DESIGN AND IMPLEMENTATION OF A MICROCONTROLLER BASED INFUSION PUMP SYSTEM WITH BLUETOOTH WIRELESS REMOTE MONITORING

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Rana Riyadh Saeed : DESIGN AND IMPLEMENTATION OF A MICROCONTROLLER BASED INFUSION PUMP SYSTEM WITH BLUETOOTH WIRELESS REMOTE MONITORING

Approval of the Graduate School of Applied Sciences

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ABSTRACT

Administering drugs to patients by the oral, subcutaneous, and intravenous means is a fundamental concept for the treatment of diseases in clinical medicine. Traditionally, drug delivery to critical patient is accomplished by using the well known roller clamp drip delivery system. Here, the drug in liquid form and in a plastic bag is attached high in the roller clamp assembly. The amout of drug delivery to the patient per unit time is adjusted by the help of the natural gravity, and by setting the pressure of a clamp attached to the cord of the drip.

Although the roller clamp system have been in use in hospitals for many decades, this system has many disadvantages. Perhaps the main disadvantage is that the amout of drug delivered cannot be controlled accurately as this depends upon the setting of a simple clamp attached to the drip cord. Although less than the required delivery may not be important, delivery of large amounts of drug in short time could cause serious health risks to the patient, and this requires constant attention of the health nurse. Another important disadvantage is that there is no way for the health nurse to know when the drug is finished or if there is a problem with the drug delivery. There has been hospital reports in the past where the drugs had not been delivered at the required times because of the simple structure of the mechanism used.

This thesis describes the design, development, and the implementation of a microcontroller based intelligent and automatic drug delivery system, based on the principle of an intravenous infusion pump. The system is designed around a fast programmable microcontroller which controls all operations of the system. A stepper motor ensures accurate and precise delivery of drugs at exactly the required times of the day. The novelty of the designed system is that it provides remote wireless Bluetooth based communication to the health nurse monitoring the state of the system at any time while drug delivery is in progress. In addition, important safety issues and error condition, such as opening the door assembly,finish of the drug in the bag, air bubble in tube, or any interruption to the delivery system can easily be mointored by the health nurse remotly, while the nurse is away from patient's bed side. With the designed system the health nurse dose not have to carry out frequent visits to patient's bed in order to check the state of the drug delivery system.

Key Words: Drug Delivery, Infusion Pump, Microcontroller System, Automatic Drug Delivery.

ÖZET

Hastalara ağız yoluyla, deri altından, veya diğer dış yollardan ilaç vermek tıp dalında bir esas teşkil etmektedir. Normal olarak günümüzde birçok hastahanelerde ve sağlık ocaklarında hastalara ilaç vermek için tekerlekli ve hareket eden demir ayak sistemleri kullanılmaktadır. Bu sistemlerde sıvı halinde bulunan ilaç sistemin üzerine yüksek bir yere asılır ve yer çekiminin de yardımıyla ilaç bir tüpden akarak hastaya verilmiş olur.

Yukarıda bahsedilen tekerlekli sistemler çok uzun yıllardır hastahanelerde kullanılmaktadırlar. Fakat bu sistemin birçok problemleri ve dezavantajları bulunmaktadır. En önemli dezavantajı ise verilecek olan ilaç miktarının hassas olarak kontrol edilememesidir. Az ilaç vermenin bir zararı olmamakla birlikte kısa zamanda çok ilaç vermenin hastaya zararı olabilmektedir. Buna ilaveten bu sistemlerin diğer önemli dezavantajları ise sistemde herhangibir arıza olduğu zaman bu arızanın erken teşhisinin mümkün olmayışıdır. Örneğin, ilaç bittiği zaman, veya hastaya arzu edilen miktarda ilaç verilmediği zamanlarda hasta bakıcı bu durumlardan haberdar olamamaktadır. Çözüm olarak ise hasta bakıcının sık sık hasta yatağına gidip ilaç veren sistemin durumunu kontrol etmesi gerekmektedir.

Bu çalışmanınamacı, mikrokontrolör tabanlı, akıllı ve otomatik ilaç veren sistem tasarımı ve uygulamasıdır. Tasarımı yapılmış olan sistemin bütün aksamları hızlı mikrokontrolör tarafından kontrol edilmeketdir. Sistemde kullanılan bir adım motoru sayesinde hastaya çok hassas ve arzu edilen dozlarda ilaç verilmektedir. Tasarımı yapılmış olan sistemin bir yeniliği ise Bluetooth haberleşme sistemi kullanılarak sistemin durumu hakkında tüm bilgiler uzakta bulunan hasta bakıcıya anında gönderilebilmesidir. Örneğin, ilacın bittiği zaman, veya sistemde herhangibir arıza olduğu zaman hasta bakıcı anında uyarılmakta ve gereken önlem alınmatadır. Böylece, hasta bakıcının sık sık hasta yatağına gidip sistemi kontrol etmesine gerek kalmamaktadır.

Anahtar kelimeler: İlaç Salgılama, Pompa Sistemi, Mikrokontrolör Sistemi, Otomatik İlaç Salgılama

CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

IV	Intravenous
SMPS	Switch Mode Power Supply
MOSFETs	Metal–Oxide–Semiconductor Field-Effect Transistor
NI-MH	Nickel–Metal Hydride Battery
MCU	Multipoint Control Unit
PIC	Peripheral Interface Controller
I/O	Input/ Output
IDE	Integrated Development Environment
RAM	Random-Access Memory
EEPROM	Electrically Erasable Programmable Read-Only Memory
UART	Universal Synchronous Receiver/Transmitter
PWM	Pulse-Width Modulation
SPI	Serial Peripheral Interface
I^2C	Inter-Integrated Circuit
CPU	Central Processing Unit
ETSI	European Telecommunications Standards Institute
RFCOMM	Radio Frequency Communication
LCD	Liquid Crystal Display
STN	Super Twisted Nematic
LSI	Logic Stock Symble
MPU	microprocessor Unit

CHAPTER 1

INTRODUCTION

1.1 Drug Delivery Systems

One of the principal activities of clinical medicine is the pharmacologic treatment of diseases. Traditionally, this has been carried out by administering drug and other materials in individual doses by the oral, subcutaneous, intramuscular,or intravenous route, by butting the fluid container in high lever from the patientand then adjust the dose manually by the roller clamp system as show in Figure1.1.

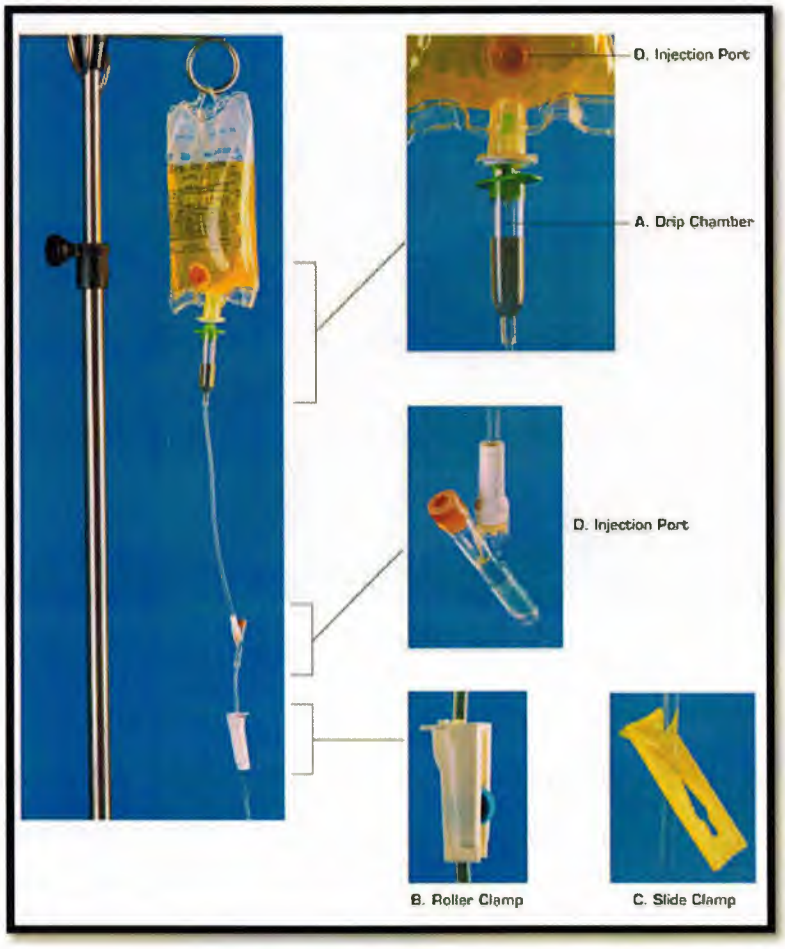


Fig. 1.1: Typical Drug Delivery System.

However, these methods of drug administration are not satisfactory, because:

- ❖ Drug level vary from one administration to next.
- ❖ For drug the therapeutic levels of which are close to their toxic level,this type of administration results in either toxic side effects or suboptimal therapy [1].
- ❖ Tissuing (Extravasation): Repeated catheter access and Extravasation occurs when fluid that should be delivered intravenously is inadvertently delivered into a tissue space [2], as show in Figure 1.2.

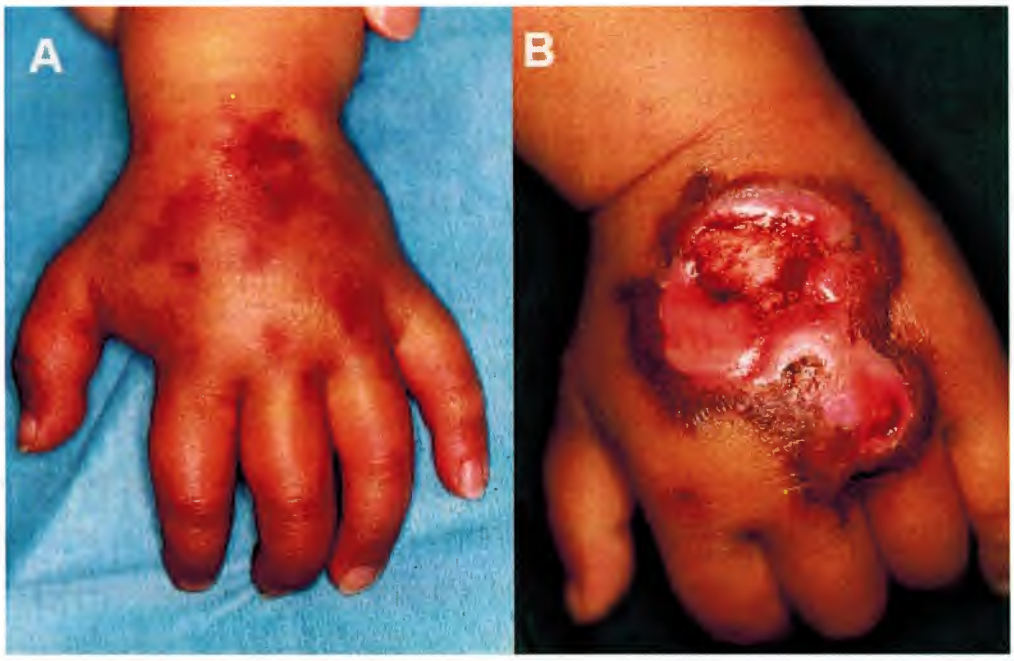


Fig. 1.2:Extravasation[1].

Methods of using physical devices to administer drug continuously within a narrow therapeutic range have been developed to overcome these problems.

Portable automated drug delivery system or implantable pump system is a small infusion pump used to gradually deliver drugs, at low doses and at a constant or controllable rate to a patient who needs to take a drug dose regularly in specific periods all the day.

1.2 What is the Automated Drug Delivery System?

An electronic medical device used to control the administration of intravenous fluids in very small amounts and at a carefully regulated rate over long periods. An infusion pump infuses fluids, medication or nutrients into a patient's circulatory system. It is generally used intravenously, although subcutaneous, arterial and epidural infusions are occasionally used. Infusion pumps can administer fluids in ways that would be impractically expensive or unreliable if performed manually by nursing staff [3]. Injections every minute, injections with repeated boluses requested by the patient, up to maximum number per hour (e.g. in patient-controlled analgesia), or fluids whose volumes vary by the time of day.

1.3 Application of Automated Drug Delivery

The application of automated drug delivery continues to grow such as the delivery of heparin for chronic anticoagulation,cytostatic drug infusion for cancer chemotherapy,morphine delivery for pain control,control insulin infusion for diabetes, hypertension control,intractable pain control, drug and alcohol antagonist, delivery chronic hormone supplement,and anti-arrhythmia control [4]. It is used to inject the radio-opaque contrast media into the body to enhance the visibility of tissues for a medical imaging procedure for CT scan, MRI, PET,Cardiovascular/Angiography fluoroscopy and Ultrasound image [5]. For meeting the exacting requirements of these applications in term of flow rate of the fluids in safe and effective manner, the pumps are becoming smaller and smarter. The use of microprocessor technology has allowed the systems to provide performance and functionality that were unattainable only several years ago and most new systems are designed for easy addition of new features through simple software improvement [3].

1.4 Places That Use Automated Drug Delivery Systems

These devices are used worldwide in healthcare facilities, in General Wards,Ambulatory, Intensive Care, Operating Room, Emergency, as well as in the home. Infusion pumps have contributed to improvements in patient care, allowing for a greater level of control, accuracy, and precision in drug delivery, and thereby reducing medication errors.

1.5 Literature Review

One of the greatest technological advances in the medical field has been that of intravenous medicine—the ability to feed, hydrate, medicate and replace blood lost in sick and injured patients directly, through the use of needles. Leading the ability to perform all these functions are infusion pumps. These devices deliver controlled amounts of nutrition, blood and medication directly to a person's circulatory system, where it has the best, most immediate effect on recovery. They can also deliver medicine just under the skin, or directly to the central nervous system.

One of the major developments in infusion pumps was the invention in the early 1970s of a wearable infusion pump, by Dean Kamen. Kamen's brother was a doctor, and complained that the infusion pumps of the day were too unwieldy. As a result, Dean Kamen invented the first ambulatory pump. It not only gave patients freedom to move when receiving treatment, it meant they could receive their medication on an outpatient basis. This advancement was a godsend to patients, such as diabetics, who need round the clock injections. Kamen's pump also automatically administered precise doses at regularly timed intervals, ushering in many advances in infusion pumps and other medical equipment, such as portable dialysis machines [6].

Thomson & Harrison invented "Automated Drug Additive Infusion System". In accordance with this invention, there is provided a system for sequentially administering to a patient fluid from a secondary fluid container and a primary fluid container at respective selected flow rates governed at a rate control site by an electromechanical device. The system includes a Y-connector upstream from the control site, a primary fluid line extending from the primary fluid container through a primary valve to the Y-connector and a secondary fluid line extending from the secondary fluid container to the Y-connector through a secondary valve. An output flow line extends from the Y-connector through the control site. The invention includes detection means for automatically detecting the absence of fluid in the secondary line immediately adjacent the Y-connector, and means operative to close the secondary valve and open the primary valve, in response to such detection by the detection means [7].

Volker Lang invented "Cassette Infusion System". In accordance with this invention, a modular cassette infusion system for multiple infusions and the automatic administration of medicament. Sterile disposable cassettes are employed, which possess integral connections

for the infusion lines, inlet valves, liquid distribution ducts, pump chambers, outlet valves, venting filters and chambers for the measurement of the infusion pressure. The system renders possible the infusion of 3, 6 or more different infusion solutions and medicaments held in disposable syringes via one or more small-volume pump chambers with outlet valve separately via a plurality thereof in parallel via only one vascular access point to the patient with the correct volume in a pulsating manner or in very small individual quantities substantially continuously in a quick succession one after the other without incompatible medicaments being mixed. After insertion in an universal, electromechanical and pneumatic or only electromechanical or furthermore electrohydraulic valve pump syringe actuating device the cassettes are operated with the aid of pressure surges [8].

Steil&Rebrin invented "Close Loop System for Controlling Insulin Infusion". In accordance with this invention, a closed loop infusion system controls the rate that fluid is infused into the body of a user. The closed loop infusion system includes a sensor system, a controller, and a delivery system. The sensor system includes a sensor for monitoring a condition of the user. The sensor produces a sensor signal, which is representative of the condition of the user. The sensor signal is used to generate a controller input. The controller uses the controller input to generate commands to operate the delivery system. The delivery system infuses a liquid into the user at a rate dictated by the commands from the controller. Preferably, the sensor system monitors the glucose concentration in the body of the user, and the liquid infused by the delivery system into the body of the user includes insulin. The sensor system uses the sensor signal to generate a message that is sent to the delivery system. The message includes the information used to generate the controller input. The sensor may be a subcutaneous sensor in contact with interstitial fluid. Also, two or more sensors may be used by the sensor system [9].

1.6 Aim of the Thesis

The aim of this thesis is to design and implement an intelligent automated drug delivery system (Remote Control programmable volumetric IV infusion pump); by using the Bluetooth technology and the PIC16F887 microcontroller. The developed infusion pump can deliver a variety of different drugs in fluid form to the patient with great accuracy and precision. The system also protects the medical staff from exposure to dangerous and harmful drugs.

1.7Thesis Layout

The thesis consists of 5 Chapters. Chapter 1 is the introduction.

Chapter 2 describesthe concepts, components and the mechanism types, application and examples of the automated drug delivery systems in general.

Chapter 3 provides theoretical fundamentals of the essential equipment which are used in the wireless monitoring programmable volumetric IV infusion pump system developed and designed by the author. The block diagram and also the total electrical description of the components of the system are given in great detail.

Chapter 4 presents the operation and procedure work of the Wireless MonitoringProgrammable Volumetric IV Infusion Pump System developed and designed by the author.

Chapter 5 presents the results, conclusions and suggestions future work.

CHAPTER 2

IV INFUSION PUMPS

2.1 Overview

The technological advances in infusion pumps during the past forty years have transformed the treatment of patients in hospitals, as well as afforded the ability to receive treatment while going about their daily lives. These pumps insure that patients receive the best care. This chapter discusses the concepts, components and the mechanism types, application and examples of the automated drug delivery systems.

