to insure high efficiency of the dialysis process. Then the dialysate solution enters the dialyzer in opposite direction of blood flow, the dialysis process is totally done by the dialyzer .

The excess fluids and waste product is removed from blood to dialysate solution, so the dialysate solution containing excess fluids and waste product outflows to the drain by a negative pressure applied by the ultrafiltration pump.

On drain line there is a blood leak detector, detects any presence of blood component in dialysate solution, in the case of blood presence the alarm system will be activated and the valve will be closed until the dialyzer is changed.

The last stage is the temperature monitoring using a temperature sensor that measures the temperature of the dialysate solution to control the blood temperature via heat transfer.

All the previous operations in both patient circuit and dialysate circuit controlled using advanced microcontroller (Arduino Due microcontroller), which acts as the brain of the system and control each component synchronously in a parallel process without any time delay, since it contains nine timers make it work with extraordinary processing speed.

The microcontroller provides a safety system to the project by displaying messages on LCD (Display unit) and activating an audible alarm using a buzzer if any problem occurred in the system in order to protect the patient's life from any risk.

The relationship between the system components and linking between them is shown in the following figure that contains general block diagram of the project (Fig.3.1).

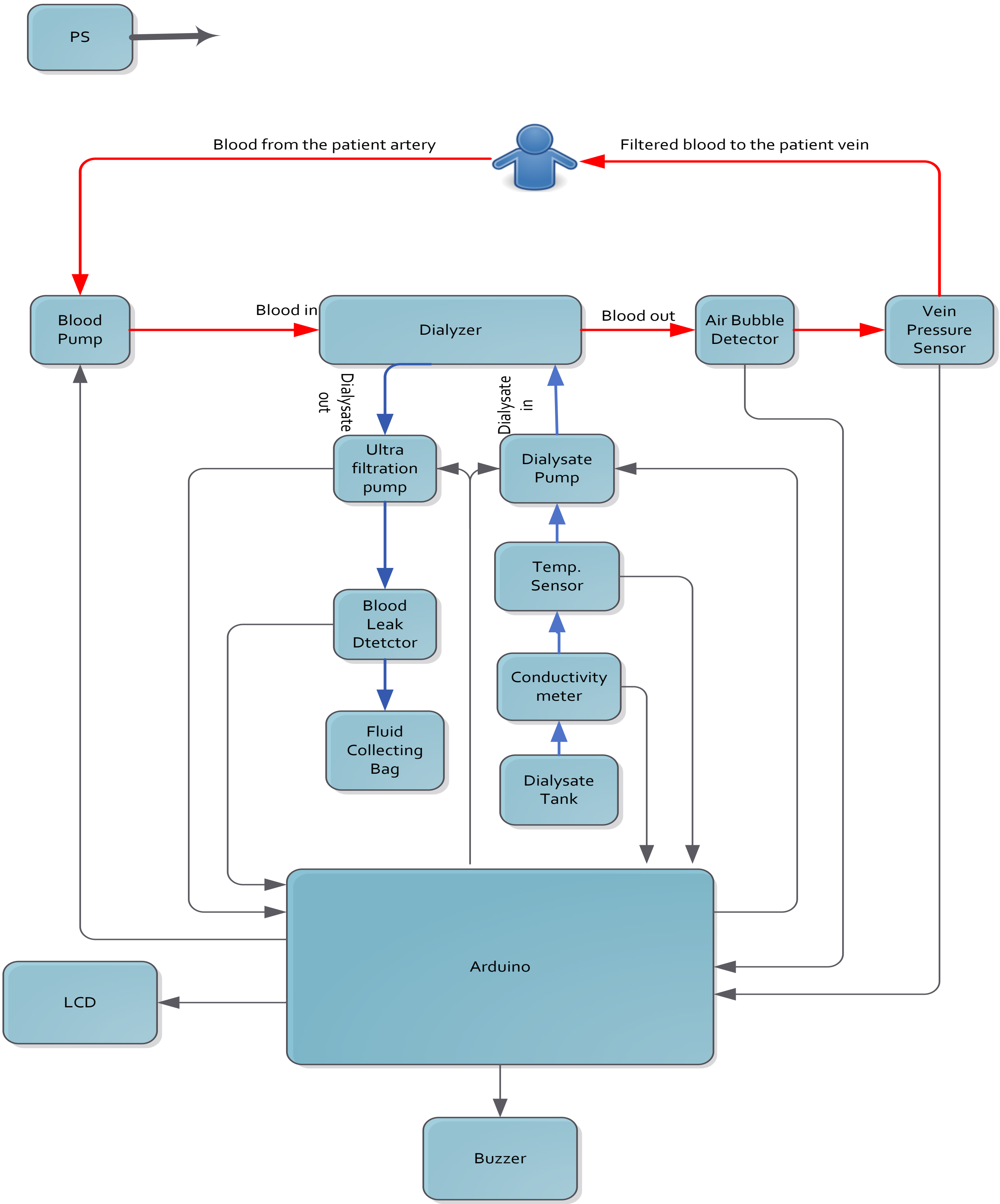


Fig 3.1 : General Block Diagram

3.3 Hardware Description

In this section all hardware components used in the project are explained, features and specifications are discussed.

3.3.1 Pumps

The system consists of three types of pumps for several purposes, as following :

- **Blood Pump** : pumps continuously the blood from the patient artery to the dialyzer.

Fig.3.2: Blood Pump

- ✓ **Features of peristaltic pump**:
  - No contamination. Because the only part of the pump in contact with the fluid being pumped is the interior of the tube, it is easy to sterilize and clean the inside surfaces of the pump.
  - Low maintenance needs. Their lack of valves, seals and glands makes them comparatively inexpensive to maintain.
  - It is able to handle slurries, viscous, shear-sensitive and aggressive fluids, like blood .
  - Pump design prevents backflow and syphoning without valves.[9]

The table below shows a comparison between different three types of peristaltic pumps in a several features. According to the table DC peristaltic pump is selected.

Table 3.1: Peristaltic Pumps Specifications

Model / Feature	version SR25.1	DC peristaltic pump	version SR25.1/Ex
Required voltage	220AC	12/24DC	220AC
Weight (kg)	0.6	0.8	0.7
Pressure max.	2200 mbar	2200 mbar	2200 mbar
consumption	3.5VA	3.5VA	3.5VA
speed	Low	High	Medium

Dialysate Pump: the dialysate solution is continuously pumped by dialysate pump from the dialysate tank to the dialyzer .

Fig.3.3: Hargraves Advanced Fluidic Pump

- ✓ **Features of Hargraves Advanced Fluidic Pump :**

  • Self-Priming/Dry Running: Monolithic diaphragm design allows for maximum suction/priming and continuous dry operation.

  • Longevity: Unique brushless DC motor design and advanced proprietary diaphragm elastomer gives the highest benchmark for service-free life.

  • Low Power Consumption: Advanced flow path and efficient valve system design allows for maximum flow with low power consumption.

  • Lightweight, Compact Size: Compact configuration allowing designers to minimize system weight and space requirements.

  • FDA-Approved Materials: Parker pumps and compressors are commonly used in FDA-approved systems.

The table below compares between several models of DC fluidic pumps in the most important features needed to achieve high performance. LTC series liquid pump is used.

Table 3.2: Hargraves Advanced Fluidic Pumps Comparison

Model / Feature	LTC Series Liquid Pumps	Peristaltic Liquid Pump with Silicone Tubing	7049 Miniature Diaphragm Liquid Pumps
Flow rate	650 mL/min	100 mL/min	110 mL/min
Current required	390 mA - 1.1A	200-300mA	100 mA
Working temp.	5 to 50°C	0 to 40 °C	0 to 40°C
Availability	Yes	No	Yes

- ❖ **Ultra filtration pump** : A device used to force the excess fluids to leave the blood to the dialysate crossing the dialyzer membrane, by applying a negative pressure.

❖ 3.3.2 Dialyzer

The dialyzer acts as an artificial kidney and replaces vital functions of the natural organ. Blood flows through as many as 20,000 extremely fine fibers, known as capillaries, clustered in a plastic tube approximately 30 centimeters long.

Pores in the capillaries filter metabolic toxins and excess water from the blood and flush them out of the body with dialysis fluid. Blood cells and vital proteins remain in the blood.

Fig.3.4: Dialyzer

✓ **Features of Diacap Lo Ps 15 Dialyzer :**

- Enhanced middle molecule clearances.
- Excellent urea clearance for enhanced URR.
- Minimal leukocyte & platelet reduction.
- Minimal activation of microinflamatory parameters.
- Minimal albumin loss.
- Endotoxin barrier.
- Minimal oxidative stress.

3.3.3 Dialysate Tank

A closed container contains the dialysate solution, which is a solution contains chemicals " acetate and bicarbonate" in a suitable concentration and pure water to make balance of minerals and fluids between the blood and dialysate.

The dialysate solution is a compound of pure water, acetate solution, and bicarbonate solution with a specific amounts to obtain the desired solution conductivity to achieve the maximum filtration of blood.

The mixing chamber contains internal chamber which contains inside it three tanks for water, acetate, and bicarbonate, each is connected to an electrical valve opens for a specific time to obtain the desired ratio of solutions to get 14 mS/cm conductivity.

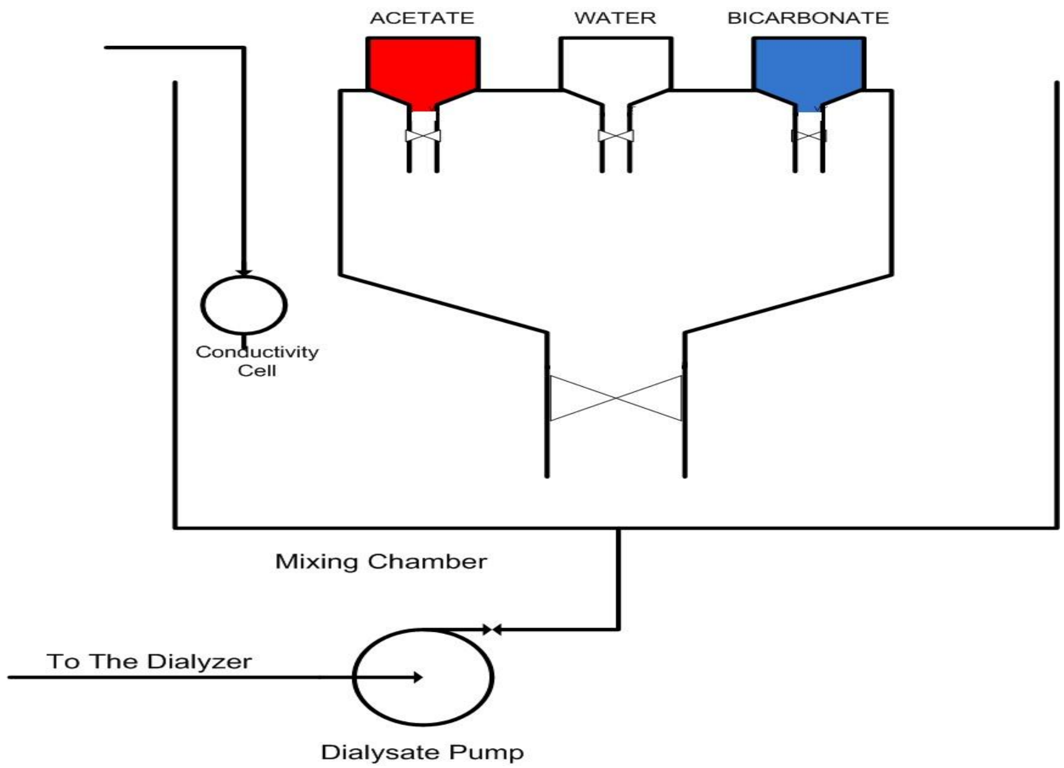


Fig.3.5: Dialysate Tank

3.3.4 Conductivity Meter

Measures the electrical conductivity of the solution " dialysate solution ", it is used to monitor the amount of minerals and other substances in the dialysate solution.

Conductivity is the amount of electrical current conducted through a dialysate and reflects electrolytes concentration.

The conductivity of the dialysate solution must be in the range [13-18] mS/cm, it depends on the blood pressure of the patient , if the pressure is high the conductivity value must be low and vice versa, to increase the efficiency of dialysis process by regulating the levels of minerals in blood. [10]

In the project, 14 mS/cm solution conductivity is assumed to be used .

Fig.3.6: 3-Pole Conductivity Cell

3.3.5 Blood Leakage Detector

Detects blood leak by sensing any presence of blood inside dialysate solution and excess fluids passing to the drain, when blood is sensed the blood circulation will be stopped.

Fig.3.7: Blood Leak Detector

The principle of operation of the module depends on emitting a light signal to detect any presence of blood components, it provides a digital signal as output, in the case of blood detection it's output will be active low, where if there is no blood the output will be active high.

- ✓ **Features of Blood leak detector :**
  - Non-invasive optical technology
  - Compact, free-entry design
  - Low cost, low power consumption
  - Field calibratable
  - Integratable electronics

3.3.6 Air Bubble Detector

When the air detector senses air it will trigger visual alarms, stop the blood pump and clamp the venous blood tubing to keep air from getting into the patient's bloodstream .