2.2 The Concept of the Automated Drug Delivery:

The automated drug delivery depends on two components: the mean of controlling the rate of delivery, and electro-mechanical means to deliver the drug.

2.2.1 The Means of Controlling the Rate of Delivery

This component determines the process that will follow to choose the best procedure for delivering the drug according to the patient's condition, where the means of controlling the rate of delivery is classified to two systems: open loop system and close loop system.

2.2.1.1 Open Loop Systems

Drug delivery is said to be open loop if the rate of infusion (possibly a function of time) is set a-priori and it is not automatically altered by the patient's response. In the open loop system as shown in Figure 2.1 the rate of the delivery is set by the physician or nurse on the basis of past experience, mathematical computation, observations made about the patient. The control action of the delivery is taken manually and the set rate is being constant until the setting is change. Most current systems operate in open loop. Both controllers and pumps allow setting the infusion rate dialing into them the desired rate of delivery. "Controllers" may count the

drops of intravenous fluid through a photoelectric device or use special cassettes that accurately meter the flow through the device.

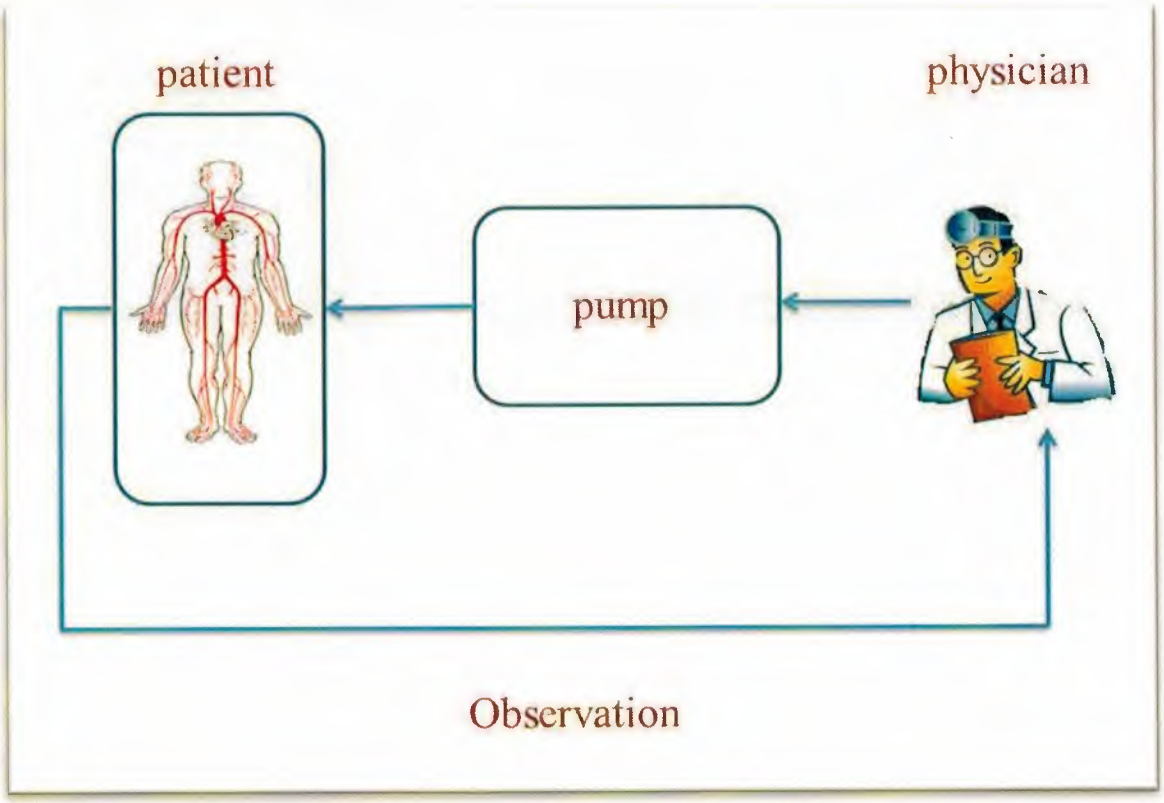


Fig. 2.1: Open Loop Drug Delivery System.

Some controllers allow the independent setting of primary and secondary ('piggyback') infusion rates. Volumetric pumps may be controlled by the step size or frequency of stepper motor, or the speed of DC motors.

This system is need to the physician or proficient person to set and adjust the drug rate and the pump setting and undirected observation will take from the patient.it is safety and it is useful in the case that did not need to have close loop system like in case of Antibiotics drugs, cytostatic drugs, pain control drugs.

The volumetric infusion pump and the portable syringe pump as shown in figure 2.2 are examples for the open loop system.

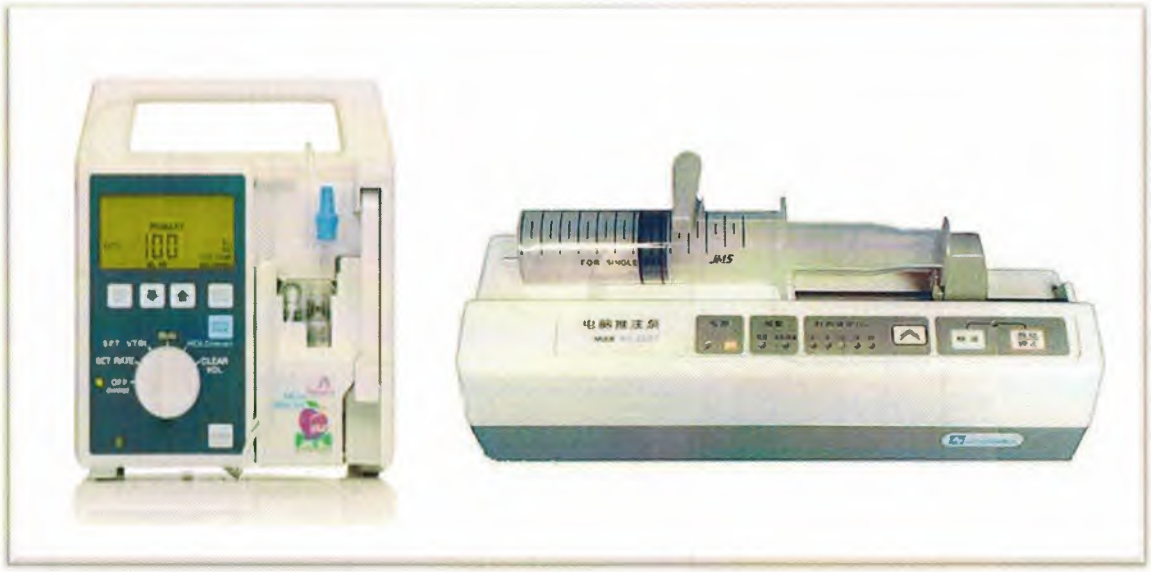


Fig. 2.2: Volumetric Infusion Pump and the Portable Syringe Pump [10,11].

2.2.1.2 Closed Loop Systems

Closed-loop drug infusion systems are among a growing number of systems designed to automate the control of physiological variables either in a clinical or laboratory setting [12]. A system and method for providing closed loop infusion formulation delivery which accurately calculates a delivery amount based on a sensed biological state by adjusting an algorithm's programmable control parameters [13]. Close loop infusion system as shown in Figure 2.3.Controls the rate that fluid is infused in to the body of patient by the sensor system, a controller, and a delivery system. The sensor system includes a sensor for monitoring a condition of patient. The sensor produces a sensor signal, which is representative of the condition of the patient. The sensor signal is used to generate a controller input. The controller uses the controller input to generate commands to operate the delivery system. The delivery system infuses a liquid into the patient at a rate dictated by commands from the controller [14].

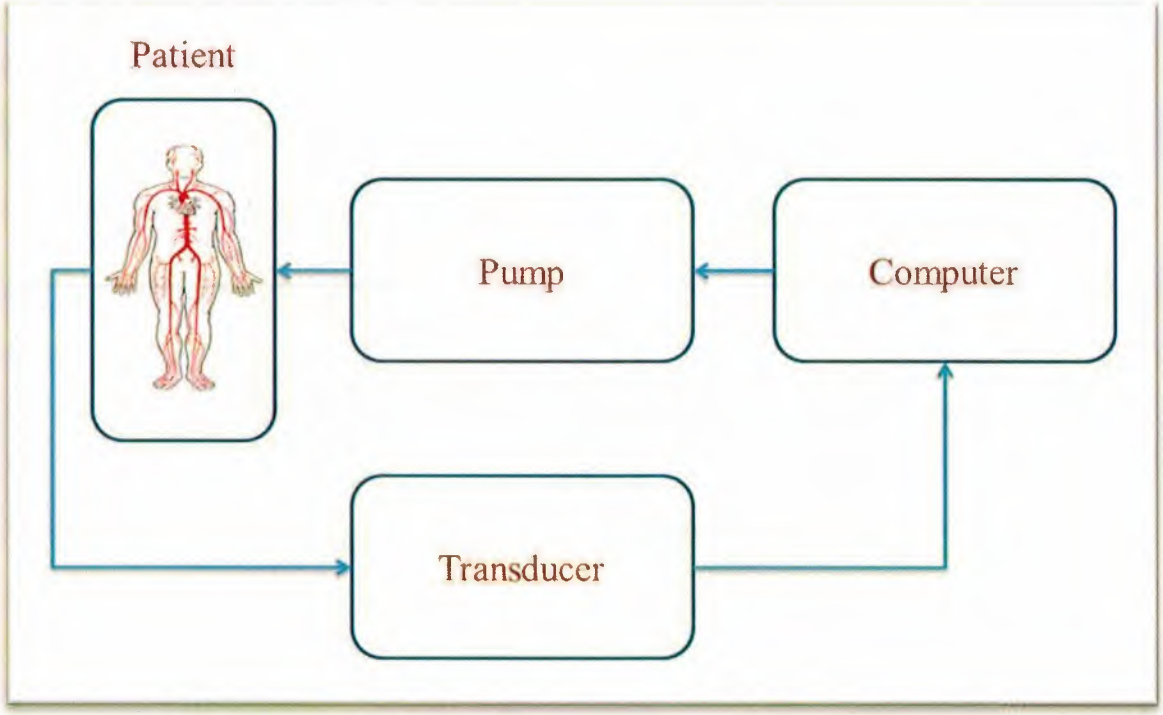


Fig. 2.3: Close Loop Drug Delivery System.

2.2.2 Electro-Mechanical Means To Deliver the Drug

The two commonly used methods are discussed below:

2.2.2.1 Peristaltic Pumps

The peristaltic pump was first patented in the United States by Eugene Allen in 1881. It was popularized by heart surgeon Dr. Michael DeBakey while he was a medical student in 1932[15].

A peristaltic pump is a type of positive displacement pump that causes the fluid to move by trapping a fixed amount of it and then forcing (displacing) that trapped volume into the discharge pipe. used for pumping a variety of fluids driven by a step motor that moves several circularly arranged rollers [16]. The fluid is contained within a flexible tube fitted inside a circular pump casing. A rotor with a number of "rollers", "shoes" or "wipers" attached to the external circumference compresses the flexible tube. As the rotor turns, the part of tube under compression is pinched closed (or "occludes") thus forcing the fluid to be pumped to move

through the tube. Additionally, as the tube opens to its natural state after the passing of the cam ("restitution" or "resilience") fluid flow is induced to the pump. This process is called peristalsis.

Peristaltic pumps have three type as shown in Figure 2.4 A,B,C:

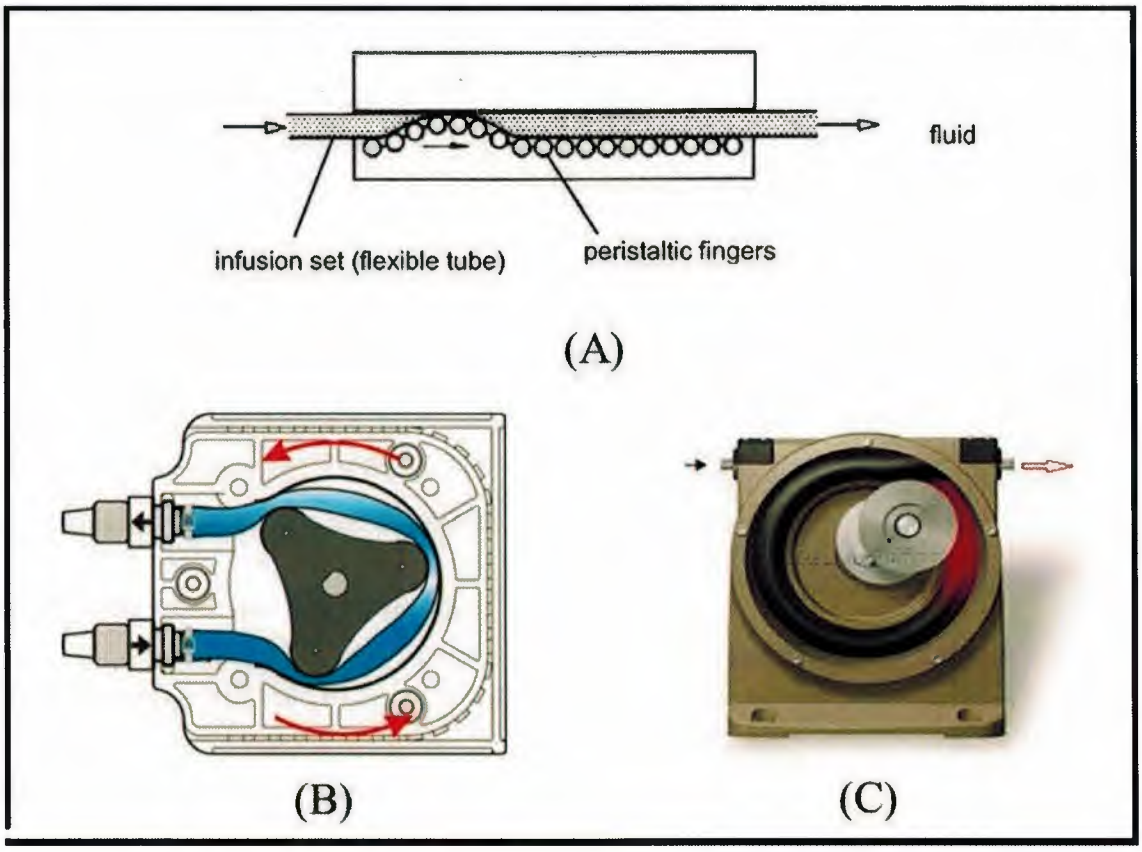


Fig. 2.4: Peristaltic Pumps Types (A) Finger peristaltic pump. (B) Rotary peristaltic pumps. (C) 360 Degree Peristaltic Pump [17,18,19].

1. Finger peristaltic pump which has a row of finger or depressors along a section of the tubing. The fingers are depressed in a series or waves creating a moving contraction along the tubing which pumps the fluid through the tubing.
2. Rotary peristaltic pumps have a number of arms on a rotor. Each arm has a roller at the end of the arm. As the rotor rotates in a circular chamber, the rollers on the end of the arms roll along and constrict the tubing lining the outer surface of the chamber. This creates a series of rolling contractions through the tubing that pumps the fluid through the tubing.

3. A rotor on an eccentric shift which squeezes an eccentric cylindrical liner (360 Degree Peristaltic Pump) [20].

Tubing

It is important to select tubing with appropriate chemical resistance towards the liquid being pumped. Types of tubing commonly used in peristaltic pumps include:

1. Polyvinyl chloride (PVC)
2. Silicone rubber
3. Fluoropolymer [21].

Advantages of the peristaltic pump

1. The fluid being pumped comes into contact with only one material (the tubing), the quality and content of which can be carefully controlled so as to minimize the risk of contamination of the fluid [22].
2. Designed to handle viscous, corrosive, abrasive and high purity solutions.

Disadvantages of the peristaltic pump

The flexible tubing will tend to degrade with time and require periodic replacement.

Applications of peristaltic pump

Peristaltic pumps are typically used to pump clean/sterile or aggressive fluids because cross contamination with exposed pump components cannot occur. Some common applications include pumping IV fluids through an infusion device, aggressive chemicals, high solids slurries and other materials where isolation of the product from the environment, and the environment from the products are critical. It is also used in heart-lung machines to circulate blood during a bypass surgery as the pump does not cause significant hemolysis [63], and with thedialysis machines.

2.2.2.2 Syringe Pump

Syringe pump was first invited by Dean Kamen, he invented the first wearable syringe infusion pump while he was a physics major at Worcester Polytechinc Institute in the early 1970s [23].

The syringe pumps consist ofa motor, through a gear-reducing mechanism and a lead screw, applies force to the plunger of a syringe containing the drug Figure 2.5.

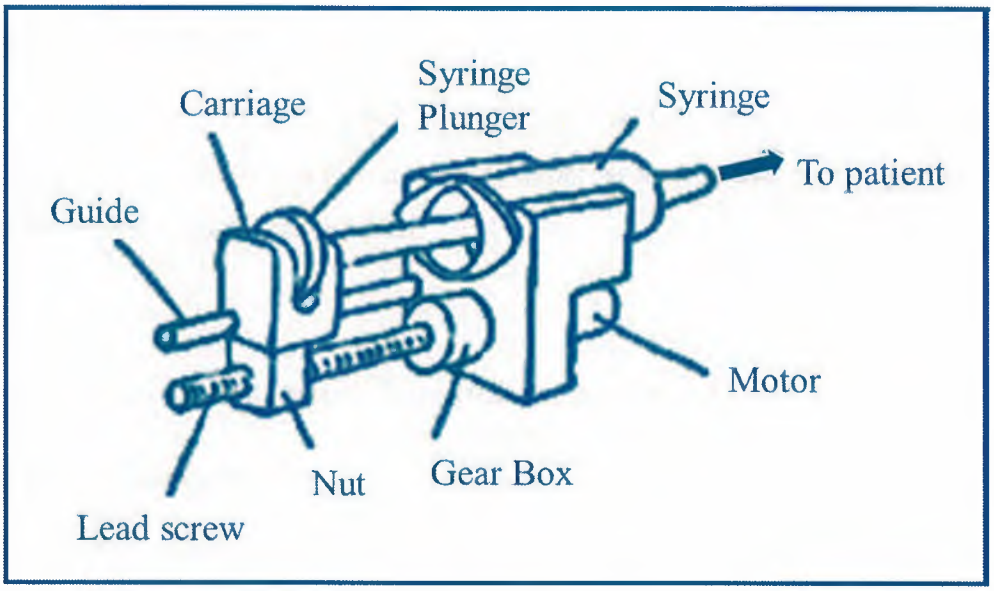


Fig. 2.5: Syringe Pump Mechanism [24].