Fig. 3.8: Air Bubble Detector

The module uses the method of ultrasonic transmission. Ultrasonic convertors are attached on either side of the venous bubble catcher. At periodic intervals of approximately 90ms, a transmitting resonator generates attenuated ultrasonic vibrations at frequency of 90 KHz, which are absorbed by a receiving resonator.

The amplitude of the received signal is dependent upon the medium between the convertors. It's minimum value with bubble-containing fluids and it's maximum value with bubble-free fluids.

✓ **Features of Air Bubble detector :**

- Reliable pulse-type, non-invasive, ultrasonic technology
- Wide range of tubing sizes
- Air detection threshold or sensitivity can be user specified
- Dry coupled / No coupling gel necessary
- High noise immunity

3.3.7 Pressure Sensor

A device used to measure the blood pressure before returning it back to the patient, the blood pressure at returning point must be in the normal range of pressure [300 - 400] mmHg, the sensor will provide information for the Arduino to compare the measured pressure with the reference, if the pressure is out of the normal range of pressure the Arduino will activates the alarm system.

Fig.3.9: Piezoresistive Pressure Sensor

Three main types of pressure sensors differ from each other in their characteristics, each type used in a specific application based on these characteristics, it is important to compare between them to select the best one. This comparison illustrated in the following table.

Table 3.3: Pressure Sensors Classifications

Model / Feature	Metal thin-film sensor	Ceramic thick-film sensor	Piezo-resistive sensor
Measurement of the absolute pressure	No	No	Yes
Wide range of pressure	No	No	Yes
Long term stability	Yes	No	Yes

3.3.8 Temperature Sensor

Used to measure the dialysate temperature to control the blood temperature, the dialysate solution is heated to a desired temperature (38°C) and the blood is heated by heat transfer from dialysate to blood.

Fig.3.10: LM35 Temperature Sensor

The sensor will provide an information about the temperature to the Arduino, in order to keep in touch with temperature.

The table above lists some features of both LM35 and TMP36 temperature sensors verifying why it's preferred to use LM35 rather than TMP36.

Table 3.4: LM35 Vs. TMP36

Model / Feature	LM35	TMP36
Supply voltage range	4 to 30 V	2.7 to 5.5 V
Operating temp.	−55°C to +150°C	−40°C to +125°C
Cost	2$	2.5$

3.3.9 Fluid Collecting Bag

Is a plastic bag, collecting the dialysate solution containing waste product and excess fluids after the blood filtration.

Fig.3.11: Collecting Bag

3.3.10 Tubes

The first tube set is used an blood circuit and consist of:

- **Outflow Tube :**
  Attached to the patient artery " carries the unfiltered blood away from the patient body".
- **Inflow Tube :**
  Attached to the patient vein " carries the filtered blood to the patient body" .

Fig.3.12: Tube Set

The second tube set is used in dialysate circuit, one tube is attached from the dialysate tank to the dialyzer through the dialysate pump carrying the dialysate solution to inlet port of the dialyzer, and the second is attached from the outlet port of the dialyzer to the drain through the ultrafiltration pump carrying excess fluids and waste product .

The difference between the two sets is dialysate tubes set are bigger in diameter than the blood tubes set, because of the higher flow rate used with dialysate solution.

3.3.11 Electrical Valves

A pinch valve is a full bore or fully ported type of control valve which uses a pinching effect to obstruct fluid flow. The air operated Pinch Valve works without any additional actuator; all it needs to close or operate is 30 psi air supply into the Pinch Valve body. As soon as the air supply becomes interrupted and the volume of air exhausts, the elastic rubber hose starts to open due to its great impact resilience.

Fig.3.13: Pinch Valve

✓ **Pinch Valve Features :**

- Saves space in equipment with compact design.
- Large range of tubing sizes available for various flow and pressure requirements.
- Zero dead volume prevents cross-contamination.[11]

3.3.11 Needles

A needle is generally a thin, cylindrical object, often with a sharp point on the end. It is inserted inside the patient veins and arteries in order to withdraw blood from or supply blood to the patient.

There is many sizes of needles in gauge used for several purposes with specific applications such as in hemodialysis needle's size depends on the blood flow rate and vascular access type, all this is shown in the table below .

Depending on the information mentioned in table 3.5 while using AV Fistula and Blood flow rate equal to 300 ml/min a16 gauge needle will be used .[12]

Table 3.5: The Relationship between Needle size, Blood Flow Rate and Vascular Access.

	Recommended Needle Gauge	
Blood Flow Rate	AV Fistula	AV Graft
<300 ml/min	17 gauge	17 gauge
300-350 ml/min	16 gauge	16 gauge
350-450 ml/min	15 gauge	15 gauge
>450 ml/min	14 gauge	15 gauge

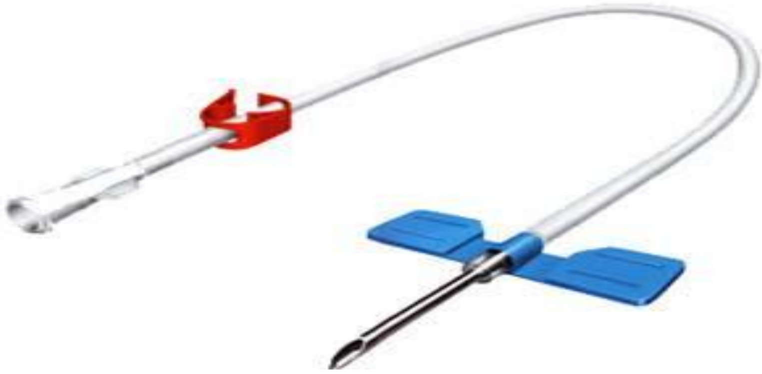


Fig3.14: 16 Gauge Needle

3.4 Microcontroller Board

The controller is the brain of the artificial kidney. It operates the pumps and provides messages on LCD, and audible alarms to the user if any parameter out of the normal range and alerts user if there any problem with the system.

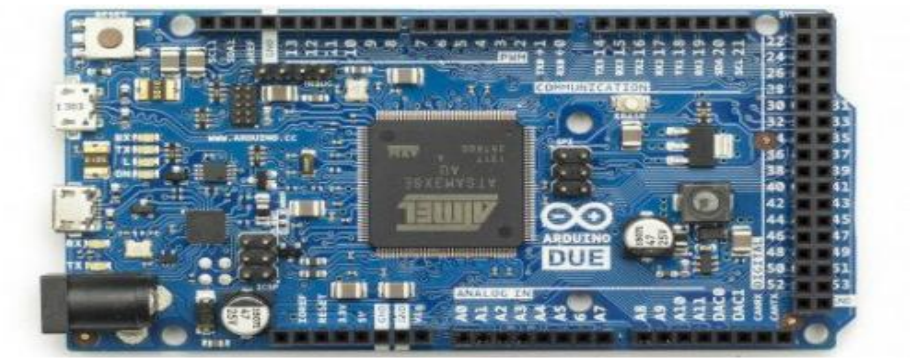


Fig 3.15: Arduino Due

- ✓ **Arduino features :**

There are many other microcontrollers and microcontroller platforms available for physical computing, such as Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, and many others offer similar functionality.

All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but it offers some advantage for teachers, students, and interested amateurs over other systems:

- Inexpensive : Arduino boards are relatively inexpensive compared to other microcontroller platforms.
- Cross-platform : The Arduino software runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.
- Simple, clear programming environment : The Arduino programming environment is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. For teachers, it's conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with the look and feel of Arduino
- Open source and extensible software: The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries.[13]

Large number of Arduino boards exist, each has features differ from others. Some applications requires high speed but others not, so the selection of the type of Arduino board depends on the application and it's features. As shown in the following table.

Table 3.6: Arduino Boards Features

Model / Feature	UNO	MEGA	DUE
Operating voltage Input/Output	5 V/7-12 V	5 V/7-12 V	3.3 V/7-12 V
CPU speed	16 MHz	16 MHz	84 MHz
Memory	32KB	256KB	512KB
Cost	50$	100$	110$

1.5 Power Supply

The system powered using two 12V DC batteries, supplies electric energy for all electrical loads used.

These batteries designed to be chargeable that it must be recharged after each use, the batteries will operate the prototype for 4 hours if fully charged.

Fig.3.16: Motoma Battery

3.6 LCD Display

LCD used to display the measured values of pressure, temperature, flow rates, conductivity, and time left for the session, it's also display massages to alarm user, and display some important parameters such as target weight loss which must be input by the patient, since it's important to keep in touch with the statues of the patient .

Fig 3.17 LCD Display

✓ **Features of the 16*4 LCD Display module** :

- Great display for micro controller project
- High quality

- Easy to use
- Affordable [14]

3.7 Alarm System

An audible alarm, alarms the user if there is any problem in the system, such as if any parameter is out of the normal range.

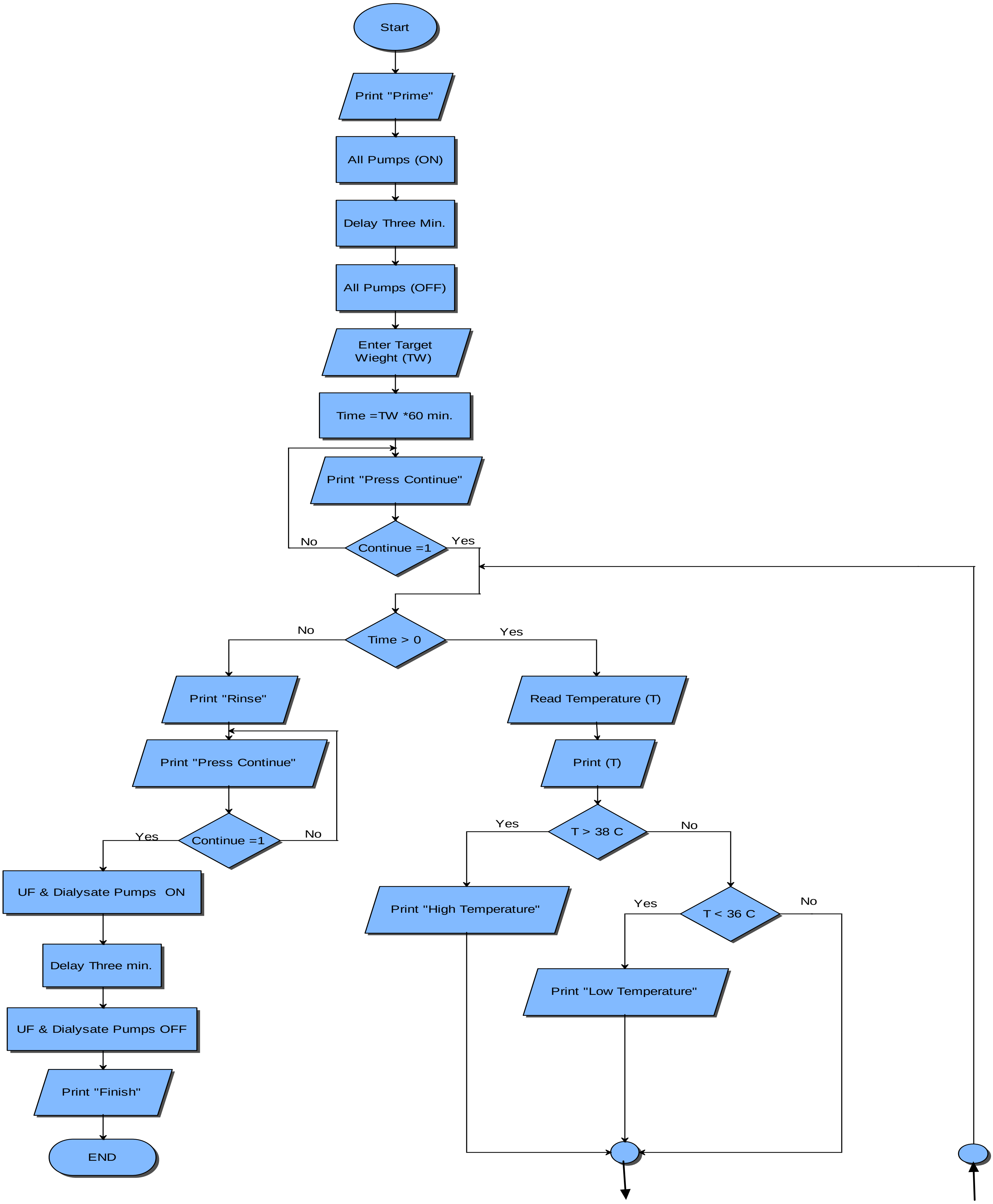
The device that is used, is the buzzer

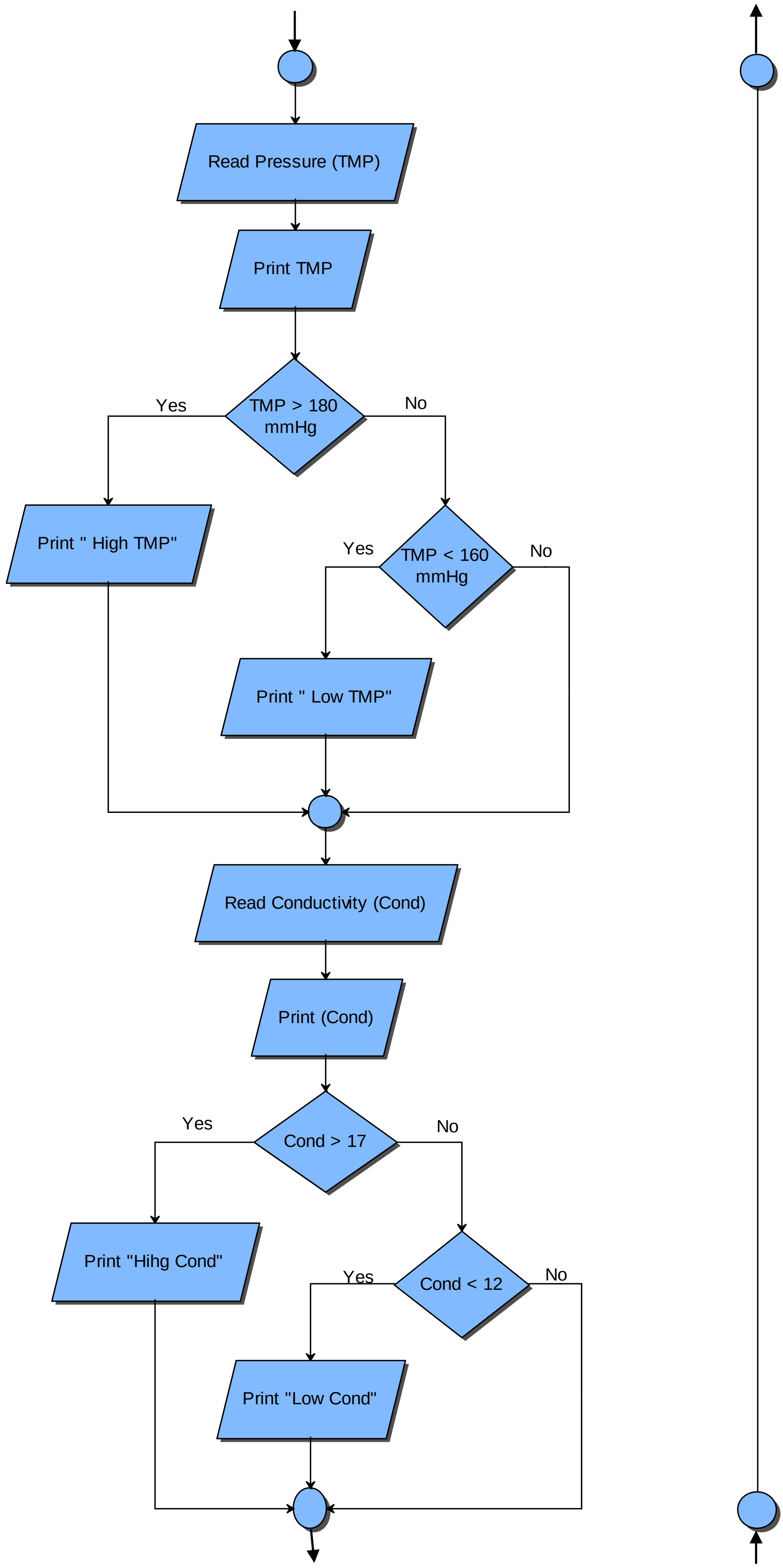
Fig.3.18: Buzzer Alarm

✓ **Features of Buzzer :**

- Low power consumption
- High sound

3.8 Project Flow Chart :





Read Pressure (TMP)
Print TMP
TMP > 180 mmHg
Yes
No
Print " High TMP"
TMP < 160 mmHg
Yes
No
Print " Low TMP"
Read Conductivity (Cond)
Print (Cond)
Cond > 17
Yes
No
Print "Hihg Cond"
Cond < 12
Yes
No
Print "Low Cond"

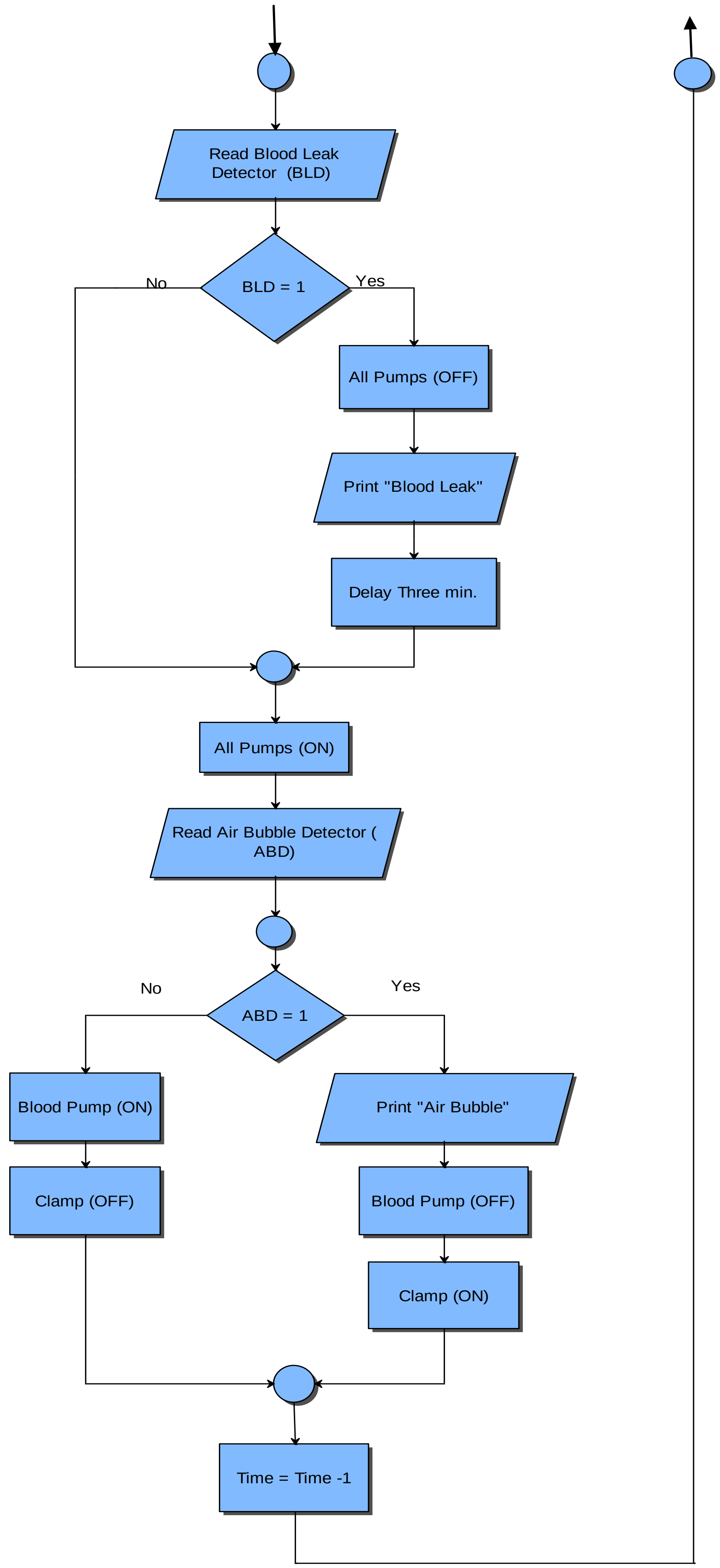


Fig.3.19: Project Flow Chart

CHAPTER FOUR

PROJECT IMPLEMENTATION

4.1 Introduction

This chapter includes an overview about the principle of operation of each part of the whole system. It is also contains the design of the main circuit of the system and sub circuits for each stage and part of the system all implemented using Proteus software.

To connect sensors and any other component with Arduino board calculations must be performed to get the appropriate values or to control the operating of some components. All these calculations explained .

4.2 HD Flow Diagram

Figure 4.1 shows hemodialysis (HD) flow diagram and the position of the system components, this flow diagram consists two parts : blood circuit and fluid circuit.

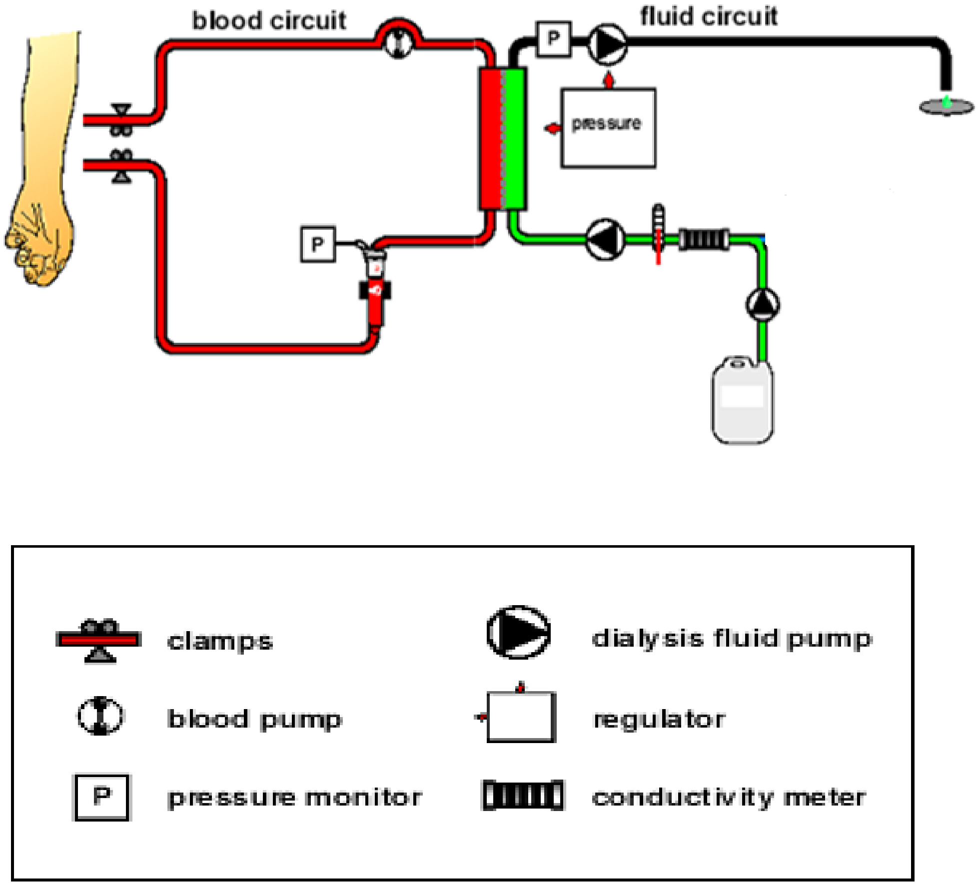


Fig.4.1: HD Flow Diagram

4.3 Project Main Circuit

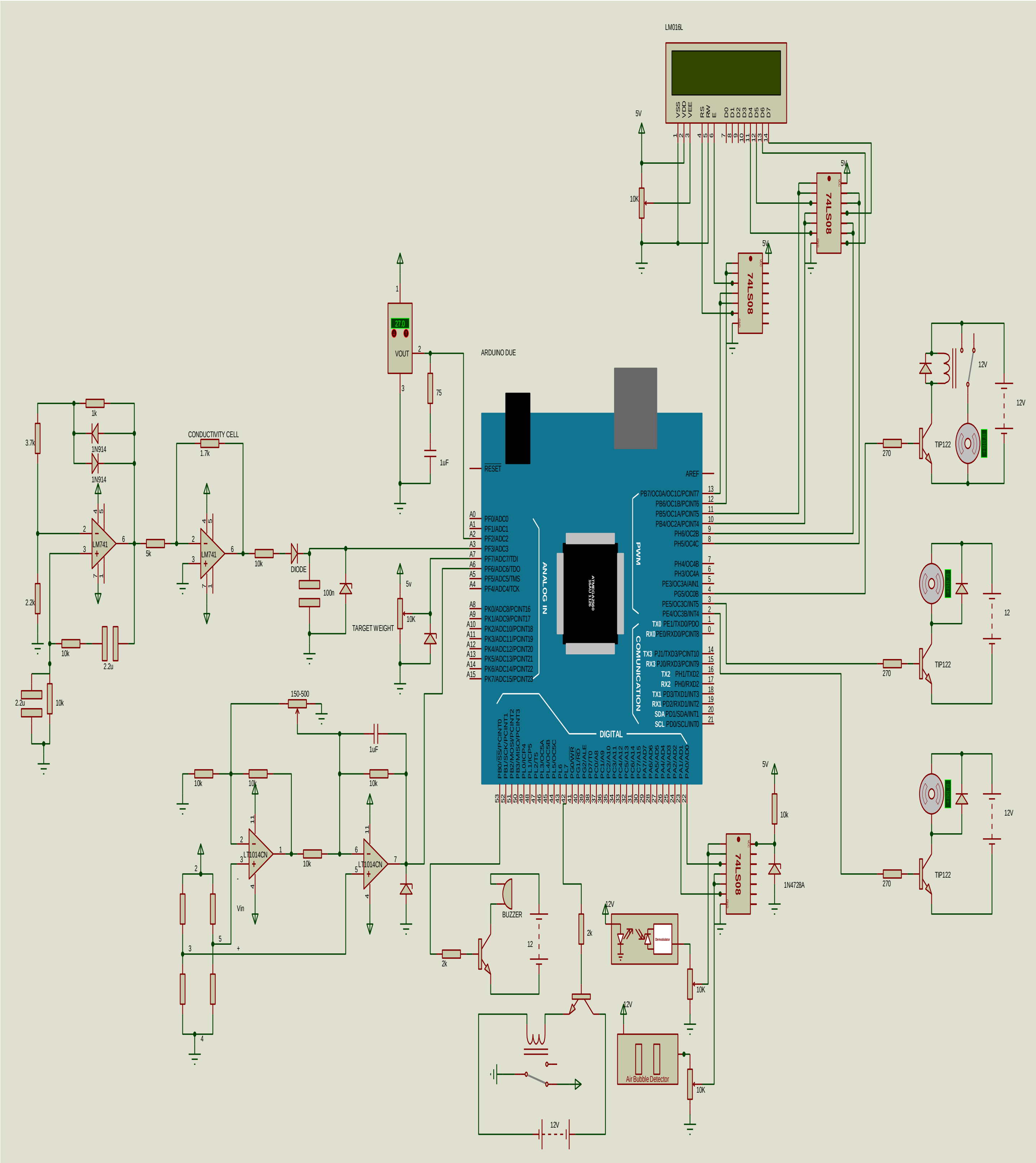


Fig.4.2 : Project Main Circuit

4.4 Project Sub Circuits

4.4.1 DC Motors Circuit

The project contains three DC motors as follow:

1) DC motor for Blood pump.
2) DC motor for Dialysate pump.
3) DC motor for Ultrafiltration pump.

These pumps are numerically indicated in figure 4.3 respectively.

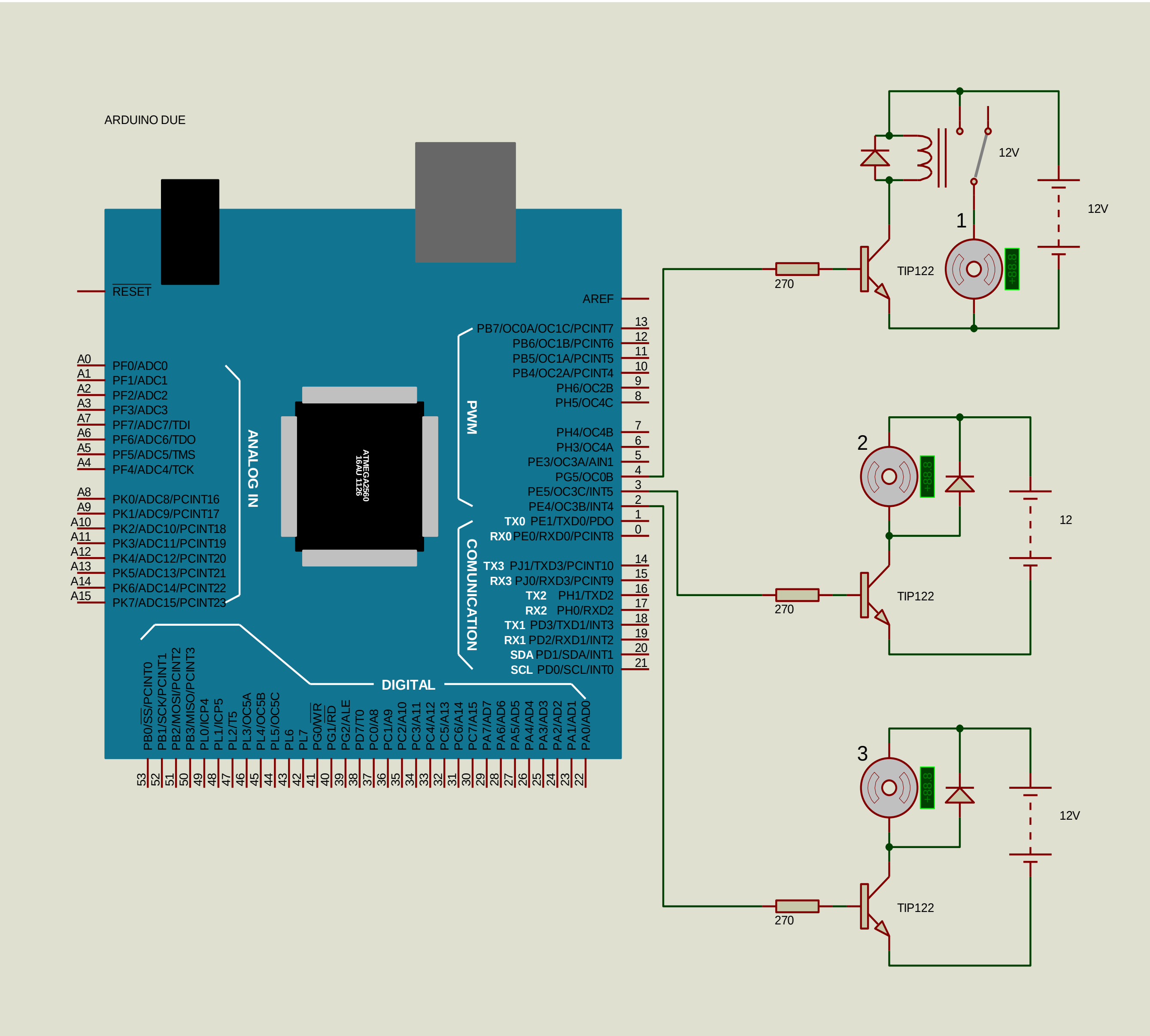


Fig.4.3: DC Motors Circuit

- **General calculations:**

- **Electrical calculations**

Since the Arduino pin provides only 3.3V and a maximum current of 3mA, so the resistance R must be greater than $(3.3 - 2.5)V/3mA = 267\Omega$.

R chosen 2kΩ .

- **Mechanical calculation:**

The following equations are important for motor speed calculations. Using equation (4.1) the fluid velocity is calculated and then the speed of the motor can be calculated using equation (4.3) :

$$Q = A \times v \tag{4.1}$$

$$A = \pi \times r^2 \tag{4.2}$$

$$\omega = {}^{v}/_{R} \tag{4.3}$$

Where:

Q: flow rate of the fluid.

A: cross sectional area of the tube.

v: velocity of the fluid.

r: radius of the tube.

R: radius of the pump.

ω: speed of motor

- **Chopper calculation:**

Chopper circuit used to provide a constant DC voltage to the motors, a frequency equal 200Hz is selected in order to make the fluid flow by the pump seems continuously to the human eyes.

$$T = \frac{1}{f} = \frac{1}{200} = 5ms \quad (4.4)$$

$$v_o = v_s \times \frac{\omega}{\omega_{max}} \quad (4.5)$$

$$T_{on} = \frac{v_o}{v_s} \times T = \frac{\omega}{\omega_{max}} \times 5ms \quad (4.6)$$

Where:

v_o: output voltage that's operate the motor.

v_s: supply voltage.

ω : speed of motor.

ω_{max}: maximum speed of motor.

❖ **Blood pump**

Using constant Blood flow rate equal to 300ml/min (due to the used needle size and cannulation type) , blood tube ID = 8.0 mm, with radius r=4*10^ -3, by substituting in equations (4.1), (4.2), (4.3).

$$A = \pi \times (4 \times 10^{-3})^2 = 0.502cm^2$$

$$v = \frac{Q}{A} = \frac{0.3 \times 10^{-3} m^3}{min} \div 0.502cm^2 = 5.96m/min$$

$$\omega = \frac{5.96m/min}{0.502cm^2} = 124.16\ rpm$$

- **Chopper calculation:**

By substituting in equation (4.6) :

$$T_{on} = \frac{\omega}{\omega_{max}} \times 5ms = \frac{124.16}{442.6} \times 5ms = 1.4ms.$$

❖ **Dialysate pump**

Using constant dialysate flow rate equal to 500ml/min, and dialysate tube ID=8.0mm (r=4*10^-3), by substituting in equations (4.1), (4.2), (4.3) :

$$A = \pi \times (4 \times 10^{-3})^2 = 0.502cm^2$$

$$v = \frac{0.5 \times 10^{-3} m^3/min}{0.502cm^2} = 9.96m/min$$

$$\omega = \frac{9.96}{2.5cm} = 398.4rpm$$

- **Chopper calculation:**

By substituting in equation (4.6) :

$$T_{on} = \frac{\omega}{\omega_{max}} \times 5ms = \frac{398.4}{517.6} \times 5ms = 3.8ms$$

❖ **Ultrafiltration pump**

Using constant Blood flow rate equal to 516.7ml/min, blood tube ID=8.0mm (r=4*10^-3), by substituting in equations (4.1), (4.2), (4.3) :

$$A = \pi \times (4 \times 10^{-3})^2 = 0.502cm^2$$

$$v = \frac{0.5167 \times 10^{-3} m^3/min}{0.502cm^2} = 10.29m/min$$

$$\omega = \frac{5.96}{2.5cm} = 411.6rpm$$

- **Chopper calculation:**

By substituting in equation (4.6):

$$T_{on} = \frac{\omega}{\omega_{max}} \times 5ms = \frac{411.6}{517.6} \times 5ms = 3.9ms$$

4.4.2 Temperature Measurement Circuit

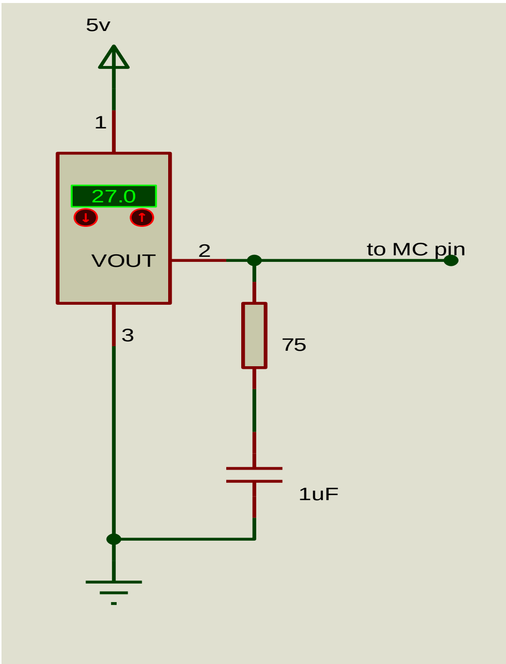


Fig.4.4: Temperature Measurement Circuit

Temperature measurement will be done by LM35 temperature sensor, which is simply give 10mV per 1Cellisouse. But its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc, as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V into ground and a series R-C damper such as 75Ω in series with 1 µF from output to ground are often useful.