The syringe drive mechanism engages the plunger of the syringe and pushes the plunger at a constant speed into the syringe barrel so that the liquid contents are delivered to the patient over a fixed period of time. The time in which the medication is delivered to the patient is a function of the volume of fluid in the syringe. In order to meet the wide variation in syringe barrel dimensions for the different size syringe used in hospital, it is necessary to have several different syringe pump, the syringe pump remain constant speed devices. Control is achieved by varying the stroke length or the stroke rate. The device is mainly convenient for applications that require the delivery of volumes limited by the syringe size[25].

Advantage of syringe pumps:

Small size and weight, portability, and low cost of the disposable components [26].

Disadvantages of syringe pumps:

The infusion rate of the drug which delivered to the patient correlate directly to the syringe size so many syringe pumps will found to many syringe size [27].

Application of syringe pump

The most popular use of syringe drivers is in palliative care, to continuously administer analgesics (painkillers), antimetics (medication to suppress nausea and vomiting) and other drugs. And used for external insulin pump.

2.3 Example of External Automated Drug Delivery System

2.3.1 External artificial pancreas

Diabetes is a disease symptomized by an increase in blood sugar levels exceeding 140 mg/dl on an empty stomach, or 200 mg/dl 2 hours after a meal. Any abnormality in these levels may be an insulin deficiency, caused by an insufficient quantity of insulin secreted by the β-cells of the pancreas [28].

Portable automated insulin syringe pump to inject the liquid medicine for a prolonged time as shown in Figure 2.6, including a syringe pump having a pump's housing, blood sugar measuring unit (Continuous Glucose Monitoring System (CGMS)), a control unit for controlling the blood sugar measuring unit and the syringe pump, and a display unit for simultaneously display the quantity of insulin dispensed to user and the blood sugar level measured by the sugar measuring unit. This device used for diabetes with type 1 and type 2patients.

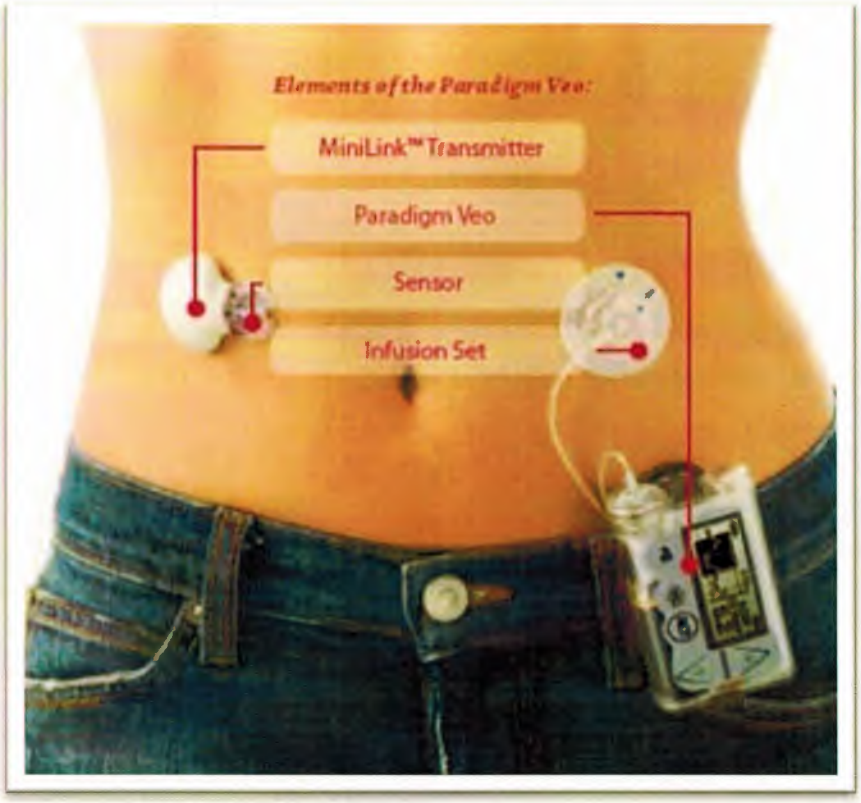


Fig. 2.6: The Paradigm Veo System includes an insulin pump with a continuous glucose monitoring (CGM)system (provided by means of a separate sensor and transmitter) [29].

Continuous Glucose Monitoring (CGM) System

CGMS, as shown in Figure 2.7 is a small flexible platinum electrode coated with the enzyme glucose oxidase within a semi-permeable membrane. It is inserted underneath the skin in the hip or abdomen with a needle-like device and is usually worn for three days at a time. Glucose from interstitial fluid (the clear fluid just beneath the surface of the skin) is converted to an electronic signal [28].

Fig.2.7: Continuous Glucose Monitoring (CGM)System [30].

Glucose Sensing From the Interstitial Space

Current commercial glucose sensors are all based on the indirect measurement of glucose from the interstitial space through amperometric enzyme electrodes based on glucose-oxidase (GOx).

The operating principle of amperometric sensors as shown in Figure 2.8 is the measurement of the current flowing from an oxidation reaction, at a working electrode, to a reduction reaction, at a counter electrode [31]. To this purpose, a potential is applied between the working electrode and a reference electrode. Three electrodes are thus needed (working, counter and reference electrodes), although some sensors use two-electrode configuration (working and counter-reference electrode), combining the counter and reference electrodes. Medtronic use three-electrode configurations. In the case of glucose sensing, GOx is immobilized at the working electrode. GOxcatalyses the oxidation of glucose to gluconolactone (eq. 2.1). To this end, GOx requires as cofactor Flavin Adenine Dinucleotide (FAD) that will act as electron acceptor reducing to $FADH_2$, according to the following reaction [32]:

$$\text{Glucose} + \text{GOx(FAD)} \rightarrow \text{Gluconolactone} + \text{GOx(FADH2)} \qquad (2.1)$$

The FAD cofactor (redox active center) is deeply embedded in the GOx molecular structure. This necessitates the use of mediators or other strategies to improve communication between the enzyme and the electrode surface guiding electrons to the electrode. The natural mediator is the couple oxygen/hydrogen peroxide (O_2/H_2O_2) (eqs. 2.2, 2.3), according to the reactions:

$$GOx(FADH_2) + O_2 \rightarrow GOx(FAD) + H_2O_2 \qquad (2.2)$$

$$H_2O_2 \longrightarrow 2H^+ + O_2 + 2e^- \qquad (2.3)$$

The flavin is re-oxidized in the presence of oxygen, producing hydrogen peroxide. This is monitored measuring the current generated after the application of a potential (around +0.6 V *vs.* Ag/AgCl) between the working electrode and a reference electrode. This is the method used, for instance, in the Medtronic and DexCom monitors.

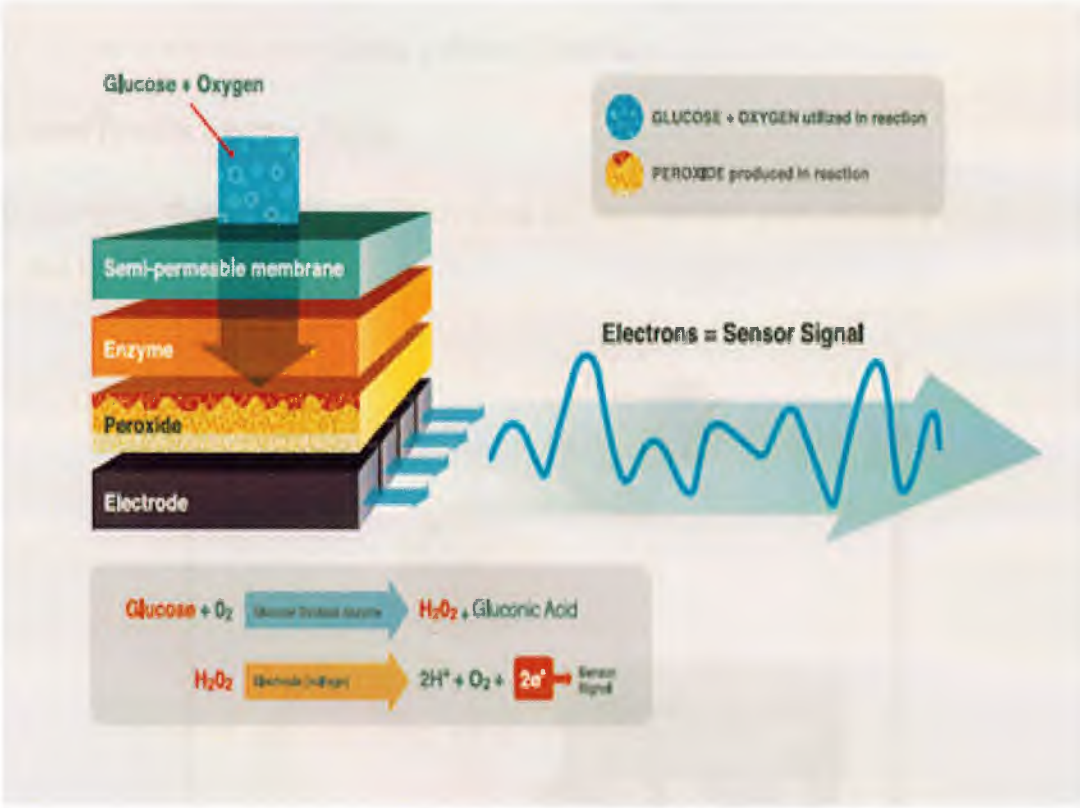


Fig. 2.8: Subcutaneous Continuous Glucose Monitoring: How It Works [33].

Two main problems have to be dealt with:

a) Other electro-active molecules such as uric acid and ascorbic acid may interfere in the measurement, depending on the potential applied. To reduce interference and increase selectivity to glucose, membranes limiting the access of these molecules to the electrode surface are included, or electrodes are built in materials requiring a lower potential.

b) Glucose concentration is much higher than oxygen concentration. A proper glucose-oxygen ratio must be obtained. To this end, membranes are included limiting the transport of glucose to the electrode in order to maximize oxygen availability [34].

Control Unit for Controlling the Blood Sugar Measuring Unit

The Control unituses a one-way wireless radio frequency link to receive blood sugar measurements from select glucose meters. Real time series adds the ability to receive data from a mated continuous blood-glucose monitor. Although the pump can use these measurements to assist in calculating a dose of insulin,

Automated Insulin Syringe Pump

Insulin pumps as shown in Figure 2.9 are drug delivery devices used to treat patients with type 1 and type 2diabetes.

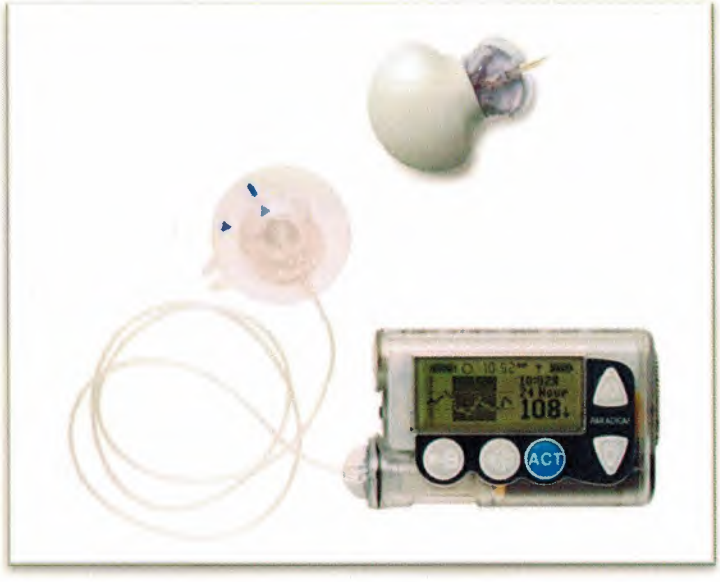


Fig.2.9: Automated Insulin Syringe Pump [35].

The pump operates with a single AAA battery and uses a piston-plunger pump to infuse a programmed amount of insulin into the patient through a length of tubing and a reservoir with rapid-acting insulin. This "infusion set" is patient-connected via a catheter to the abdomen region. The infusion set can remain in the place for 3 days while the pump is clip-belt worn. There is a quick-disconnect feature for the tubing. Figure 2.10 shows a block diagram of the internal circuitry of a typical insulin pump. The pump featured on the left includes alert systems, sensor tracking with memory, and the ability to output data to a computer. The figure on the left show the six most significant systems which interact to create all of the major functions insulin pump. These include the MCU Insulin Dispensing System, Display and Keypad System, Power System, Audio System, Date and Time System, and Interfacing System. Each of these systems is described below.

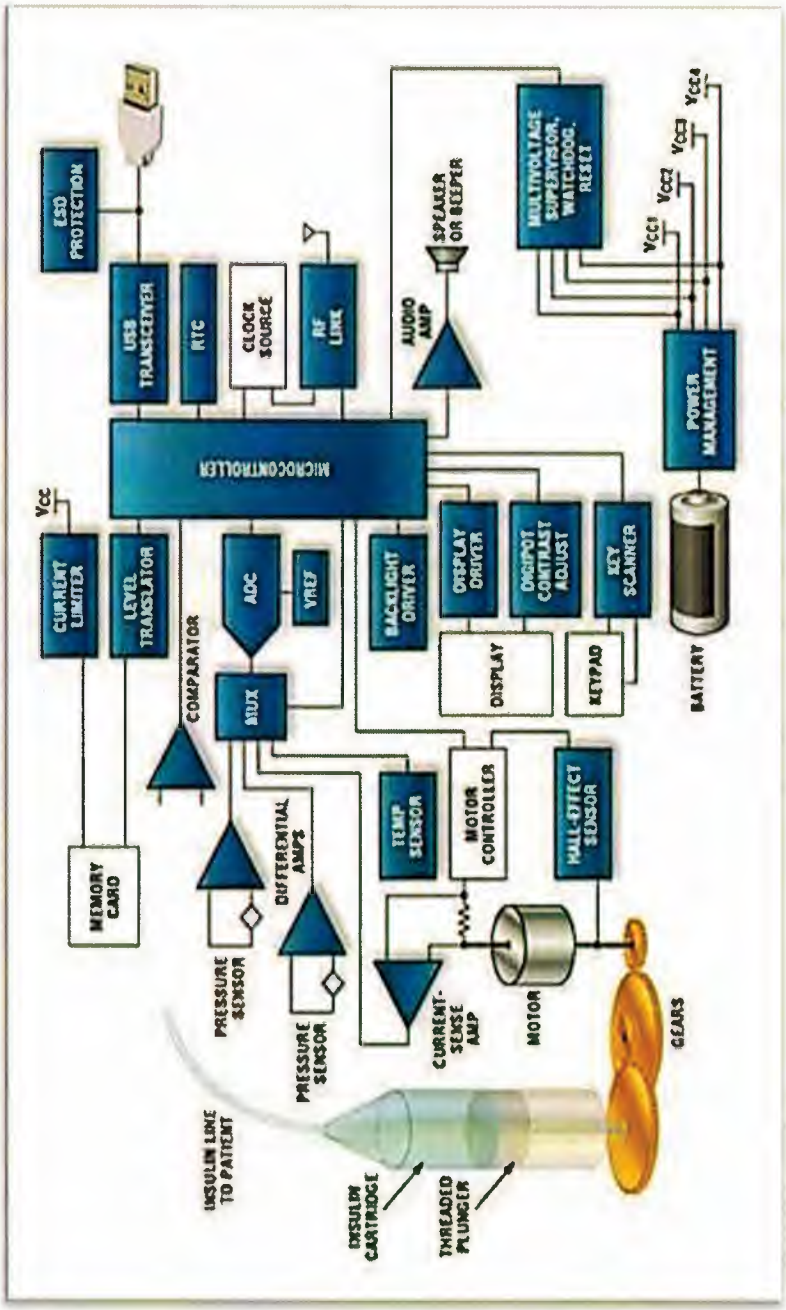


Figure 2.10: Block Diagram of The Internal Circuitry of Typical Insulin Pump [36].

The MCU:

There are several systems that are integrated together to allow an insulin pump to run properly. The microcontroller is the small computer chip that digitally controls all of these systems and ensures that each of these systems interact and run correctly.

Insulin Dispensing System:

The dispensation of insulin is driven by a motor controller, which is ultimately controlled by the microcontroller. The motor controller controls the motor, which in turn controls a series of gears to allow the plunger to dispense very small increments of insulin (on the order of microliters). The gears slowly compress the threaded plunger, which pushes insulin out of the cartridge, through the catheter and into the patient. The Hall-Effect Sensor assists by ensuring that the motor is quiet and runs smoothly. The multiplexor receives an input from the microcontroller (after being converted to an analog signal by the ADC) and sends information through a current sense amplifier to regulate the rate and quantity of insulin dispensed. The pressure sensors and temperature sensor are in place to ensure normal operation of this system.

Display and Keypad System:

The display and keypad system is used to relay information between the microcontroller and the user. The display driver outputs the information from the microcontroller to the digital readout, and uses the backlight driver and digit spot contrast adjust to aid in visualization of the screen text and images. The reverse of this is the key scanner, which keeps track of the user's keypad inputs and sends the information to the microcontroller. This information can be used to determine the amount of insulin to be administered, or to set the clock or adjust the screen contrast.