4.4.3 Conductivity Measurement Circuit

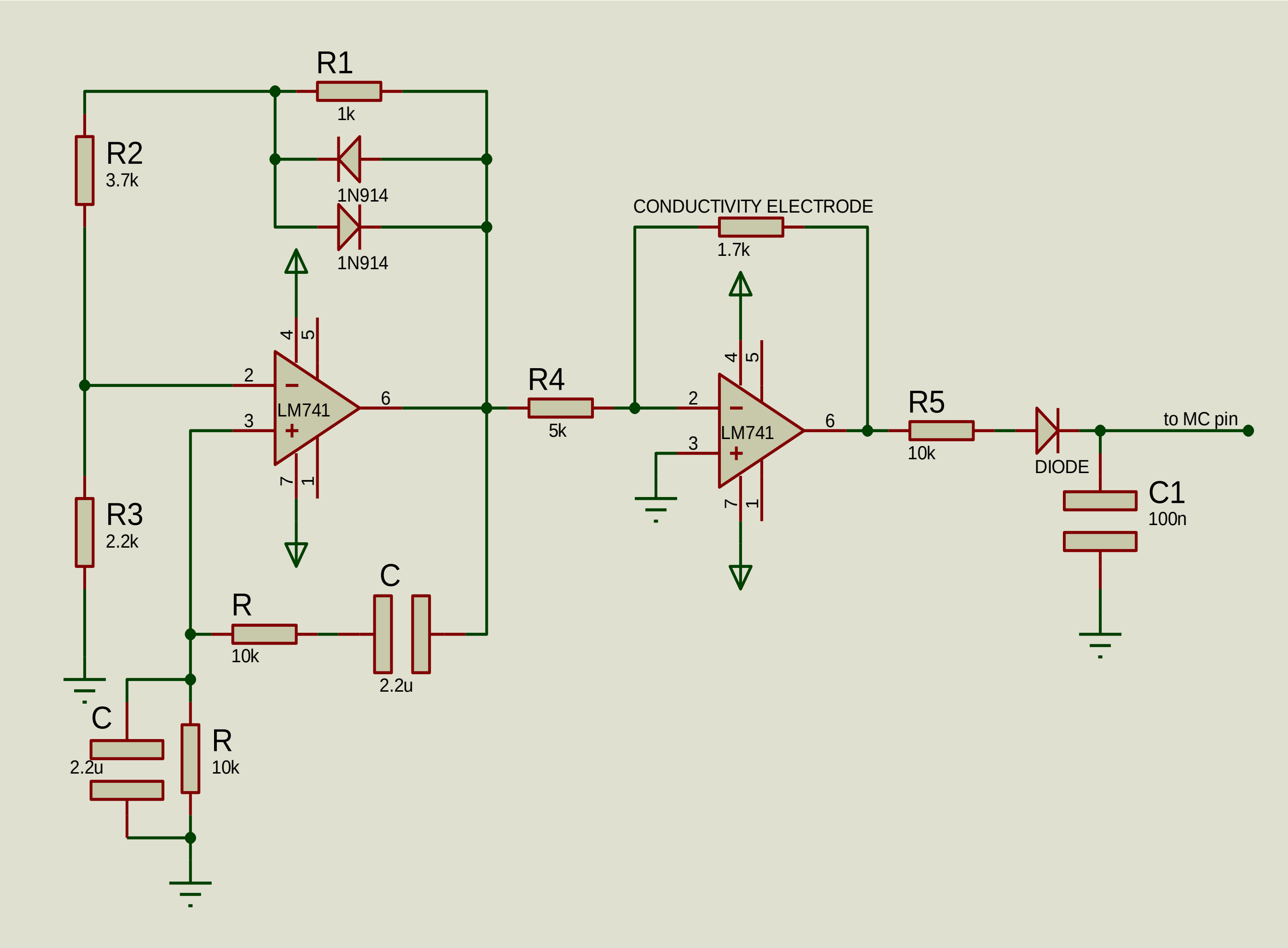


Fig.4.5: Conductivity Measurement Circuit

A three-pole conductivity cell will be used for conductivity measurement, this cell needs an AC current, so Wien bridge oscillator used to provide sinusoidal signal with output voltage $10V_{p\text{-}p}$ and frequency equal to:

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi(10k)(2.2\mu)} = 7.2\ H_z \qquad (4.7)$$

Wien bridge is able to oscillate only if the gain of negative feedback ≥ 3 [14], so R1, R2 and R3 chosen to achieve this condition:

$$A = 1 + \frac{R1+R2}{R3} = 1 + \frac{1k+3.7k}{2.2k} = 3.1 \qquad (4.8)$$

In the second op-amp, the conductivity electrode is connected in the feedback so the output of the amplifier is

$$v = -\frac{Z_{cond}}{R4} v_{in} = -\frac{Z_{cond}}{5k} 10v = -\frac{Z_{cond}}{0.5\times 10^3}$$

(4.9)

The following figure show the output voltage from Wien Bridge circuit and conductivity circuit assuming $R_{cond} = 1.7k\Omega$

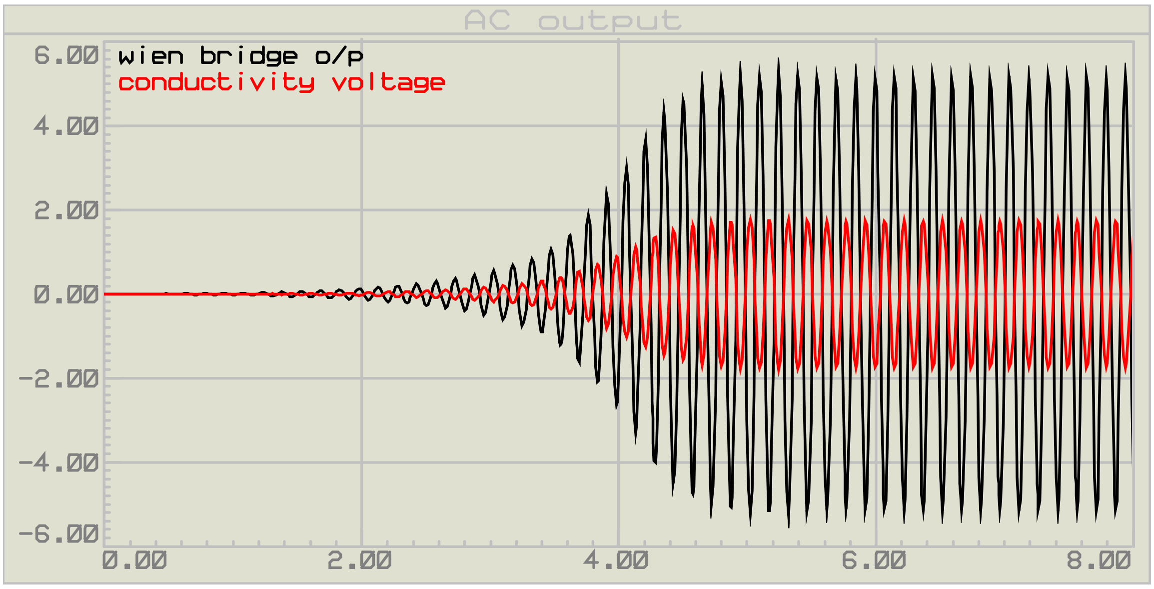


Fig.4.6 : Conductivity Circuit Output

In order to read the analog signal by the microcontroller, a half wave rectification and smoothing capacitor is used to convert the AC signal into DC signal, the final output voltage will be:

$$v_{out} = \frac{v}{2} - 0.7 = (R_{cond} \times 10^{-3}) - 0.7 \qquad (4.10)$$

$$Z_{cond} = (v_{out} + 0.7) \times 10^3 \tag{4.11}$$

The following figure show half wave rectification and smoothed signal assuming $Z_{cond} = 1.7k\Omega$

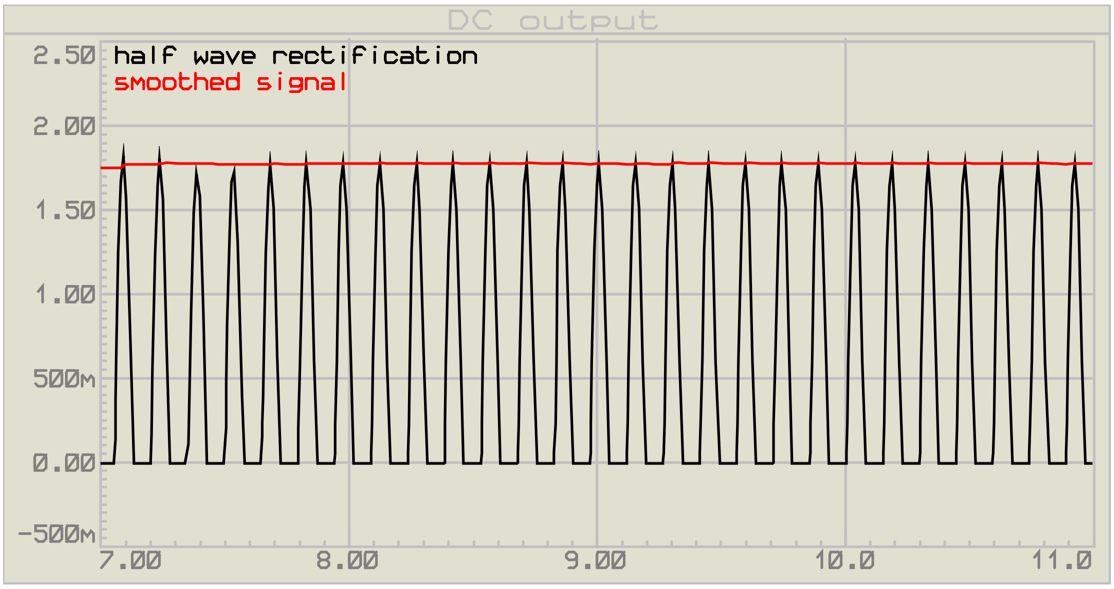


Fig.4.7 : Smoothed Output Signal

The conductivity in mS/cm will be calculated using the following equations :

$$G = {}^{1}/_{R_{cond}} \tag{4.12}$$

$$C = G.k \tag{4.13}$$

Where: R_{cond} =Dialysate resistivity

k =cell constant (cm^{-1}) =24cm^{-1}

G =conductance (S)

C= conductivity mS/cm

So the final equation obtained by substituting equation (4.12) in equation (4.13) to calculate the conductivity of dialysate solution will be:

$$C = \frac{24}{v_{out}+0.7}\ mS/cm \tag{4.14}$$

4.4.4 Pressure Measurement Circuit

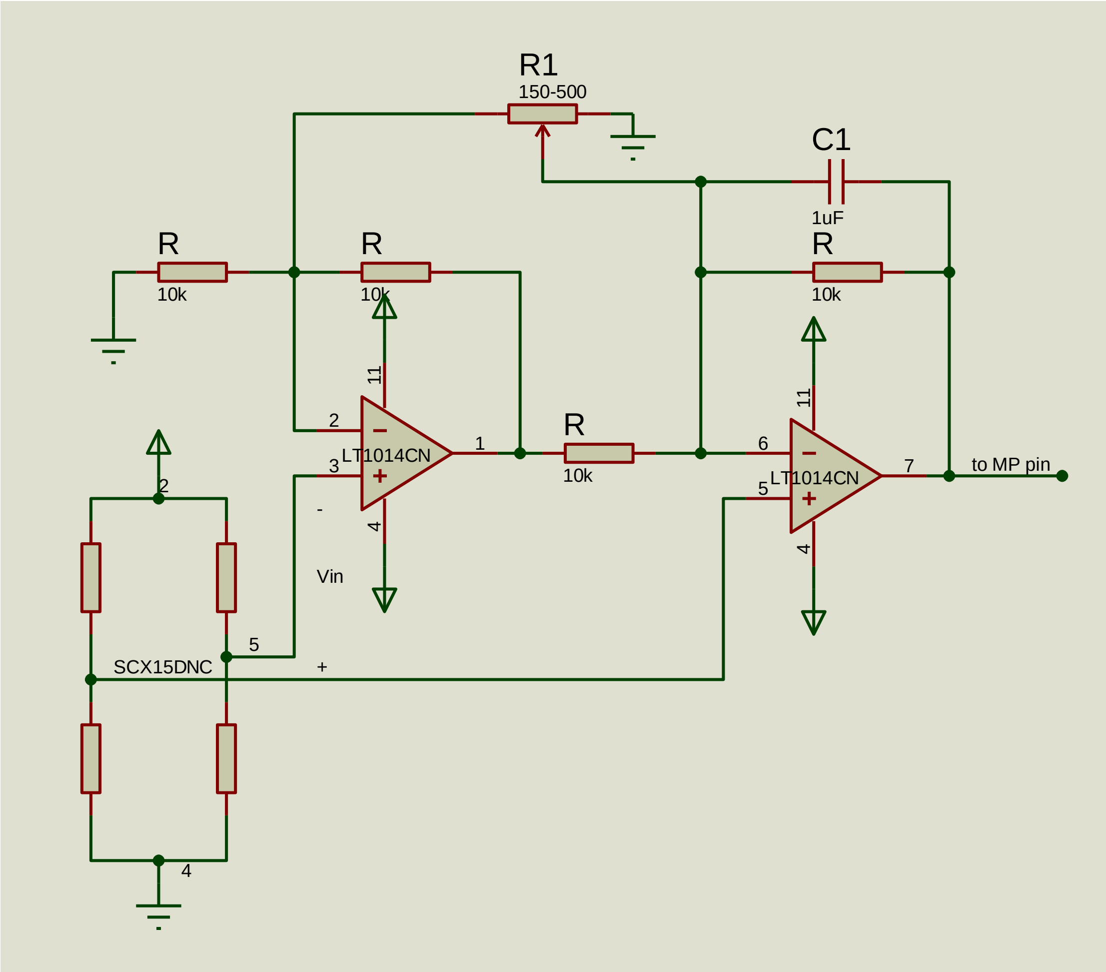


Figure 4.8: Pressure Measurement Circuit

This circuit measures blood pressure using SCX15DNC pressure sensor, which provides a linear relationship between input pressure and output voltage. The sensor has a span of 90 mV. The measured pressure value must be passes through this procedure as following:

- A low-pass filter implemented with $f_c = \frac{1}{2\pi RC1} = \frac{1}{2\pi \times 10k \times 1\mu} = 15.9H_z$ in order to attenuate any noise signal may be connected to the pressure signal.
- The measured pressure value is too small so it must be amplified with total gain equal to: $v_o = v_{in} \times 2\left(1 + \frac{R}{R1}\right)$ to make it suitable for display.

While v_{min} produced at minimum pressure where $P_{min} = 0$ and $R1$ used for calibration v_{max} at maximum pressure.