Power System:

The power system of the pump consists of the battery, power management, and multivoltage supervisor. The power source is a single AAA battery, which is changed about once every 5 or more weeks. There are many safeguards put in place to prevent the power from dissipating quickly or without the user being forewarned. The power management system is used to decrease power during times when it is less active, and the multivoltage supervisor resets the device when it becomes unresponsive. The battery life information is again sent back to the microcontroller, which directs the audio system to alert the user when the battery is low.

Audio System:

The audio system is used to alert the user when a problem arises with the device, such as critical battery, low insulin levels in the cartridge, or blockages in the catheter. An audio alert can also be set to remind the user to inject another dosage of insulin at specified times during the day. These signals are also sent from the microcontroller to the speaker via an audio amplifier. A comparator is usually involved with this function as well.

Date and Time System:

The date and time system is responsible for keeping track of date/time data, which is used for the digital readout of the device, as well as for tracking trends in insulin/glucose levels, providing alert capabilities, and saving tracked data on the memory card. This date/time system comprises of a clock source and Real Time Clock (RTC). The clock source provides a periodic signal, which the Real Time Clock keeps track of for all of the above uses.

Interfacing System:

The interfacing system involves the USB transceiver, memory card, current limiter, ESD protection, and RF link. The memory card records usage data, programming information, and other potentially useful data on the device, and the USB transceiver allows the device to communicate with a USB drive to transfer collected data to a computer. This allows for further analysis by a physician or the user himself. ESD protection prevents electrostatic discharge from affecting the device, while the current limiter prevents excessive current from

being delivered. Finally, the RF (radio frequency) link gives the capability of interfacing with another wireless device, such as the Medtronic Continuous Glucose Monitoring System or to the included USB drive associated with the pump [36].

The pump delivers insulin in three modes. In Basal rate mode, the delivery is continuous in small doses similar to a pancreas, for example 0.15 units per hour throughout the day. Basal rates are set to meet individual metabolic rates. In Bolus mode, the delivery is programmed to be a one-time delivery prior to eating or after an unexpected high, for example 18 units spread out to several hours. In sensor mode It alerts if a glucose level falls below or rises above preset values. This type of continuous treatment is in contrast to traditional multiple daily injections (MDI) that use slower-acting insulin. Continuous treatment reduces glucose variability.

The Paradigm Veo is equipped with a Low Glucose Suspend18 (LGS) mechanism. if data transmitted from the sensor show the patient's glucose levels have dropped below a defined threshold, the device alarms to alert the patient. If these alarms are ignored, the insulin pump automatically suspends insulin delivery for up to two hours. This helps to protect against potentially dangerous hypoglycemic events [29].

2.4 Summary

This chapter has described the basic operating principles of the IV infusion pumps. In addition, example of infusion pumps used in hospital are given in detail. Both the open loop and close loop systems are discussed in the chapter.

CHAPTER 3

THE DESIGNED WIRELESS PROGRAMMABLE VOLUMETRIC IV INFUSION PUMP SYSTEM

3.1 Overview

The wireless programmable volumetric IV infusion pump system designed by the author provides precisely controlled rate of fluid delivery to the patient through an intravenous (IV) line. The system includessafety features to ensure that any single failure of any significance is detected and monitoring immediately. This chapter provides theoretical fundamentals of the essential equipment which are used in the design. The block diagram and also includes the total electrical description of the components of the designed infusion pump system are given in detail in the chapter.

3.2 The Block Diagram of the Wireless Programmable Volumetric IV Infusion Pump System.

As shown in Figure 3.1 the block diagram of the wireless monitoring programmable volumetric IV infusion pump system consists of several blocks. The description of each block is given in the following sections.

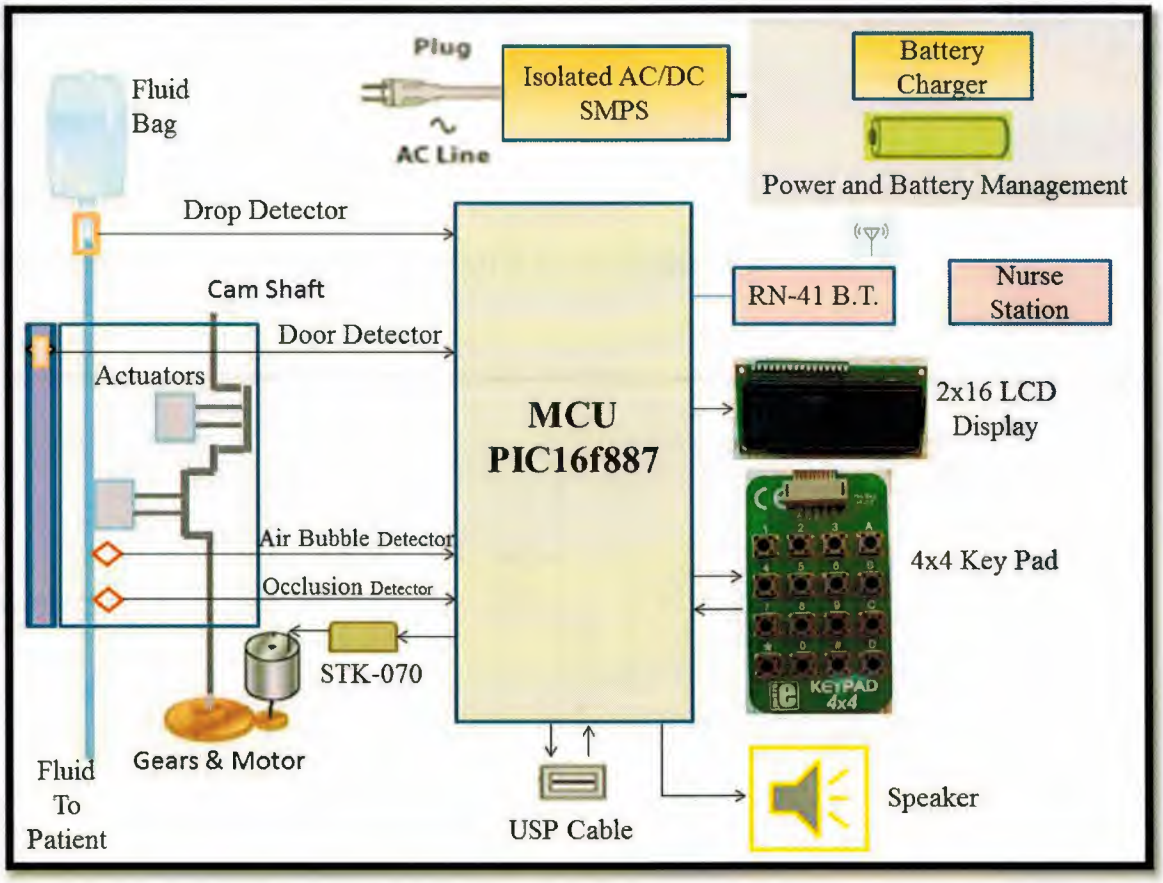


Fig. 3.1: The Block Diagram of the designed Wireless Programmable Volumetric IV Infusion Pump System.

3.3 Power Supply

Efficient conversion of electrical power is becoming a primary concern to companies and to society as a whole. Switching power supplies offer not only higher efficiencies but also offer greater flexibility to the designer [36]. A switched-mode power supply(PS-25-15)(switching-mode power supply, SMPS, or simply switcher) is an electronic power supply that incorporates a switching regulator in order to be highly efficient in the conversion of electrical power. Like other types of power supplies, an SMPS transfer power from a source like the electrical power grid to a load, while converting voltage and current characteristics. An SMPS is usually employed to efficiently provide a regulated output voltage, typically at a level different from the input voltage, the pass transistor of a switching mode supply switches very quickly (typically between 50 kHz and 1 MHz) between full-on and full-off states, which

minimizes wasted energy. Voltage regulation is provided by varying the ratio of on to off time [59].

How SMPS Work:

The circuit diagram of the designed SMPS system is shown in Figure 3.2.

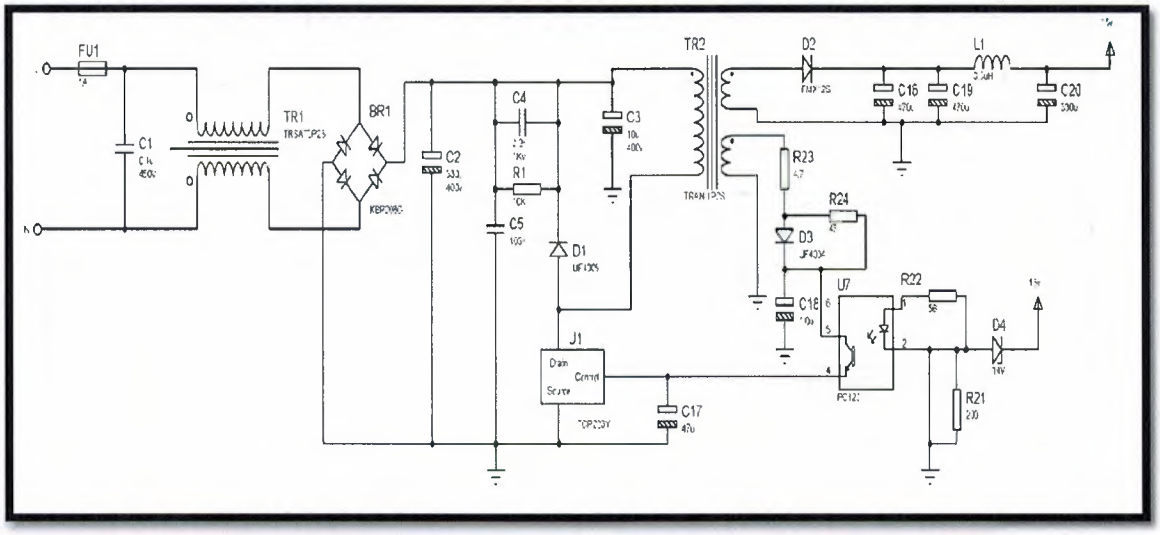


Fig.3.2: SMPS (PS-25-15) Circuit.

Input Rectifier Stage:

If the SMPS has an AC input, then the first stage is to convert the input to DC. This is called rectification. The rectifier circuit can be configured as a voltage doubler by the addition of a switch operated either manually or automatically. This is a feature of larger supplies to permit operation from nominally 120 V or 240 V supplies. As shown in Figure 3.3 the rectifier produces an unregulated DC voltage which is then sent to a large filter capacitor. The current drawn from the mains supply by this rectifier circuit occurs in short pulses around the AC voltage peaks. These pulses have significant high frequency energy which reduces the power factor. Special control techniques can be employed by the SMPS to force the average input current to follow the sinusoidal shape of the AC input voltage, correcting the power factor.

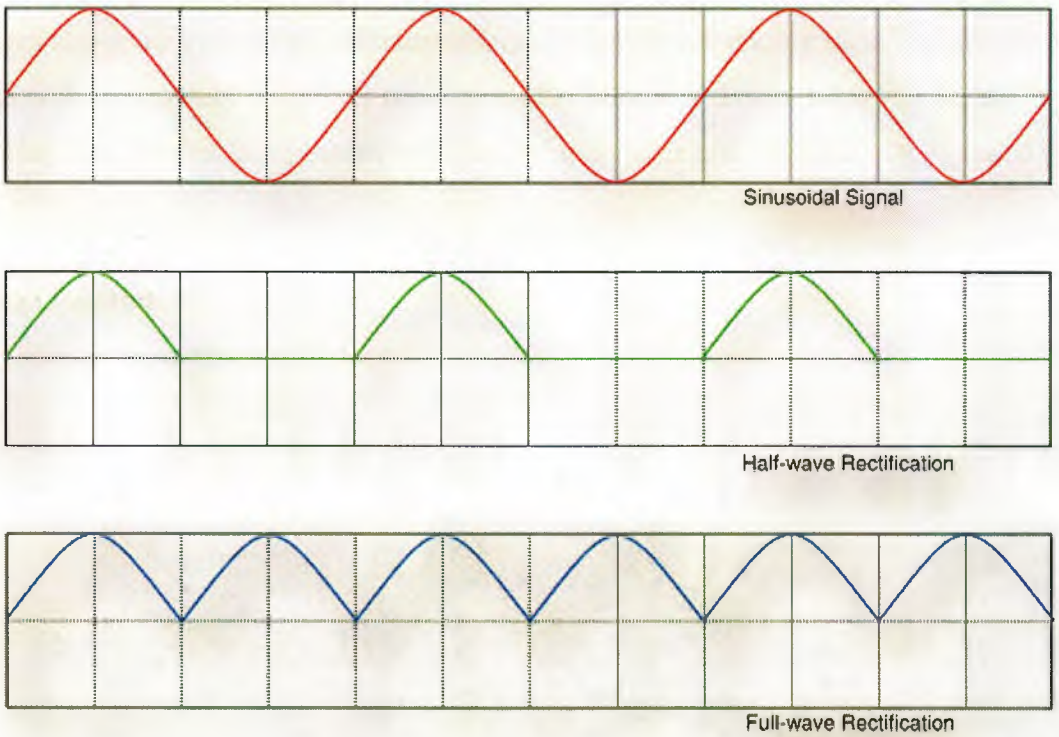


Fig. 3.3: AC, Half-wave and Full-wave Rectified Signals.

Inverter Stage:

The inverter stage converts DC, whether directly from the input or from the rectifier stage described above, to AC by running it through a power oscillator, whose output transformer is very small with few windings at a frequency of tens or hundreds of kilohertz. The frequency is usually chosen to be above 20 kHz, to make it inaudible to humans. The switching is implemented as a multistage (to achieve high gain) MOSFET amplifier. MOSFETs are a type of transistor with a low on-resistance and a high current-handling capacity.

Voltage Converter and Output Rectifier:

If the output is required to be isolated from the input, as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency transformer. This converts the voltage up or down to the required output level on its secondary winding.

If a DC output is required, the AC output from the transformer is rectified. For output voltages above ten volts or so, ordinary silicon diodes are commonly used. The rectified output is then smoothed by a filter consisting of inductors and capacitors. For higher switching frequencies, components with lower capacitance and inductance are needed [37].

Voltage Regulators:

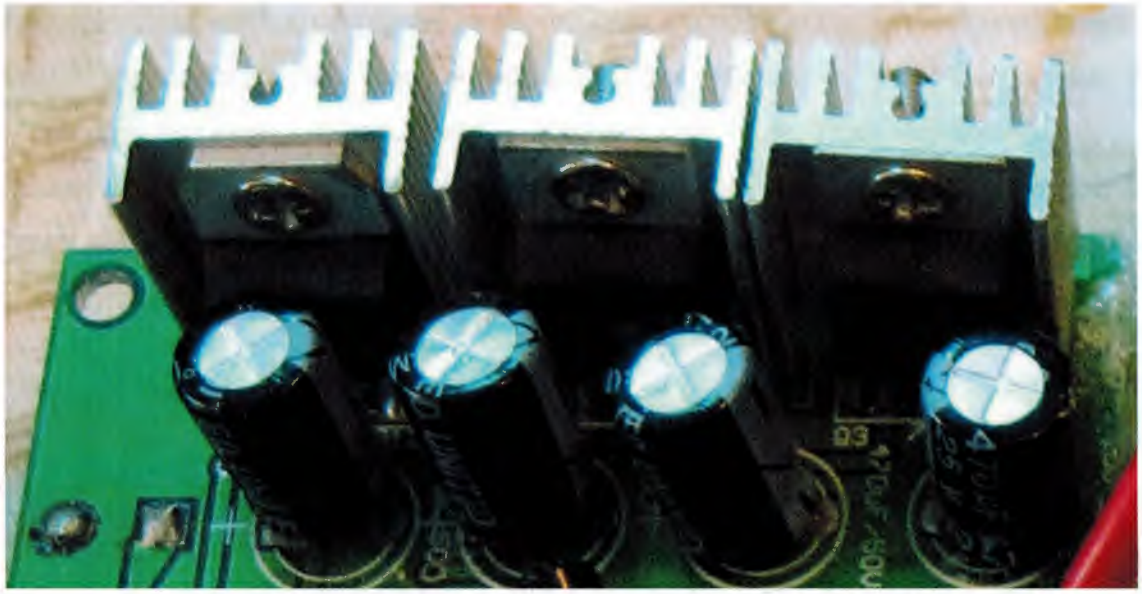


Fig. 3.4: Three Step Voltage Regulator.

Voltage regulators are used for providing a stable supply voltage, free of noise and AC ripple, to power a circuit. Linear regulators: Starting with a higher than required input voltage, these provide a stable, lower output voltage. The regulator heats up as it dissipates the voltage drop times the current as heat. As shown in Figure 3.5 the electrical circuit of the three step voltage regulator.

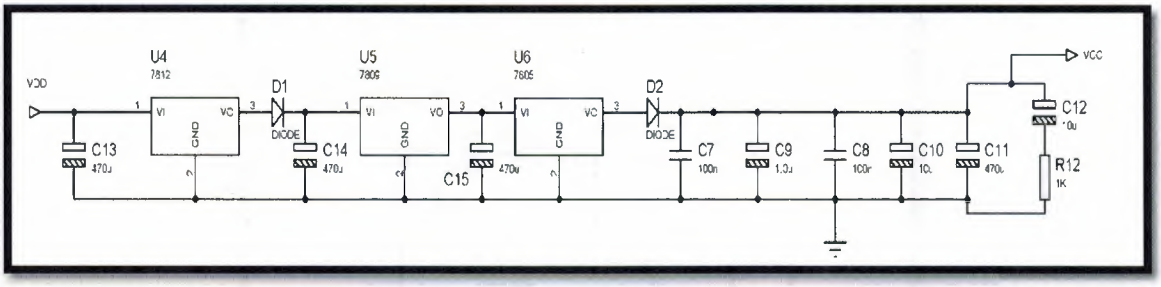


Fig. 3.5: The Electrical Circuit of the Three Step Voltage Regulator.