The measured pressure can be determined by this equation:

$$P = (v_o - v_{min}) \times \frac{P_{max}}{v_{max} - v_{min}} \tag{4.15}$$

4.4.5 LCD Circuit

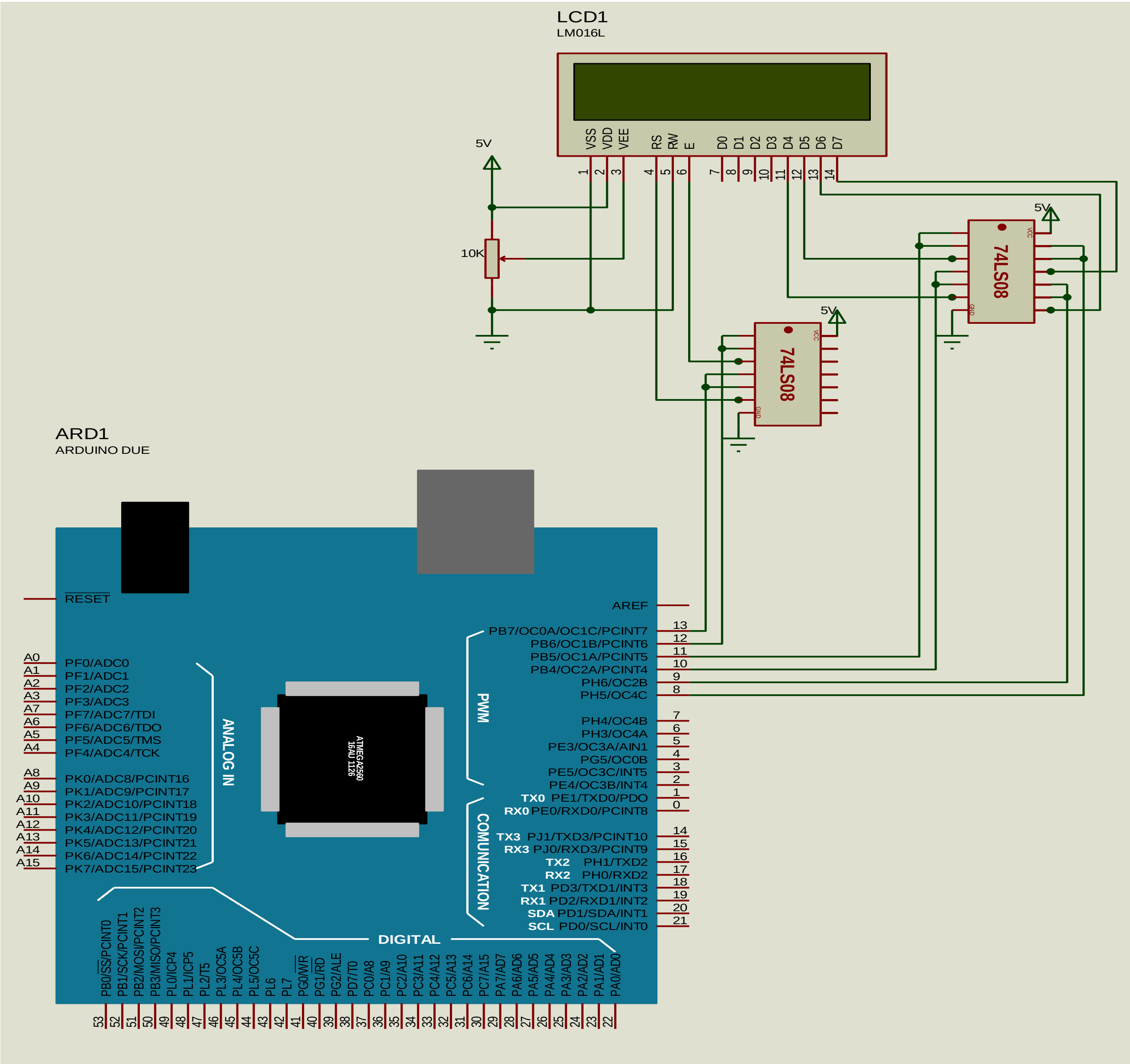


Figure 4.9 : LCD Circuit

The LCD is used to display different parameters, this type of LCD's needs 5V to drive it, but Arduino DUE provides only 3.3V!

For that reason, two AND-gate IC's is used as voltage level-up shifter at the control and data lines of LCD.

4.4.6 Blood Leak And Air Bubble Detector

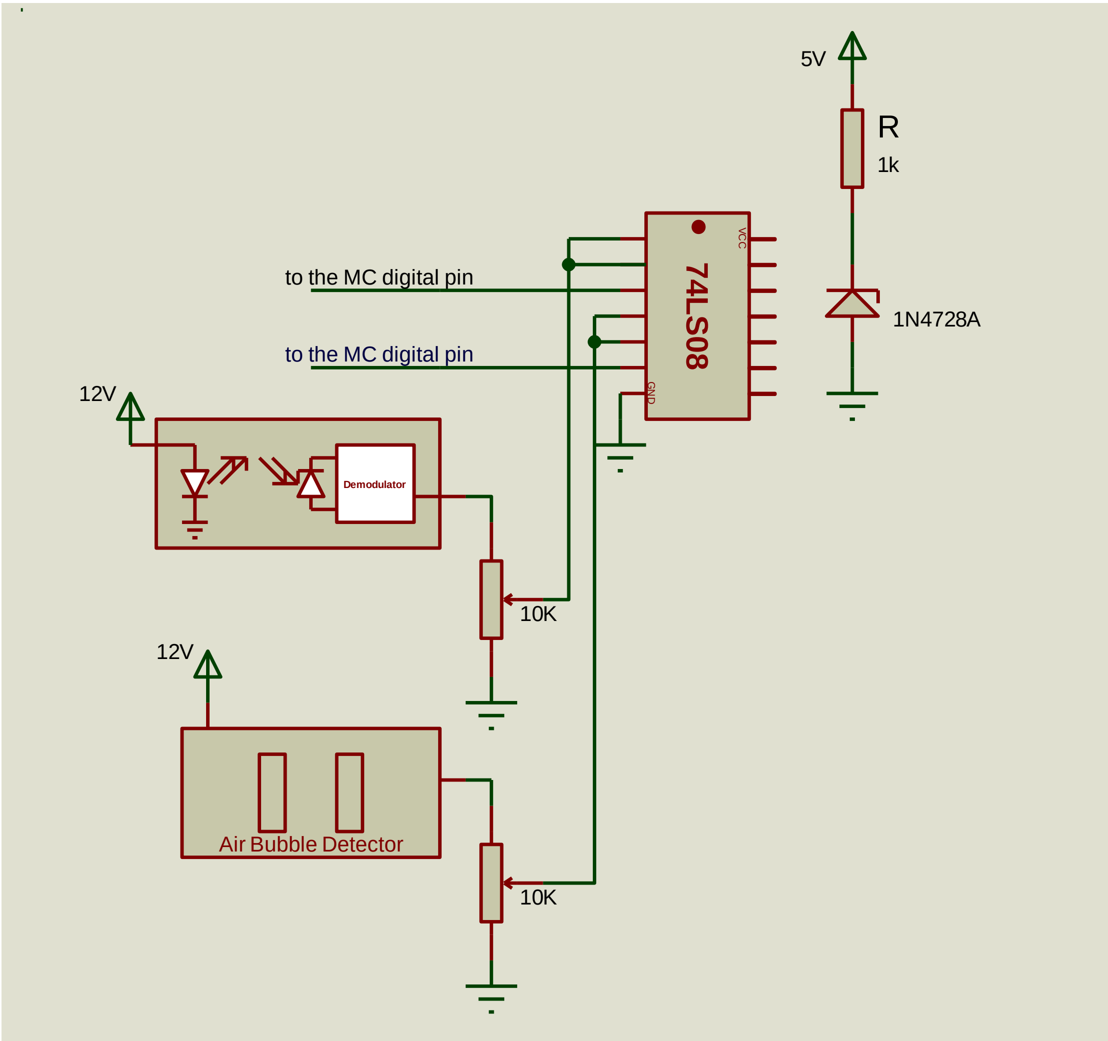


Figure 4.10 : BLD And ABD Modules Connection To Arduino

These two modules give 0V as output in the cases of blood leak or air bubble detection, and give 12V as outputs in the cases of no blood leak or no air bubble detection.

12V is too high voltage, so a trimmer potentiometers are used for making voltage divider, so 12V is converted into 5V.

By supplying AND-gate with 3.3V at Vcc ,using Zener diode as regulator, it is become as level-down shifter which has a maximum output of 3.3V, thus the value can be enter the MC as a digital input without damaging it.

4.4.7 Power Supply Circuit

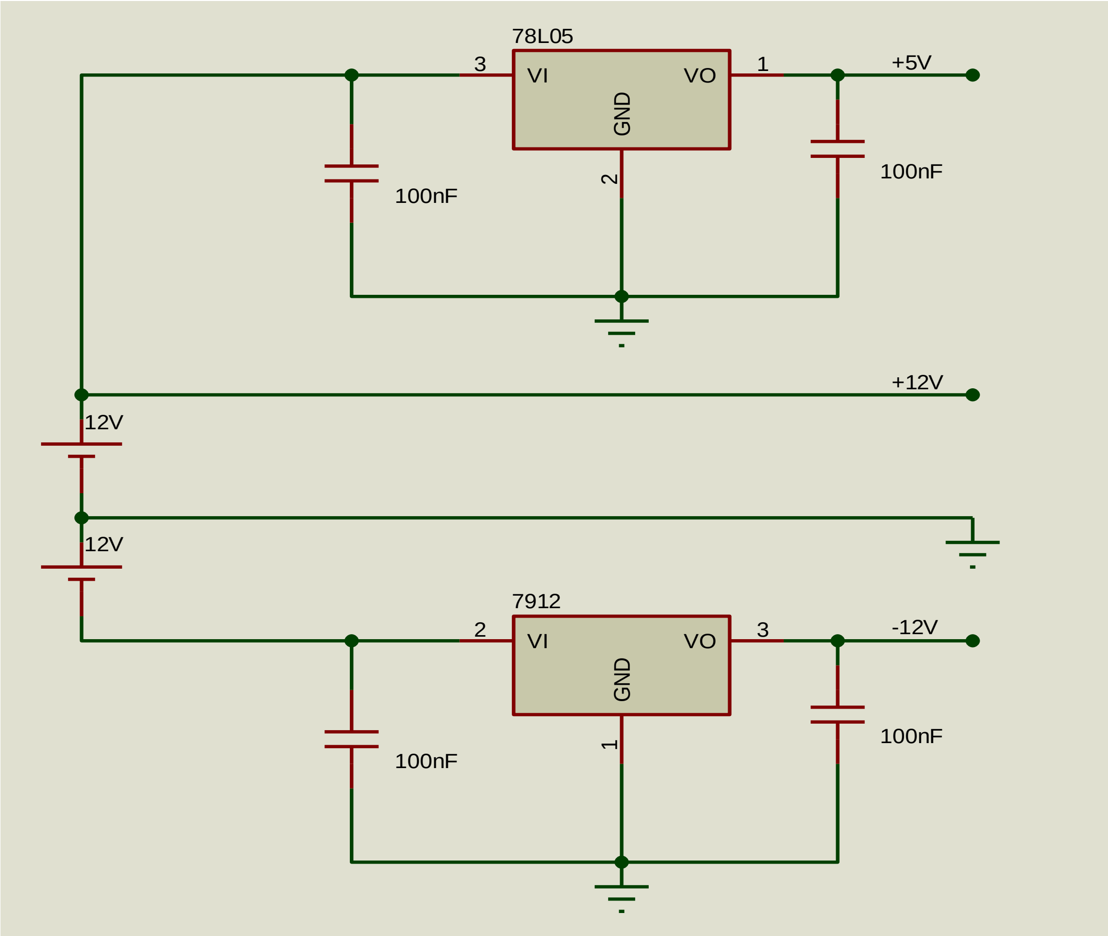


Fig.4.11: Power supply circuit

The prototype can be powered using two batteries (12Volt DC), some components require 12V which delivered directly from the battery, and other components require -12V which delivered using 7912 regulator, also the remaining components require 5V which delivered using 7805 regulator.

CHAPTER FIVE

TESTING AND RESULTS

5.1 Introduction

5.2 System Circuits "Testing and Results"

5.2.1 Conductivity Circuit

5.2.2 Pressure Circuit

5.2.3 Display Unit

5.2.4 DC Motors Circuits

5.2.5 Temperature Measuring Circuit

5.2.6 Blood Leak Detection Circuit

5.2.7 Air Bubble Detection Circuit

5.3 Final Design

5.1 Introduction

Practical implementation of the project has been done in the second semester, this implementation started by implementing each individual sub circuit. After completing implementing each individual sub circuit, they are connected together to accomplish the project as one unit.

5.2 System Circuits "Testing and Results"

In the following sections, all sub circuits of the project has been built in on printed circuits.

5.2.1 Conductivity Circuit

After implementing the conductivity measurement circuit we got a results from each part of the hole circuit, as following :

- **Wien Bridge Oscillator :**

As shown below, we got a pure sine wave of $10V_{P\text{-}P}$, and frequency of 7.7Hz .