The simplest and best known regulators are the 78xx series, where xx is the desired output voltage. They have three pins: input, output and ground. 7805 will get you 5V on the output pin, as long as you supply an input voltage of at least 2-3V more. Three step voltage regulators used (7812, 7809, 7805) are great for making a simple and stable power supply. The first voltage regulator (7812) feed the batter charge circuit and the third regulator (7805) feed the microcontroller and the sensors of the designed IV infusion pump.

DC Voltage Supply:

Figure 3.6 show the circuit of the battery charge. DC 12V1800mA/h NI-MH rechargeable battery as shown in Figure 3.6.The advantages of nickel-metal hydride battery pack are the Environmental protection, high-capacity, high temperature, stable performance, small internal resistance, discharge time is long; battery quality and reliable performance, enough power, battery mantle cardboard packaging, when used with high temperature effect.Come into 10pcs a pack.

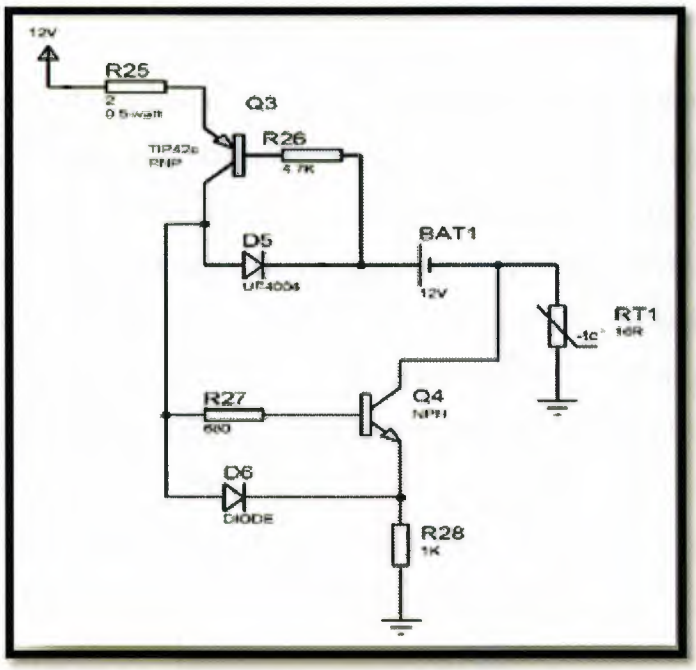


Fig.3.6: Typical Circuit of the Battery Charge.

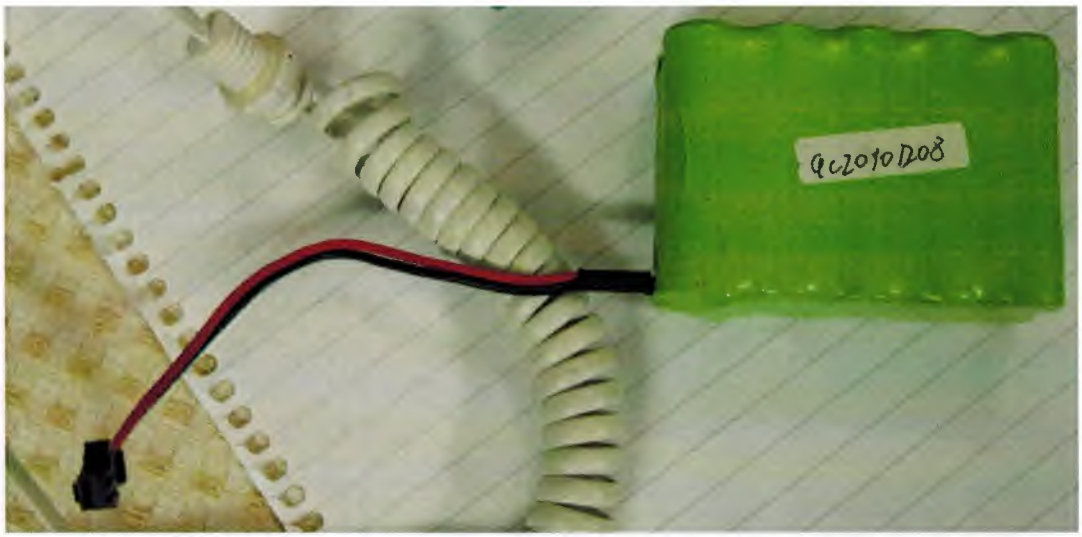


Fig. 3.7: DC 12V 1800mA/h NI-MH Rechargeable Battery.

3.4 The MCU

The MCU is building the "Ready for PIC" board, shown in Figure 3.8, developed by the MikroElektronika, and supporting both 28 and 40 pin microcontroller. The board comes with PIC16F887 microcontroller which is preprogrammed with an UART boot loader firmware and thus eliminates the need of an external programmer. The on-board USB-UART module allows the serial data transfer between the PIC and a PC using an USB cable. It has also got a reasonable size prototyping area to add more functionality to the board as required. Four 2×5 male header pins are available on the board for easy access to the MCU I/O pins. The on-board FT232RL chip provides a USB to asynchronous serial data transfer interface so that the MCU can communicate with a PC through a virtual COM port using a USB cable. The board has two LEDs marked with Rx and Tx which blink when data transfer via USB UART module is active. The board can also be used with a 3.3 V type PIC microcontroller. There is an on-board jumper for selecting between 5 V and 3.3 V supply voltage for the MCU.

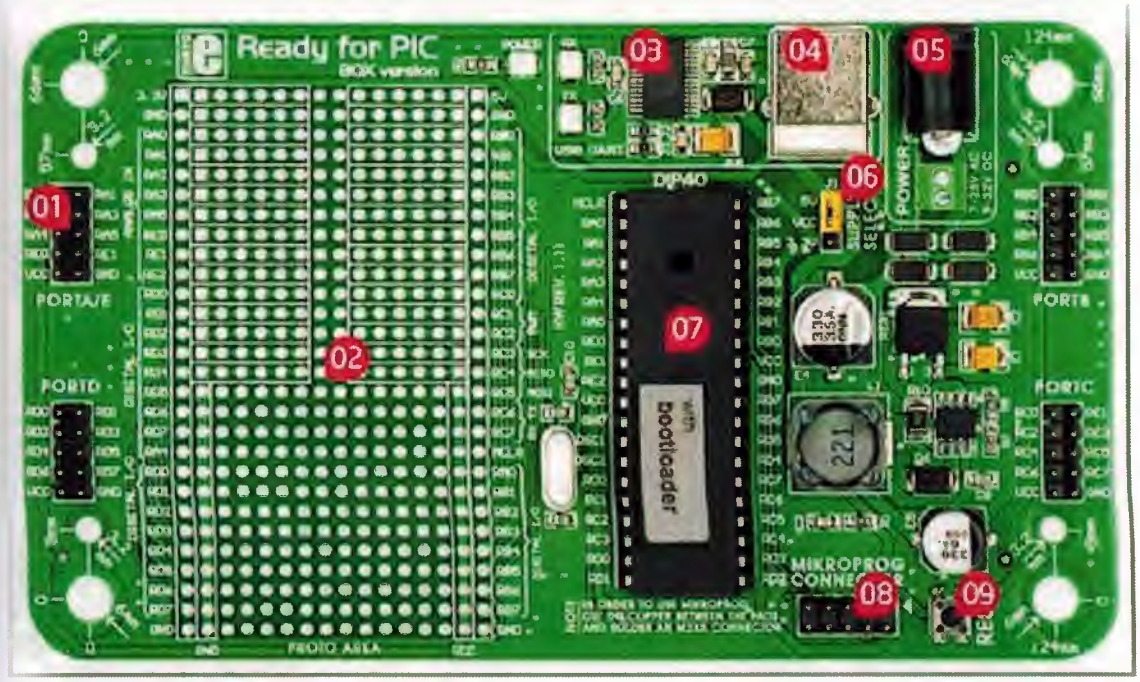


Fig.3.8: Ready for PIC Development Board.

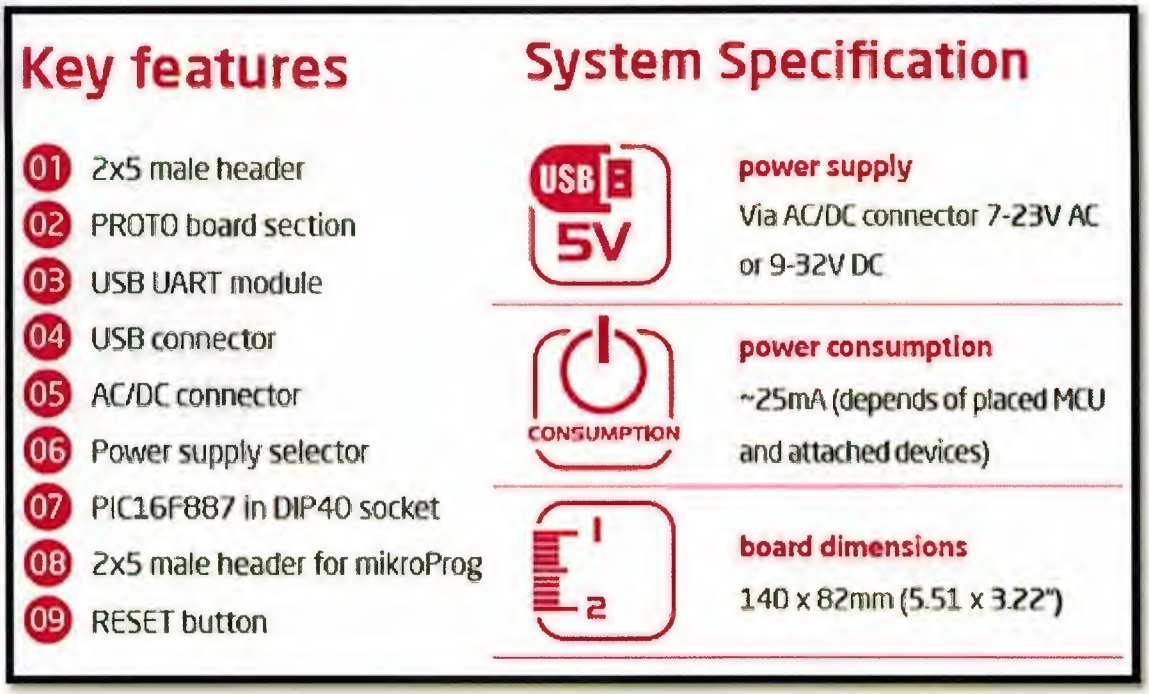


Fig. 3.9: Ready for PIC Development On-board Features and Specifications [38].

Power supply

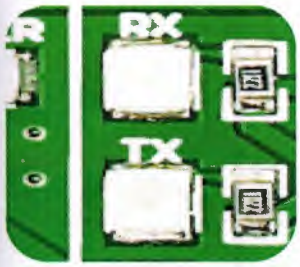
7-23V AC or 9-32V DC is provided via a screw terminal.

MCU Oscillator

The MCU is connected to 11.592MHz oscillator which provides clock ideal for RS232 communication.

Power Regulator

On board power regulators for 3.3V and 5V ensure that each part of the board gets necessary stable voltage and current levels.



Communication LEDs

Board contains specialized RX and TX LEDs for monitoring UART communication.

Power LED

Power LED turns on when power supply is brought either using USB cable, or via external power connectors.

Figure 3.10 shown the Ready For PIC16F887 Board Schematics.

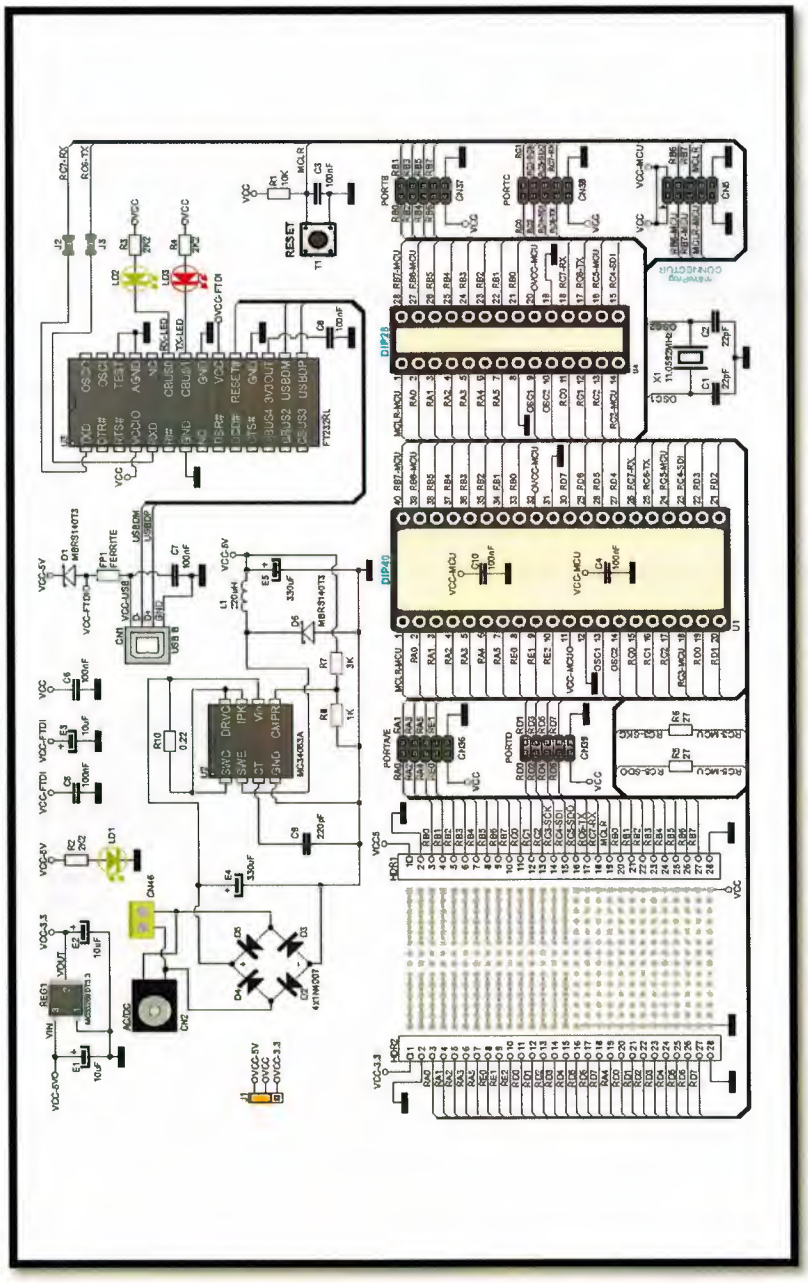


Fig. 3.10: Ready for PIC16F887 Board Schematics [36].

3.4.1 Processing

Processing is an open-source software development environment designed for simplifying the process of creating digital images, animations and interactive graphical applications. It is free to download and operates on Mac, Windows, and Linux platforms. The Processing Interactive Development Environment (IDE) has the same basic structure as that of the Arduino IDE and is very easy to use. The firmware for PIC16F887 is written in mikroC Pro for PIC. The built-in UART and SPI library routines make the programming part on PIC side much easier [39].

Used the Bootloader

1. Connect with MCU

Reset the board and click on **'Connect with MCU'** within 5s timeframe to force the chip into bootloader mode as shown in Figure 3.11.

Fig. 3.11: Connect with MCU.

2. Load your HEX

Click on **'Browse for HEX'** button as shown in Figure 3.12, and find the desired HEX file which will be used for programming microcontroller on your PIC-Ready1 board.

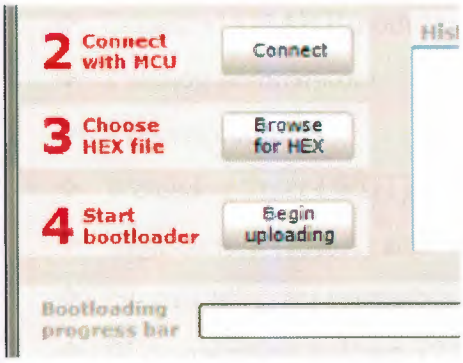


Fig. 3.12: Load the HEX File.

3. Start Bootloading

Click on **'Begin Uploading'** button to start the process as shown in Figure 3.13,After uploading is completed, reset the chip to start your new program [40].

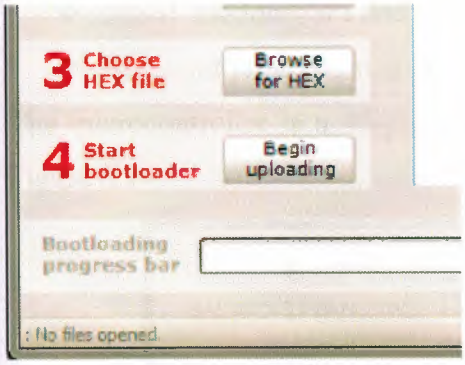


Fig.3.13: Start Bootloading.

3.4.2 The PIC16F887 Microcontroller

The PIC16F887 microcontroller is a medium speed general purpose microcontroller having the following basic features [41]:

- Only 35 instructions (assembly level)
- DC to 20 MHzoperation
- 8192 words of program memory
- 368 bytes of data RAM
- 256 bytes of data EEPROM
- 35 I/O port pins
- 14 channel, 10-bit A/D converter

- Enhanced USART module
- 2 analog comparators
- 3 timers/counters
- Watchdog timer (WDT)
- High current (25mA) sink/source capability of each port pin
- Internal program selectable oscillator
- Wide operating voltage (2.0V to 5.5V)
- Power saving sleep mode
- Power-up timer (PWRT)
- Power-on reset (POR)
- Brown-out detector
- Very low standby current (50nA at 2.0V)
- Enhanced PWM module
- MSSP module (SPI and I^2C modes)
- In-circuit programming (ISP)

The microcontroller is a 40-pin chip in a DIL package. The pin configuration is shown in Figure 3.14.