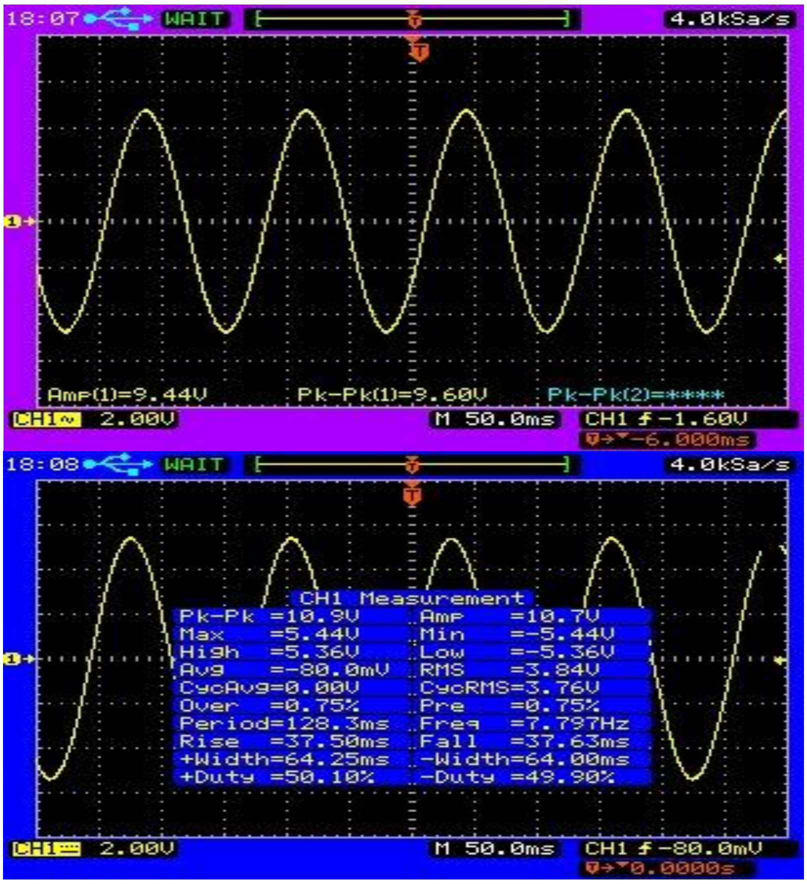


Fig.5.1: Wein Bridge Output Waveform

❖ **Half Wave Rectification :**

Fig.5.2 : Half-Wave Rectification Waveform

5.1.2 Pressure Circuit

By testing the pressure sensor for verifying the linear relationship between the input pressure and the output voltage, the results was as following :

Table 5.1 : Pressure Sensor Outputs

Pin (mmHg)	**0**	**100**	**200**	**300**	**400**
Vout (Volt)	0	0.5	1.1	1.5	2.05

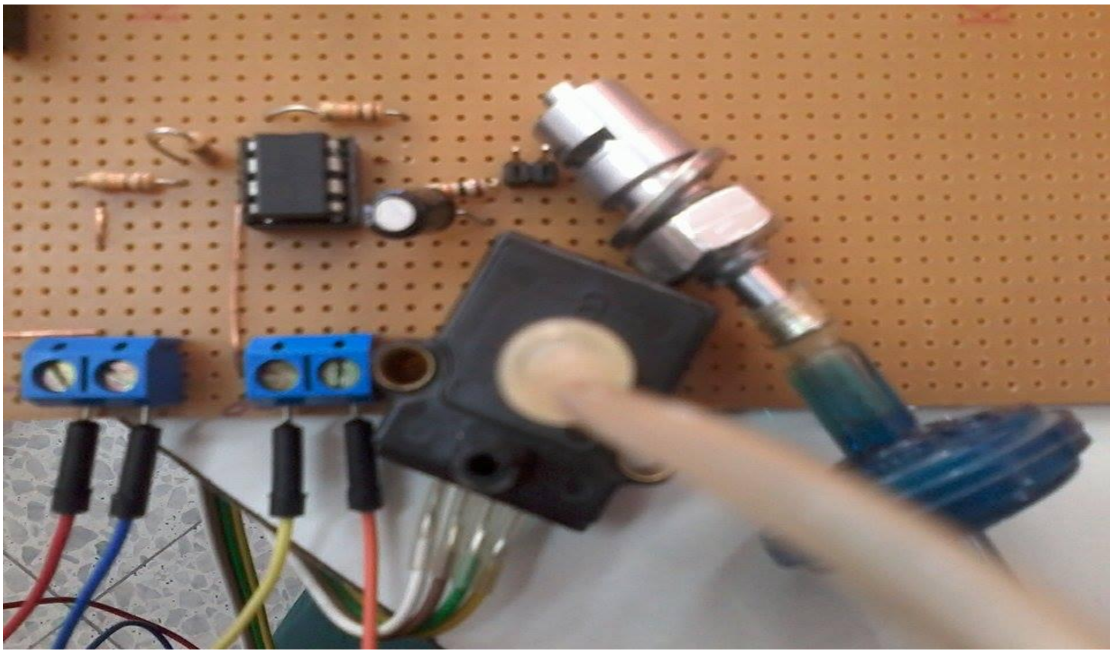


Fig.5.3: Pressure Measurement Circuit

5.2.3 Display Unit

A 16*4 LCD used to display the most important parameters for dialysis session, AND gates were used as a voltage level shifter because the LCD require 5V while the Arduino provides only 3.3V.

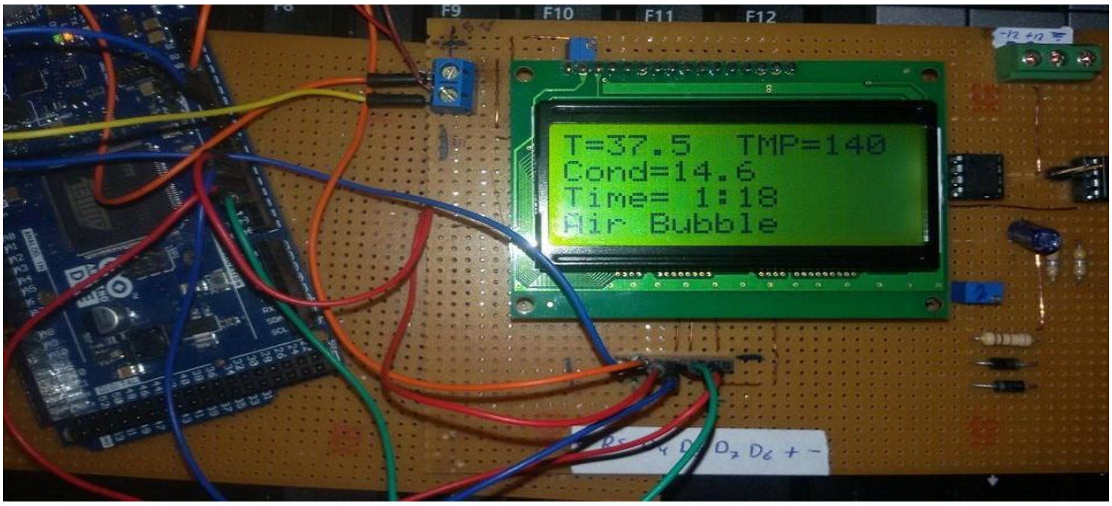


Fig.5.4 : Display Unit Circuit

5.2.4 DC Motors Circuits

For each DC motor used for the pumps, the buzzer, and the electrical solenoid valve a power transistor used as a switch to provide fixed voltage for each to get the desired flow rate for each pump.

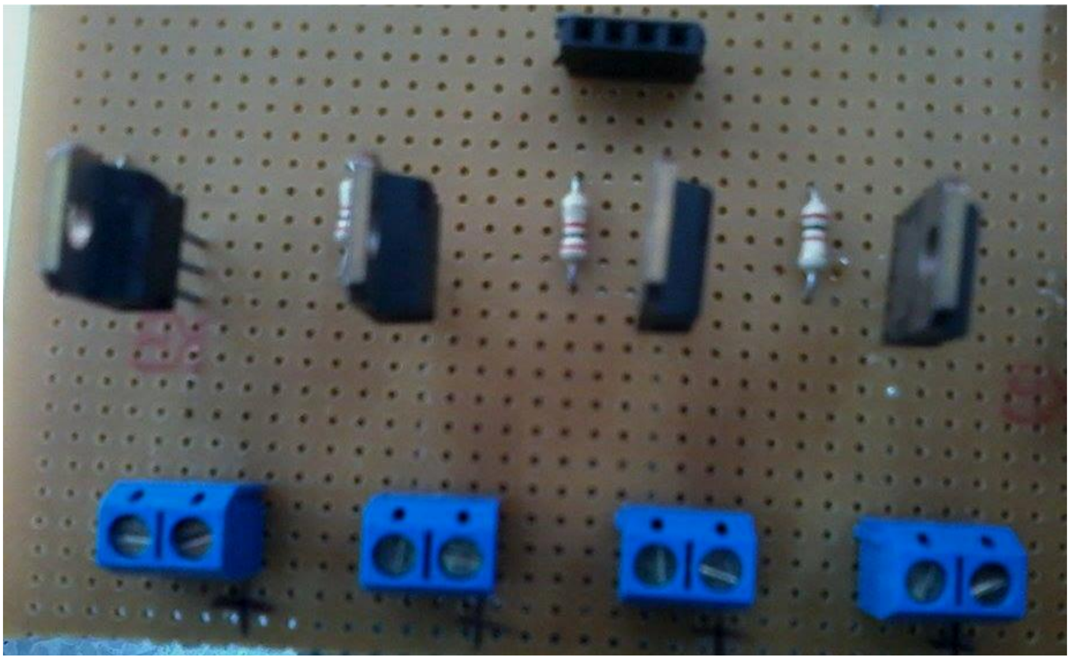


Fig.5.5 : Dc Motors Switches Circuit

5.2.5 Temperature Measuring Circuit

The temperature sensor used gives outputs of 10mV for each 1°C, the following table shows many temperatures and it's output from the sensor.

Table 5.2: Temperature Sensor Outputs

Temperature(°C)	**10**	**15**	**20**	**25**	**30**	**35**
V_{out} (mV)	100	152	201	249	303	354

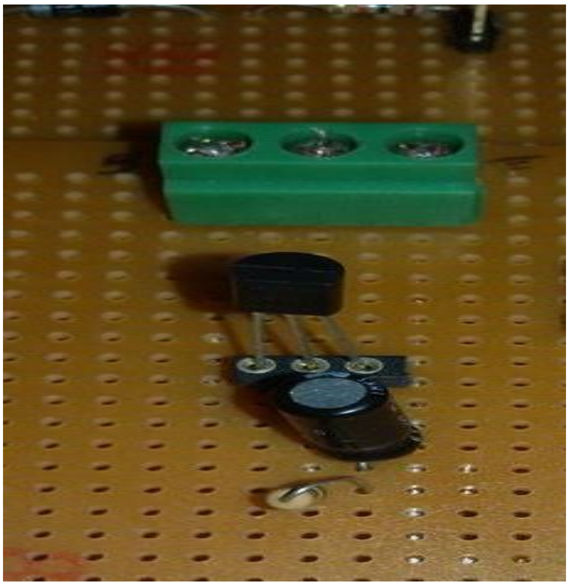


Fig.5. 6: Temperature Measurement Circuit

5.2.6 Blood Leak Detection Circuit

When the blood leak detection module connected on the drain line it tested in two cases, as following :

❖ **Case 1 : The Blood Detection**

In this case we get an active low (approximately 0 Volt) as output from the module .

Fig.5.7 : Blood Detection Case

❖ **Case 2 : No Blood Detection**

In this case we get an active high (approximately 5 volt) as output from the module.

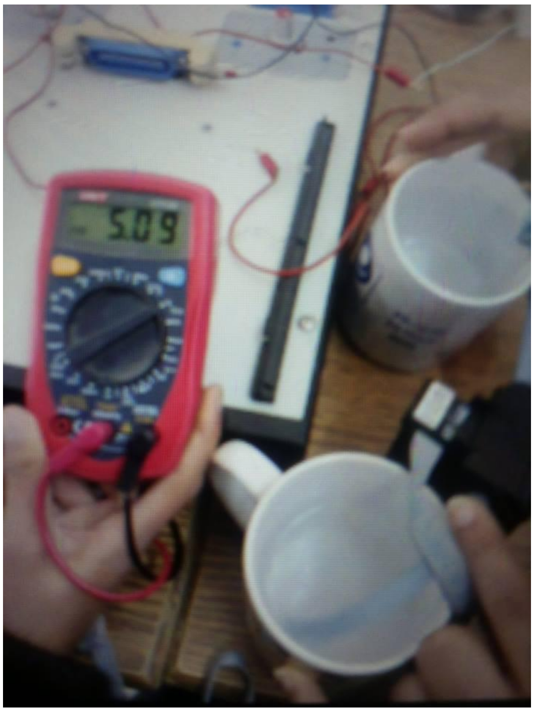


Fig.5.8 : No Blood Detection Case

5.2.7 Air Bubble Detection Circuit

When the air bubble detection module connected on the returned blood line it tested in two cases, as following :

- **Case 1 : Air Bubble Detection**

  In this case the module output is active low signal (approximately 0Volt) .