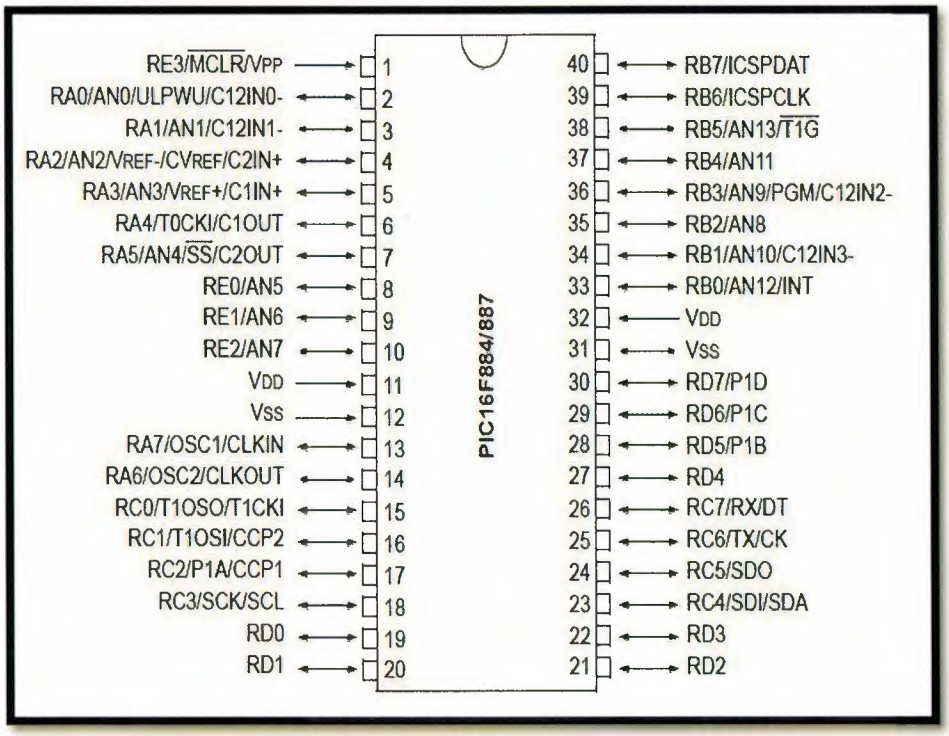


Fig. 3.14: PIC16F887 Pin Configuration [42].

3.4.3 PIC16F887 Internal Architecture

As shown in Figure 3.15. The CPU is at the center of the diagram and consists of an 8-bit ALU, and an 8-bit work accumulator register (WREG). The program counter and program memory are shown in the upper left portion of the diagram. Program memory addresses consist of 13 bits, capable of accessing 8 Kbytes of program memory locations. The program memory contains a 8-level stack which is normally used to store the interrupt and subroutine return addresses. The data memory can be seen at the top center of the diagram. The data memory is 9 bits wide, capable of accessing 512 byte of data memory locations (only 368 bytes of data RAM are used). The data memory consist of special function registers (SFR) and general purpose registers, all organized in banks. The bottom portion of the diagram shown the timers/counter, capture/ compare/PWM register, USART, A/D converter, and EEPROM memory. The rest circuitry is shown in the middle of the diagram. The input-output ports are located at the right hand side of the diagram. The device has five parallel ports named PORTA, PORTB, PORTC, PORTD, and PORTE. Most port pins have multiple functions. For example, PORTA pins can either be used as parallel digital input-output, or as analog inputs [41].

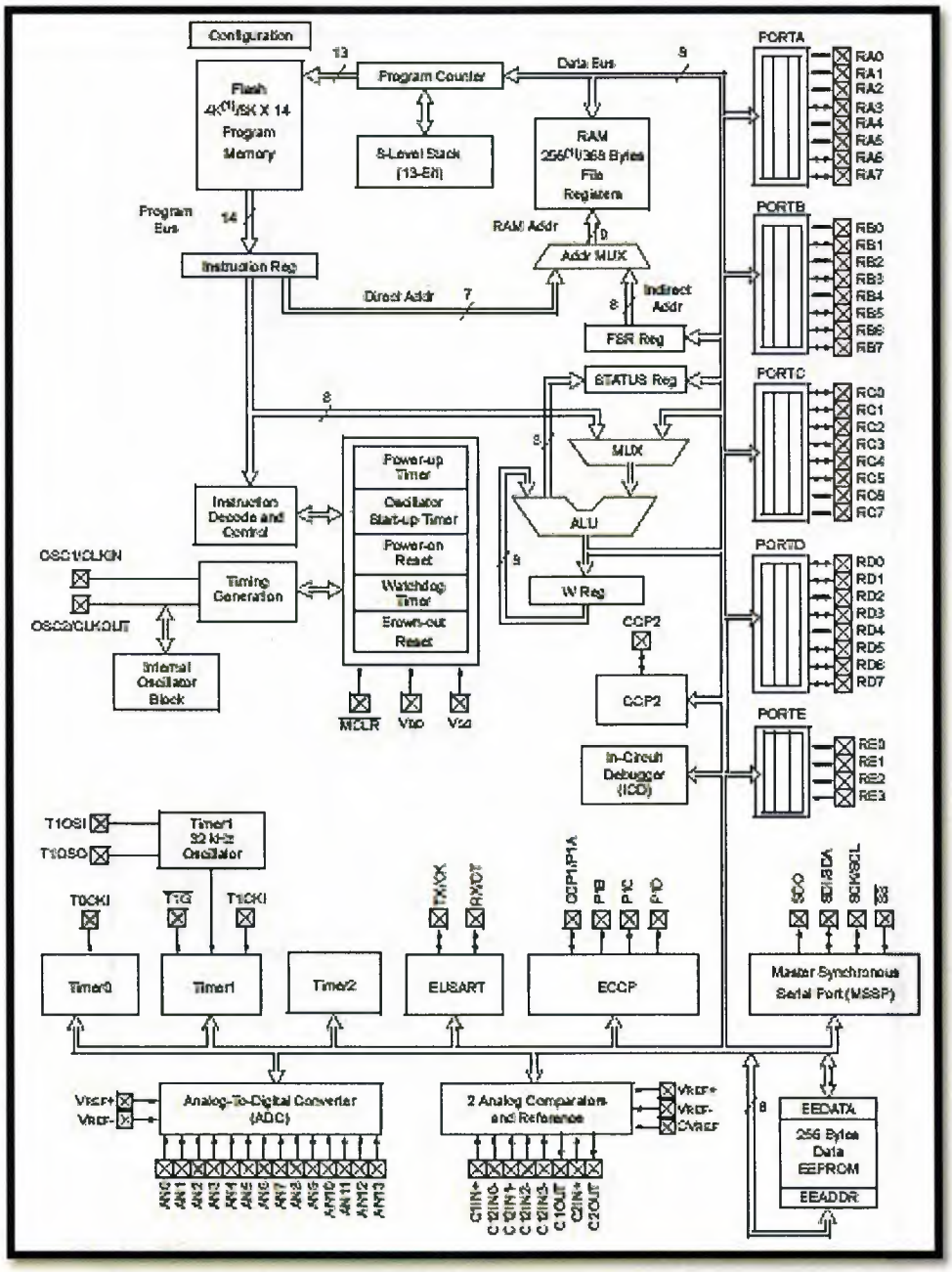


Fig. 3.15: Block Diagram of the PIC16F887 microcontroller [41].

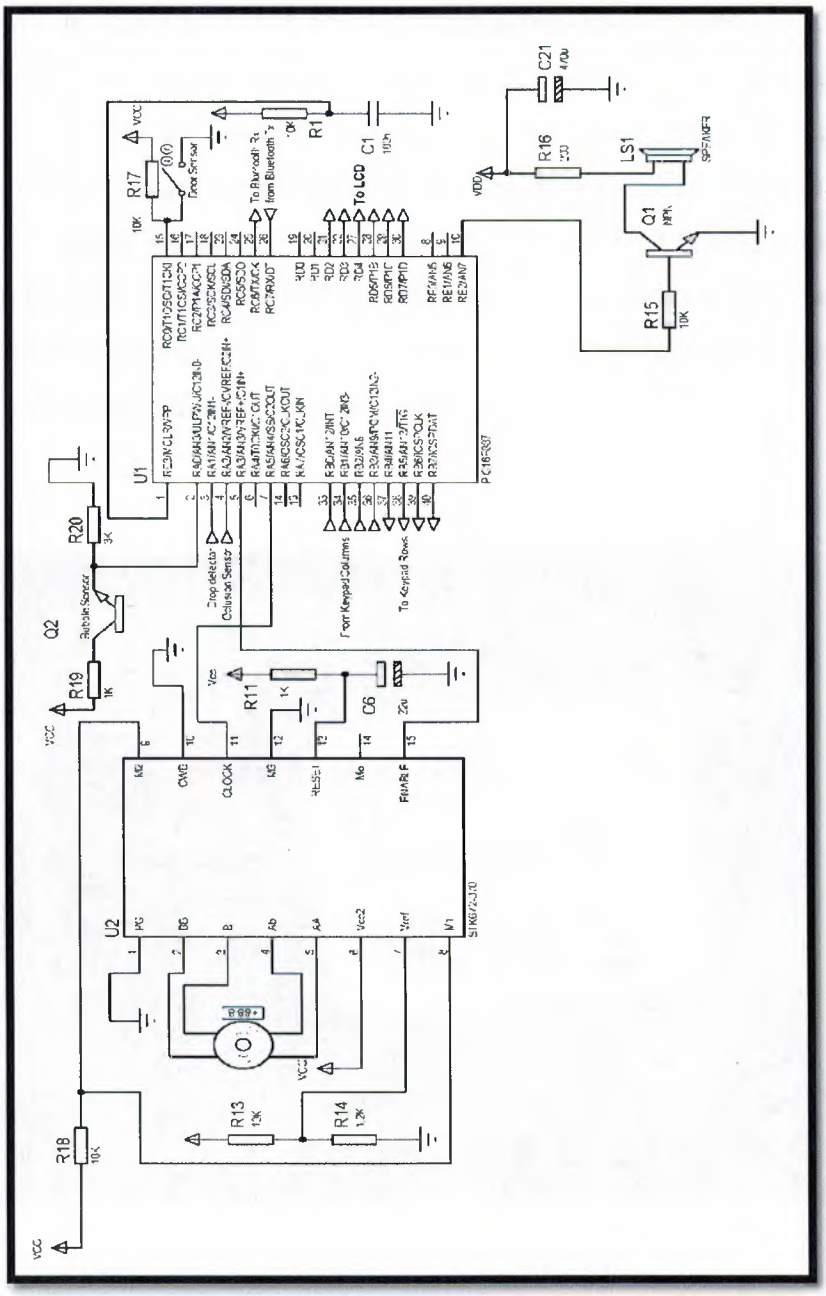


Fig.3.16: The Electrical Circuit Connection of the PIC16F887 MCU of the Designed System.

3.5 The Bluetooth Connection

The RN-41 is shown in Figure 3.17. The RN-41modelfeatures module with UART interface which is easy and simple to use. Device is a Class 1 high power radio and can operate up to 100m distance. Board offers low power (30mA connected, less than 10mA sniff mode), highly economic Bluetooth radio for adding wireless capability to the products. Board is designed to use 3.3V power supply only. It's connected in Serial Port Profile (SPP). This profile is based on ETSI 07,10 and the RFCOMM protocol. It emulates a serial cable to provide a simple substitute for existing RS-232, including the familiar control signals [43], as shown in Figure 3.18 the Bluetooth Click board schematics.

Fig.3.17: RN41-1BLUETOOTH Click Board [44].

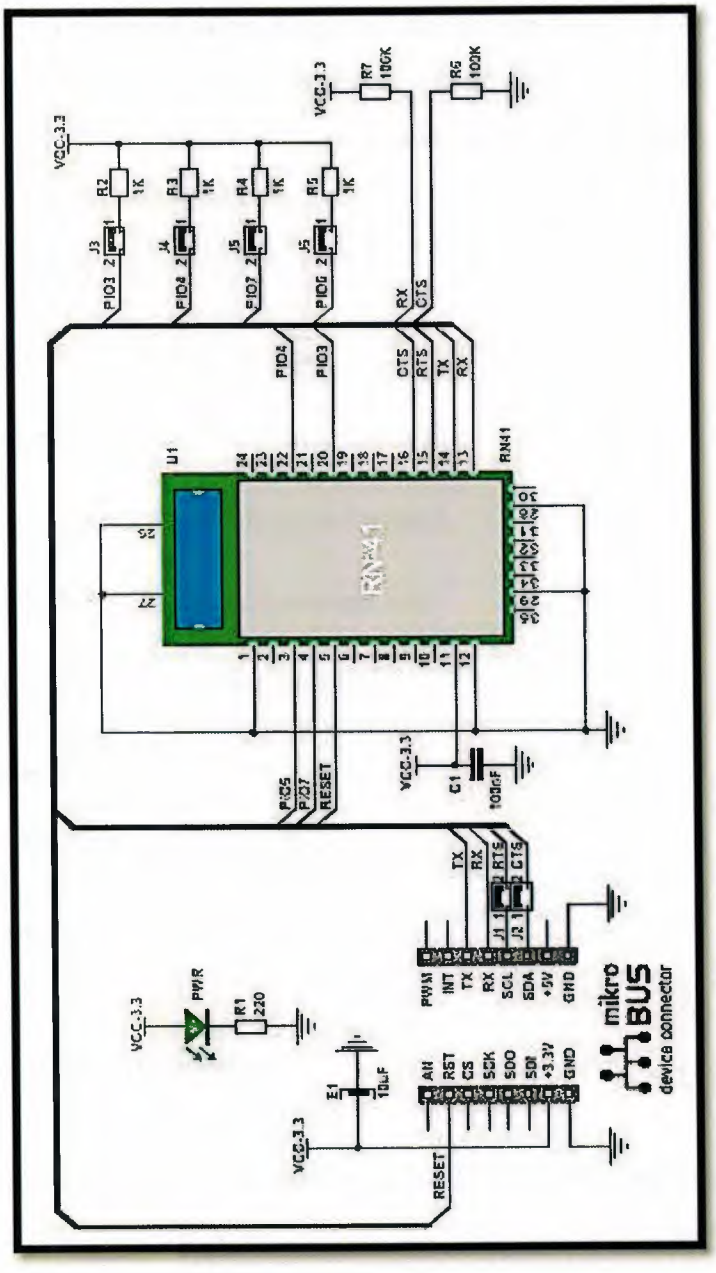


Fig. 3.18: Bluetooth Click Board Schematics [44].

mikroBUS™ host connector

Each mikroBUS™ host connector consists of two 1x8 female headers containing pins that are most likely to be used in the target accessory board. There are three groups ofcommunication pins: SPI, UART and I2C communication. There are also single pins for PWM, Interrupt, Analog input, Reset and Chip Select. Pinout contains two power groups: +5V and GND on one header and +3.3V and GND on the other 1x8 header. mikroBUS™ host connector perfectly fits into standard bread boards [45].

AN - Analog pinRST - Reset pin

CS - SPI Chip Select lineSCK - SPI Clock line

MISO - SPI Slave Output lineMOSI - SPI Slave Input line

+3.3V - VCC-3.3V power lineGND - Reference Ground

PWM - PWM output lineINT - Hardware Interrupt line

RX - UART Receive lineTX - UART Transmit line

TX - UART Transmit lineSCL - I2C Clock line

SDA - I2C Data line+5V - VCC-5V power line

GND - Reference Ground

3.6 Designed Infusion Pump Mechanism

A finger peristaltic pump for propelling liquid through a flexible tube segment, the pump as shown in Figure 3.19 comprising the stepper motor, gear box, cam shaft, followers, plate, and the tube set.

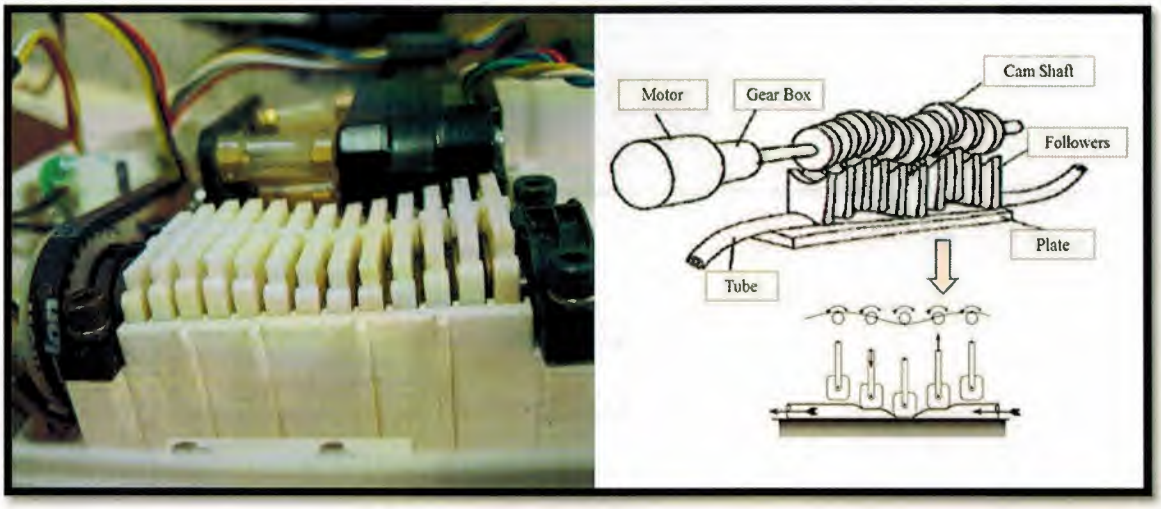


Fig. 3.19 : Principle Operation of Fingure Peristaltic Pump.

A Uni-polar stepper motor is an electromechanicaldevice which converts electrical pulses intodiscrete mechanical movements. The shaftor spindle of a stepper motor rotates indiscrete step increments when electricalcommand pulses are applied to it in the proper sequence [46]. The STK672-070 is a stepping motor driver hybrid IC thatuses power MOSFETs in the output stage as shown in Figure 3.20. It includes abuilt-in microstepping controller and is based on a unipolar constant-current PWM system. Can provide control of the basic steppingangle of the stepping motor divided into 1/16 step units. Italso allows the motor speed to be controlled with only aclock signal which come and determine from the PIC microcontroller.The use of this hybrid IC provide high and accurate motor torques which change according the load on the motor when the drug infuse through the tube set, low vibrationlevels, low noise, fast response, and high-efficiency drive.

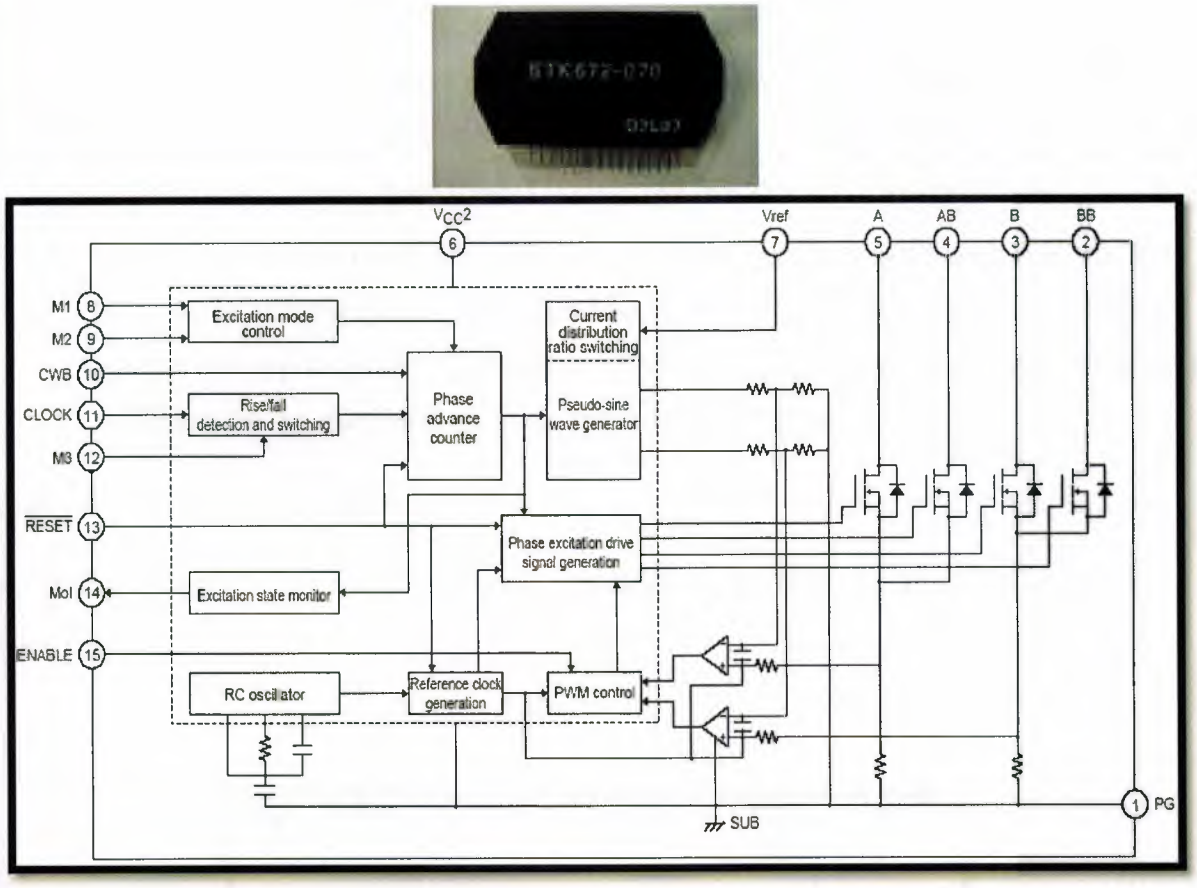


Fig. 3.20: The STK672-070 Internal Block Diagram [47].

The gear box contains the arc teeth belts which transfer the moving from the motor shaft gear to the cam shaft gear of the pump. The cam shaft carried a plurality of cams. The motor for rotating the cam shaft whereby the cams cause the cams followers to each engage and occlude the flexible tube segment to form a propagating depression wave in the flexible tube segment for propelling liquid; the restriction cam followers preventing back flow of the liquid.Increasing the tube diameter or the pumping cycle frequency increases the flow rate. A major attraction of peristaltic pumps is cleanliness. The fluid is completely isolated from the pump components since it never leaves the tube. Furthermore, it is a simple matter to change the tubing to avoid cross-contamination between fluids. The pumping action is relatively gentle, making peristaltic pumps suitable for reactive liquids or cell suspensions.

The first step in the simplified analysis is estimating the volume of fluid transported in a complete pumping cycle. To do this, must apply the following rules:

1. When thefollowersclose, the fluid within is completely expelled.

2. When the followers open, it completely fills with fluid.
3. If thefollowersremain closed during a step in the sequence, no fluid may pass across it.
4. If, in a single step, some followers open while others close, and there is a path for fluid to flow between them, then fluid is transferred from the latter to the former.
5. If the followers open or closes with no closed followers between it and either the inlet or the outlet, the transfer of fluid is made equally from or to both sides. Once the fluid volume is computed, the flow rate flows from the actuation frequency. Maximum head is taken to be the maximum pressure exerted by the followers.

Simplified Sequence Analysis

As an illustration of the simplified analysis, consider the three-step cycle shown in Figure 3.21.

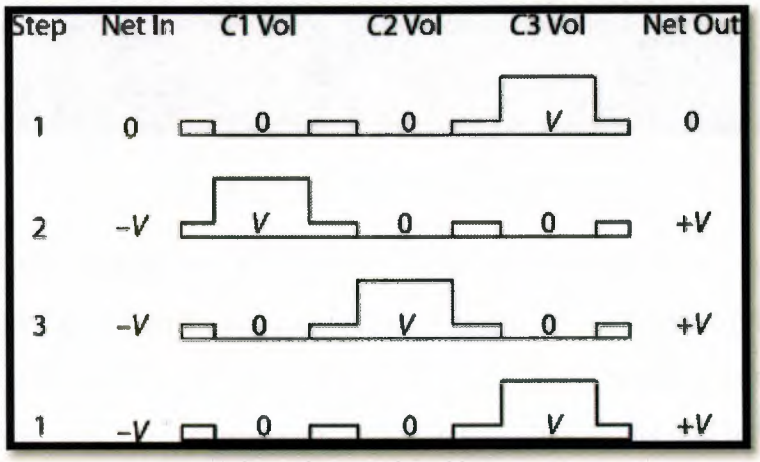


Fig. 3.21:A Three-step, Three-actuator Pumping Sequences, used in numerous pumps. The stroke volume is designated *V*. Chambers 1, 2, and 3 are abbreviated *C*1, *C*2, and *C*3. At every step two chambers are closed, reducing leakage.

For a pump consisting of three identical ideal actuators with stroke volume V. At the start of the cycle, no fluid has yet been transferred. In step 2, chamber C1 opens while chamber C3 closes. By rules 1 and 2, C1 must fill with volume V while C2 expels volume V. Since the intervening chamber C2 is closed, by rule 3 C1 must take volume V from the inlet, while C3 must expel volume V to the outlet. In step 3 C1 closes while C2 opens. By rule 4, since there is an open path between them, this transfers volume V from C1 to C2. Likewise the return to

step 1, which completes the cycle, transfers volume V from C2 to C3. We conclude that, ideally, volume V is pumped per complete three-step cycle. At the final step the net fluid volume increase at the outlet must equal the net decrease at the input[48].

3.7 Drop Detector

Fig.3.22: Drop Detector.

Photoelectric sensing technology is used to monitor the infusion speed and residual quantity.The infrared light transmitter-receiver is mounted on both sides of the tube in the drip pot, infrared light transmitter emit infrared light, the light shines through a drip pot and is received by receives. The light signal is converted to electrical signal and output. The advantage of using infrared sensor is non-contact detection and it meets the clinical requirement of aseptic operation. As shown in Figure 3.23 the principle diagram of drop detection unit.

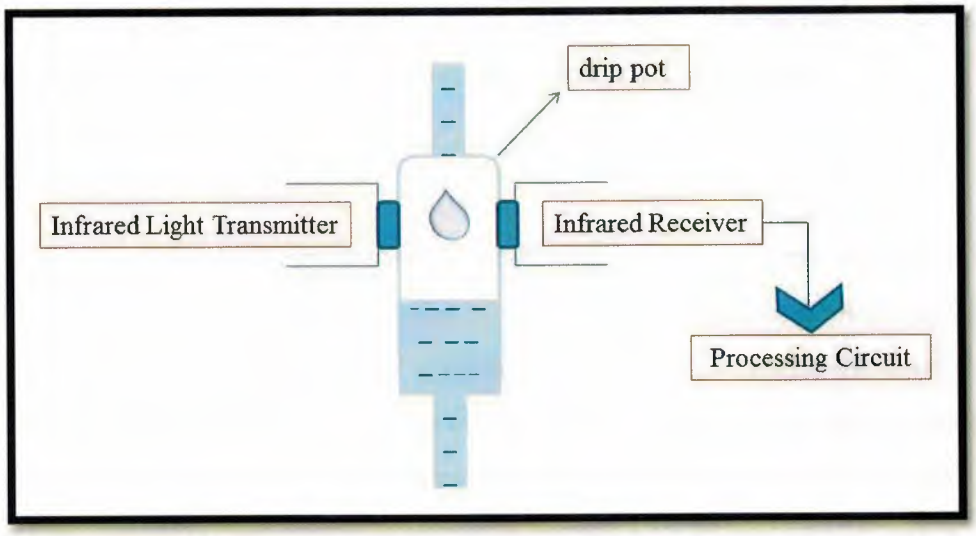


Fig. 3.23: Principle Diagram of Drop Detection Unit.

In the absence of drop dripping, the infrared receiver receives the greatest degree of illumination and the resulting photocurrent is also the largest. When drop falling, the beam scatter due to the optical property of drop and the light intensity projected onto the infrared receiver will decrease, sothat the photocurrent decreased. Whether the drops fall through the drip pot can be detected as long as detecting the output current pulse of infrared receiver. Photosensitive device output pulse signal is extremely small and is sensitive to external interference, so the output pulse signal should be further processed before input into microcontroller. Figure 3.24, is the measuring circuit of drop.

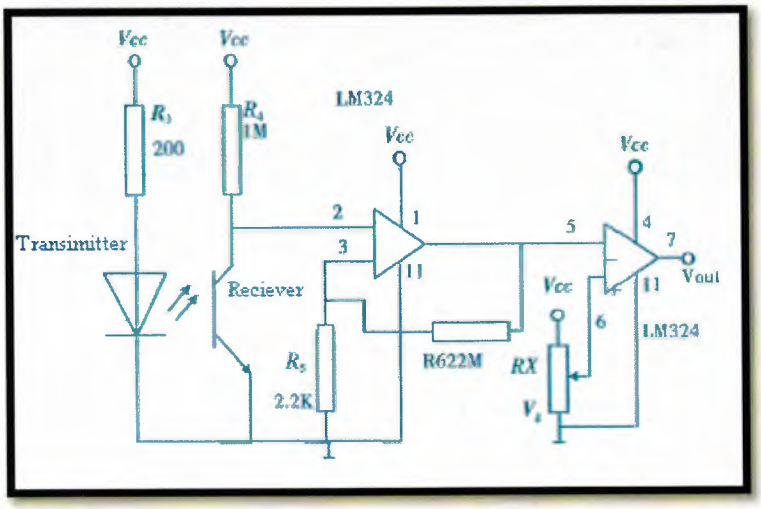


Fig. 3.24: Drop Detector Circuit [49].

To protect the infrared LED from burning for too large current, pull-up resistor R3, R4 are in series in the transmitter and receiver as the current limit protection [49].

3.8 Air Bubble Detector

The incidence of air bubble during the use of medication infusion pumps has created the need for reliable, sensitive, and continuous means of monitoring the fluid line for the presence of air bubbles, resulting from an air leak or any other reason, is immediately detected so that the infusing can be stop immediately before an air bubble is allowed to enter the patient's vein along with the blood. A volume of 40 - 50 cm3 (cubic centimeter) of air is certainly dangerous [50]. An air bubble sensor as shown in Figure 3.25 includes an ultrasonic transmitter acoustically coupled to an ultrasonic receiver to detect the presence of a gas (e.g. air) in a portion of a tube comprising the IV line.

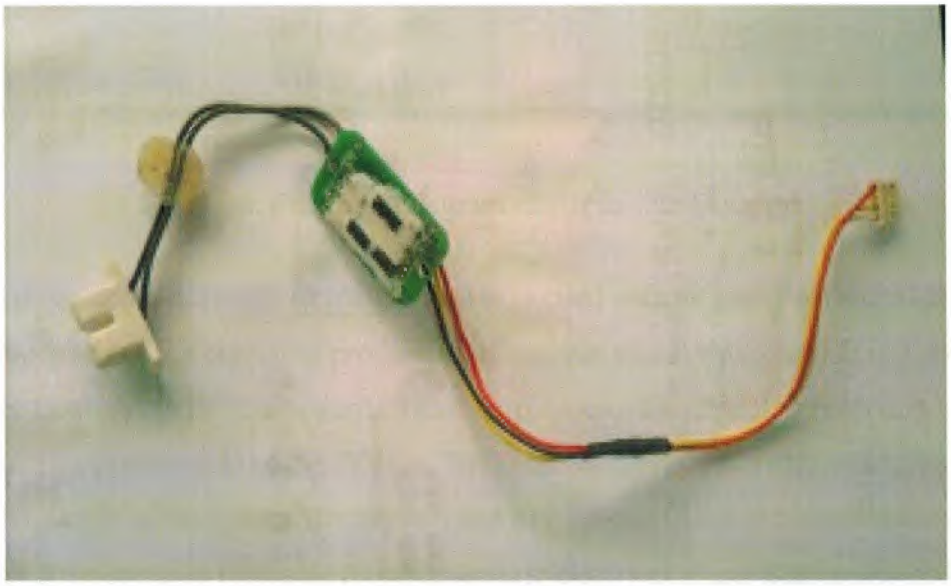


Fig. 3.25: Air Bubble Detector and Occlusion Detector.

The transmitter and receiver are mounted on pivoting transducers that are disposed on opposite sides of the tube. The transmitter and receiver contact opposite sides of the tubing. A controller precisely monitors the flow of medicinal liquid through the tubing to detect the gas bubbles. An air bubble sensor is usually disposed at a fixed position in the housing of an IV pump. As shown in Figure 3.26, a typical air bubble sensor includes two piezoelectric crystals that are mounted on each side of a slot adapted for gripping a portion of an IV line (tubing).

The tubing is forced into the slot so that it is held in close association with the inner surfaces of each side of the slot.

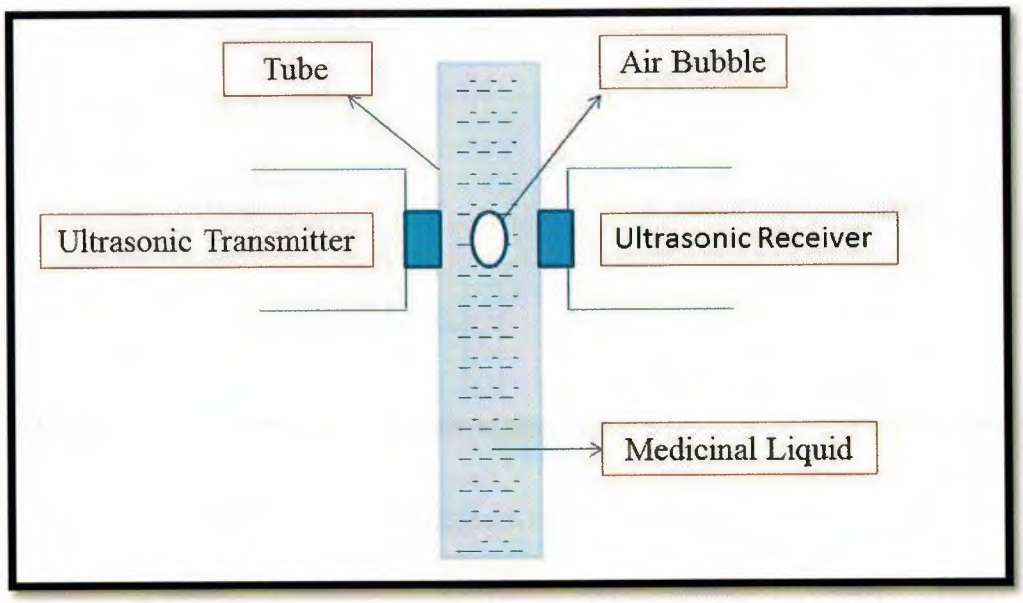


Fig. 3.26: Principle Diagram of Air in-line Detector.

one of two piezoelectric crystals (a transmitter) is excited with an electrical signal at the resonant frequency of the crystal to produce an ultrasonic sound wave, which is directed transversely through the IV line towards the other piezoelectric crystal (a receiver), which is disposed on the opposite side of the IV line. The receiver crystal resonates at approximately the same frequency as the transmitter crystal, and in response to the ultrasonic sound waves that it receive, the receiver produces a corresponding electrical signal that is proportional to the amplitude of the sensed ultrasonic waves. Since it is well known that the transmission of ultrasonic sound waves through a liquid is substantially greater than through a gas, any gaseous (air) bubbles entrained in the liquid flowing through the IV line at the point between the transmitter crystal and the receiver crystal will attenuate the ultrasonic sound waves in proportion presence of the bubbles. Thus, a strong electrical signal produced by the receiver crystal indicates that only a liquid is flowing through the portion of the tubing disposed between the transmitter and receiver crystals, while a weak or missing signal indicates the presence of a gas [51].

Each change in the magnitude of the ultrasonic sound waves received by the receiver crystal causes a corresponding change in the electrical signal that it produces. Figure 3.27 shown typical block diagram of the air bubble detector.