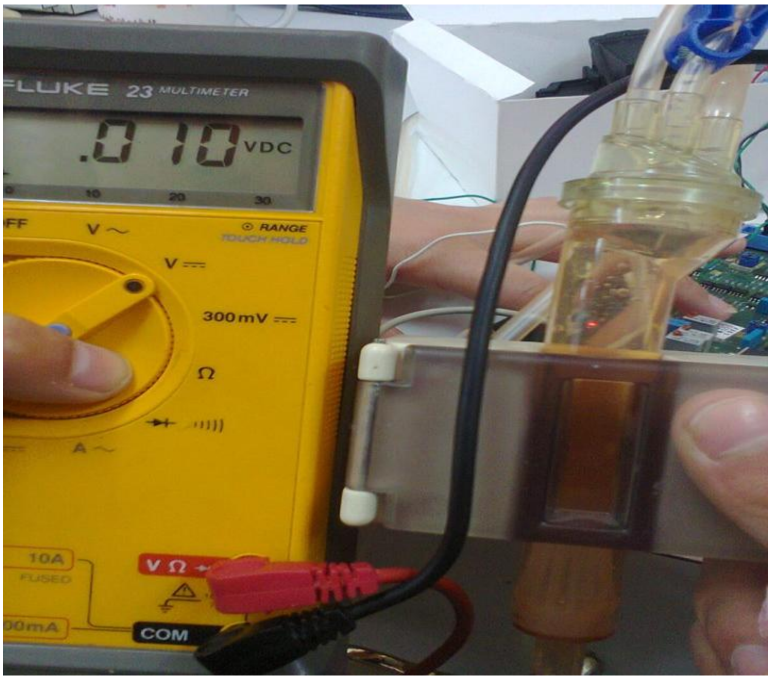


Fig.5.9 : Air Bubble Detection Case

- **Case 2 : No Air Bubble Detection :**

  In this case the module output is active high signal .

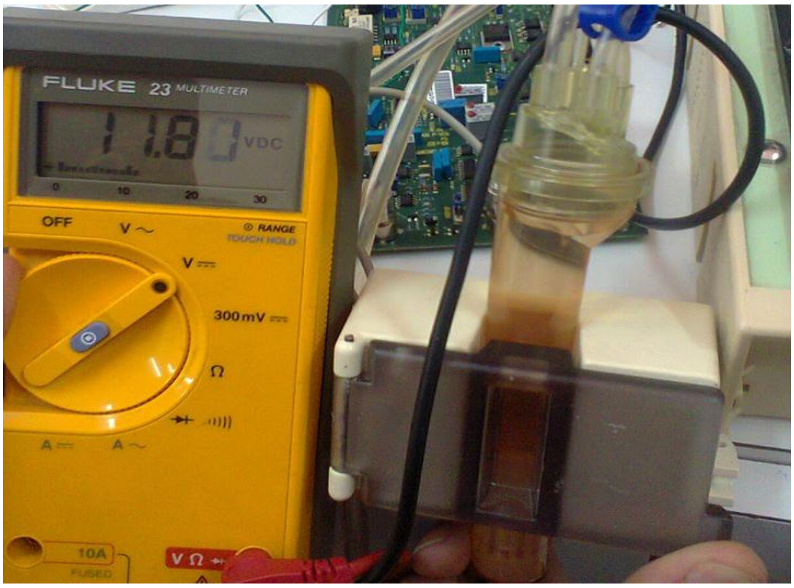


Fig.5.10 : No Air Bubble Detection Case

5.3 Final Design

After final collection of all project sub circuits with Arduino controller and designing the wearable artificial kidney jacket, the final shape were ready, the following figure shows the final shape followed by a brief description.

Figure.5.11: Final Design of the Project

The numbered components in the previous figure are as the following :

1) Blood Peristaltic Pump
2) Solenoid Electrical Valve.

3) Air Bubble Module
4) Pressure Sensor
5) Dialyzer
6) UF Pump
7) Dialysate Pump
8) Conductivity Cell
9) Blood Leak Detector
10) Buzzer " Audible Alarm"

User instruction manual included in appendices describes who to use the artificial kidney prototype. See appendix A.

CHAPTER SIX

RECOMMENDATIONS, CHALLENGES, AND CONCLUSION

6.1 Recommendations

The project can be improved by the following :

- Use touch screen for display and entering the target weight to lose.
- Weight reduction as much as possible.

6.2 Challenges

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

- Some of required components for the project are not available in the local markets.
- Some of project components are very expensive .
- Lack of knowledge in local markets about the components required and also the lack of datasheets for some components which leads to use the "service manual" to deal with these components.
- The Arduino used provides only 3.3V which leads to use level up IC's for LCD display and level down IC's for another components.
- The peristaltic pump has a stepper motor which is too difficult to be controlled and also it need 65V -2.3A that means the power equal to 150 Watt " too high ", alternative DC motor used with 12V only " the power 36 watt only " .
- The Air bubble module, Blood leak detector, and Solenoid valve are too expensive and can't be imported from abroad in a short time.

6.3 Conclusion

- The project is divided in three main parts :
  1. Patient " Blood" Circuit
  2. Dialysate Circuit
  3. The Controlling and Synchronization System.
- The peristaltic pump is very important to be used because It is able to handle slurries, viscous, shear-sensitive and aggressive fluids, like blood, but the available one needs 65volt so it's operating motor changed to another DC motor requires 12volt only.

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APPENDCIES

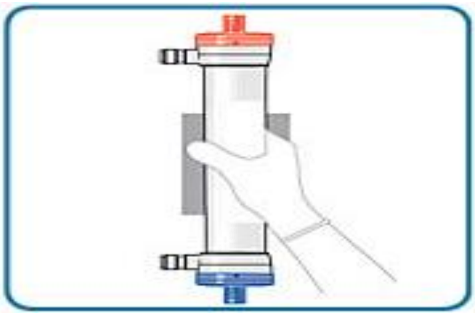
APPENDIX A

Appendix A : User Instructions Manual

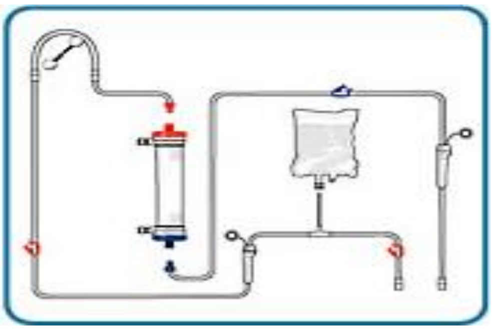
To use the wearable artificial kidney prototype, many steps must be performed to get high dialysis session performance. The kidney works in three stages, as following:

- ❖ Priming stage.
- ❖ Treatment stage.
- ❖ Rinse stage

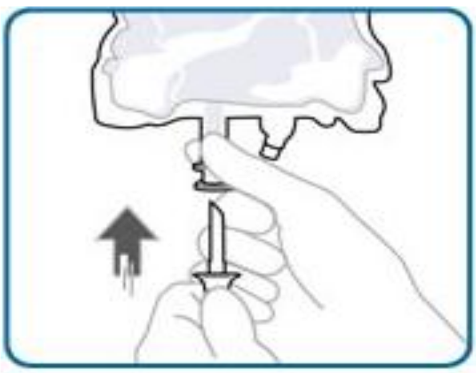
1. Press power button ON.



2. Position the dialyzer on the machine with the arterial header (red) up.

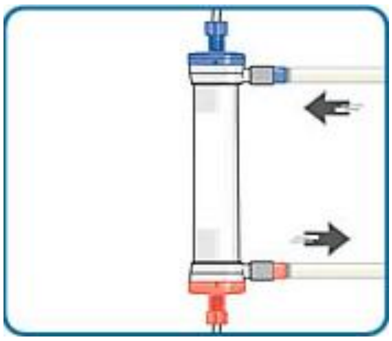


3. Place arterial and venous bloodlines on their places according to the next figure.



4. Connect the saline bag to the I.V set.

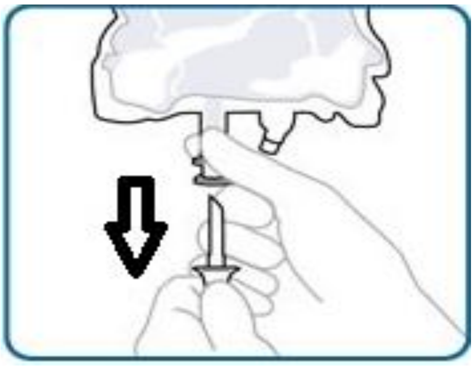
5. Attach dialysis lines to the dialyzer and UF pump.



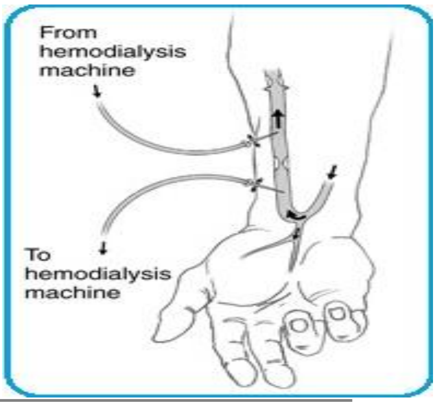
6. Press start button.

7. Start all pumps to prime dialyzer end of arterial line. Be sure to fill drip chamber to avoid saline-air mix in bloodline. ensure all air is removed from blood pump segment.

8. When bloodline is completely free of air, stop blood pump then remove saline bag from I.V set.

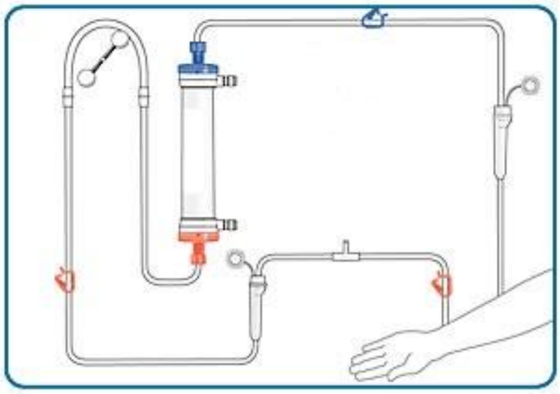


9. Attach the I.V set to the patient hand.

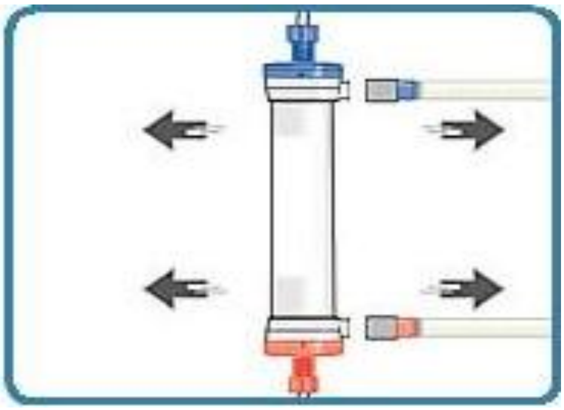


10. Press continue button.

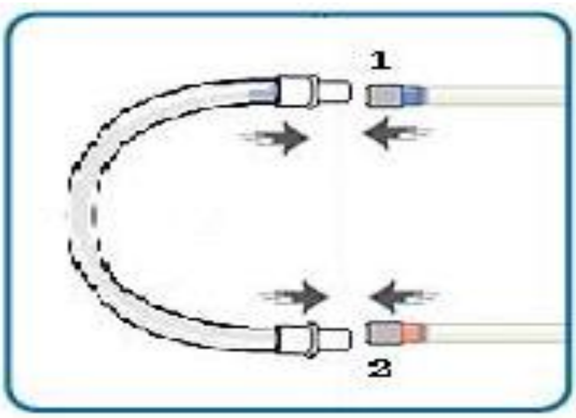
11. Wait until treatment stage end and the system stop.



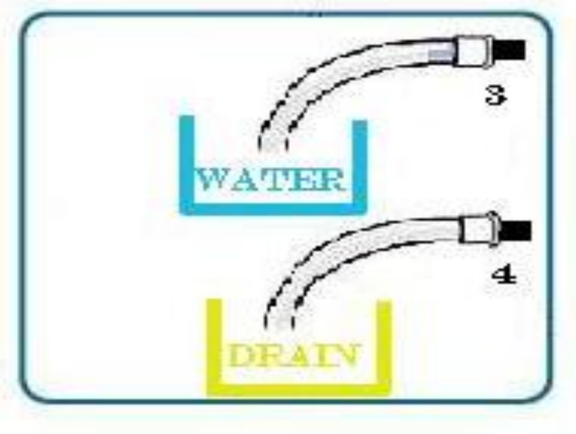
12. Connect rinse stage :-
    I. Disconnect the dialyzer.



    II. Connect between tube 1 and tube 2 with external tube.



III. Connect tube 3 to the water and tube 4 to the drain.



IV. Press continue.

V. After 2 minuit , Rinse will be finished, so turn power off.

APPENDIX B