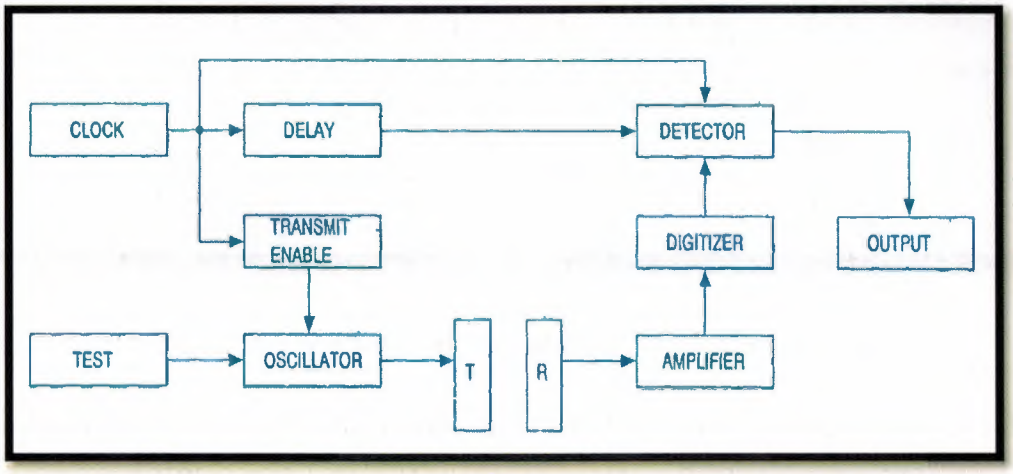


Fig. 3.27:Typical Block Diagram of the Air Bubble Detector [52].

Usually, a controller is employed to monitor the electrical signal produced by the receiver crystal, for detecting the presence of air bubbles in the medicinal liquid. The controller generates an alarm and/or stops the IV pump when it detects an air bubble.

3.9 Occlusion Detector

The occlusion detector is detecting the presence of an occlusion in an intravenous (IV) line supplying amedicinal liquid to a patient. Pressure occlusion sensor is employed to produce a value for the pressures within an IV pumping cassette that is disposed in the fluid path of the IV line. Figure 3.28 shows the electrical circuit of the occlusion detector.The pressure occlusion sensor includes a strain gauge connected to a leaf spring that is fixed at one end within a pump chassis and a rod that is disposed transverse to the leaf spring. The rod has one end that responds to the force of a portion of an elastomeric membrane inside the pumping cassette and another end that contacts a free end of the leaf spring.

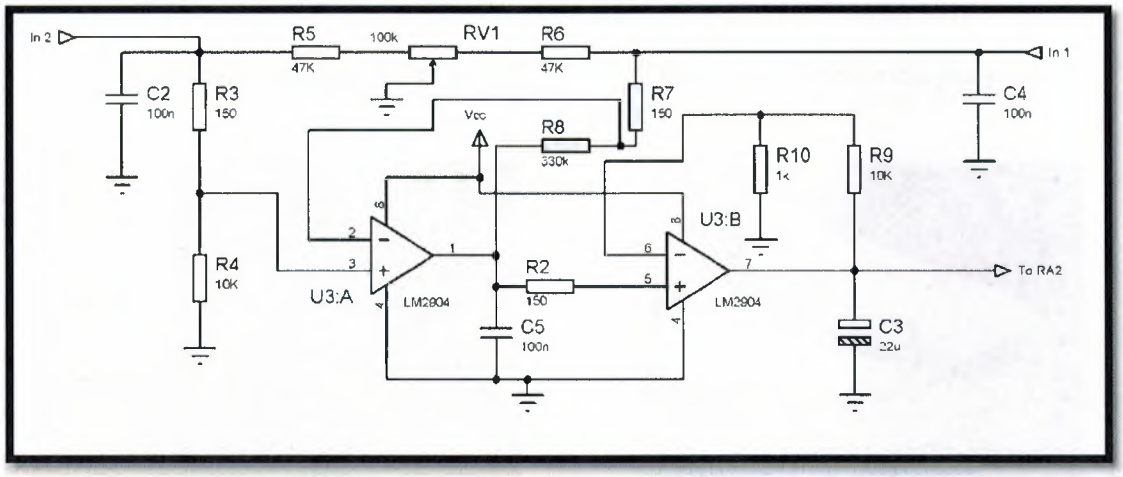


Fig. 3.28: The Electrical Circuit of the Occlusion Detector.

When a leaf spring is flexed by the movement of a rod, the strain gauge mounted on the leaf spring produces a differential voltage that corresponds to a fluid pressure within the pumping cassette. The output from the pressure sensors sampled at least once per second to ensure that maximum pressure values are not exceeded and that a pressure sensor failure is immediately detected.The strain gauge produces a signal indicative of the fluid pressure. An alarm is provided to indicate an impediment to fluid flow through the intravenous line. Coupled to the strain gauge to receive the signal is a controller. The controller samples the signal and determines a baseline pressure while the pump is operating. As a function of the baseline pressure, the controller determines a relative pressure. An impediment to the fluid flow through the intravenous line is detected by the controller as a function of the relative pressure and if such an impediment is detected, the controller activates the alarm to alert a user and stopped the motor [53].

3.10 Door Detector

The door open detector consists of read switch. Reed switch as shown in Figure 3.29 is very similar to relays, except a permanent magnet is used instead of a wire coil.

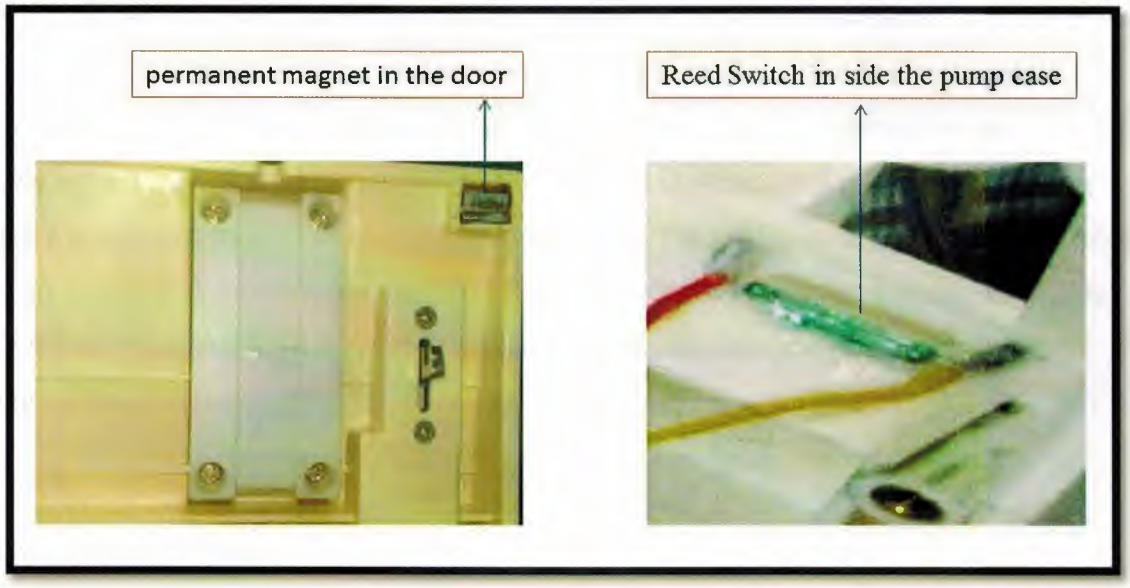


Fig. 3.29: Door Detector.

When the magnet is far away the switch is open, but when the magnet is brought near the switch is closed [54]. A Reed Switch consists of two ferromagnetic blades (generally composed of iron and nickel) hermetically sealed in a glass capsule. The blades overlap internally in the glass capsule with a gap between them, and make contact with each other when in the presence of a suitable magnetic field. As shown in Figure 3.30

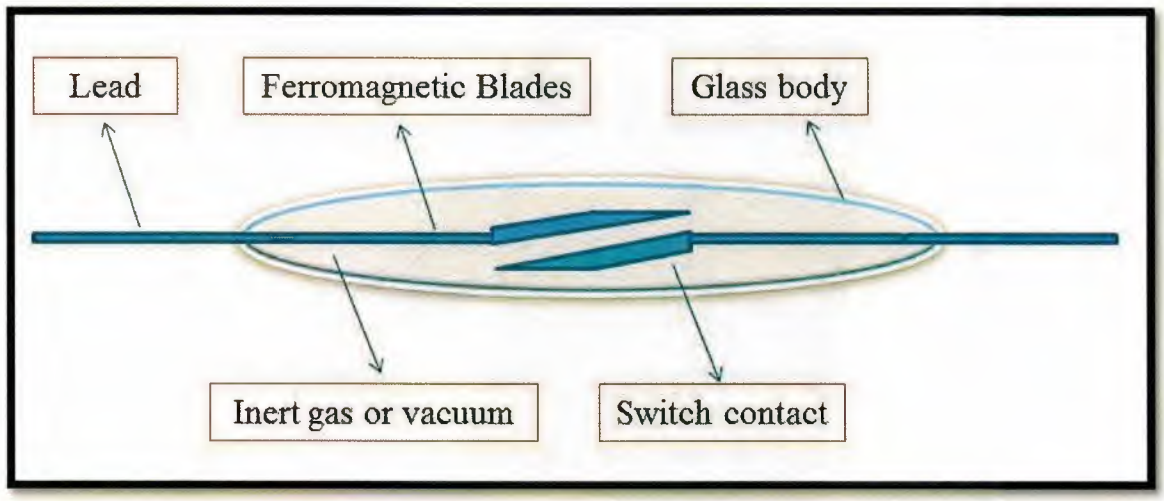


Fig. 3.30: (Normally Open) Reed Switch and its Component Makeup.

The contact area on both blades is plated or sputtered with a very hard metal. The gas in the capsule usually consists of Nitrogen or some equivalent inert gas. Some Reed Switches, to increase their ability to switch and standoff high voltages, have an internal vacuum. The reed blades act as magnetic flux conductors when exposed to an external magnetic field from either a permanent magnet or an electromagnetic coil. Poles of opposite polarity are created and the contacts close when the magnetic force exceeds the spring force of the reed blades. As the external magnetic field is reduced so that the force between the reeds is less than the restoring force of the reed blades, the contacts open [55].

3.11Keypad 4x4 Board

Keypad 4x4 Board as shown in figure 3.31 is used for loading numeric into the microcontroller. It consists of 16 buttons arranged in a form of an array contacting four lines and four columns. It is connected to the development system by regular IDC 10 female connector plugged in some development system's port [56].

Fig. 3.31: Keypad 4x4 Board.

The Keyboard is usually used as follows:

- Four microcontroller's pins should be defined as output, and other four pins should be defined as inputs. In order the keypad to work properly, as shown in Figure 3.32 pull-down resistors should be placed on the microcontroller's input pins, thus defining logic state when no button is pressed.

- Then, the output pins are set to logic one (1) and input pins logic state is read. By pressing any button, a logic one (1) will appear on some input pin.

- By combining zeros and ones on the output pins. It is determined which button is pressed.

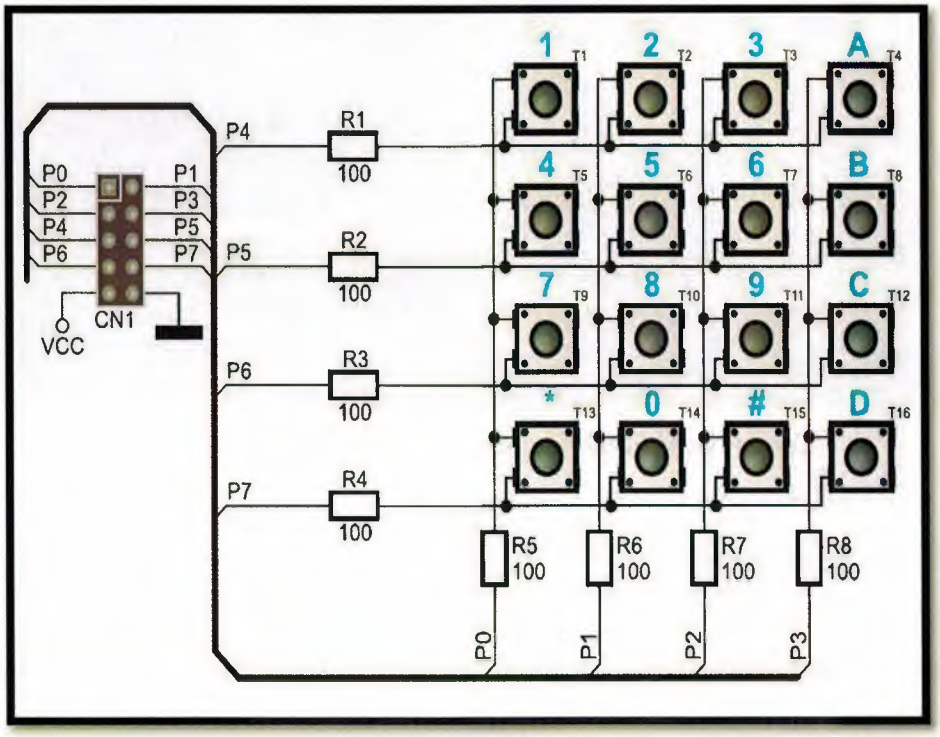


Fig. 3.32: Keypad 4x4 Connection Schematic [56].

3.12LCD Display

The LCD displayas shown in Figure 3.33 is a 2x16 character STN blue (negative) display with a white LED backlight. The LCD display Module (winstar WH1602b-TMI-ET#) is built in a LSI controller, the controller has two 8-bit registers, aninstruction register (IR) and a data register (DR).The IR stores instruction codes, such as display clear and cursor shift, and address information fordisplay data RAM (DDRAM) and character generator (CGRAM). The IR can only be written from theMPU. The DR temporarily stores data to be written or read from DDRAM or CGRAM. Whenaddress information is written into the IR, then data is stored into the DR from DDRAM or CGRAM [57].

Character located	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
DDRAM address	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
DDRAM address	40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F

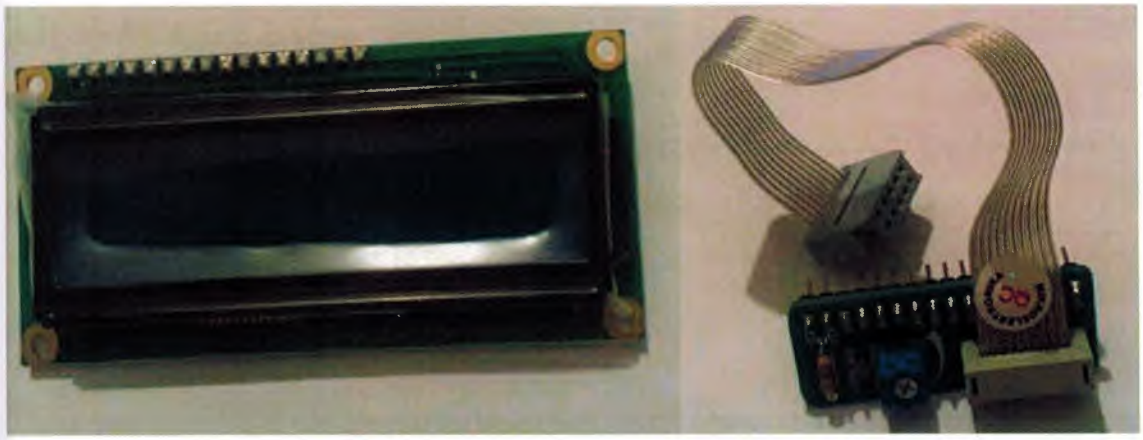


Fig. 3.33:LCD Display and LCD Adapter Additional Board.

The LCD adapter additional board shown in Figure 3.34 is used to connect the pins of the microcontroller provided on the development system to a 2x16 LCD or a 4x20 LCD. The additional board is connected to a development system via a 2x5 femal conector provided on the flat cable, whereas a 1x16 male connector provided on the additional board enables connected with an LCD display. In additional to this connector there is also poteniometer used for the display backlight regulation provided on the board [58].

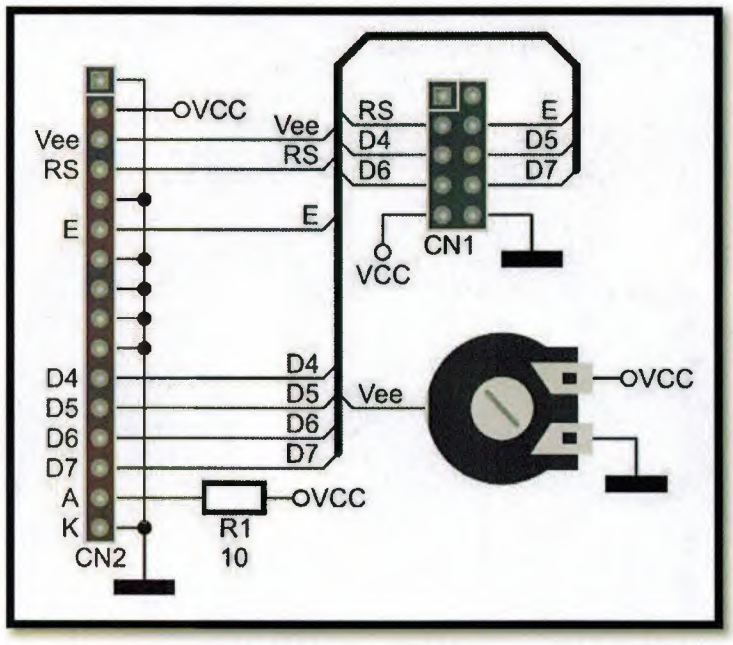


Fig. 3.34: LCD Adapter Additional Board Connection Schematic [58].

3.13 Audio Alarm System

The audio system is used to alert the nurse when a problem arises with the device, such as drops stop, air bubble in tube, door open or blockages in the catheter.These signals are also sent from the microcontroller to the speaker via an audio amplifier.

3.14IV Infusion Pump Sets

There was no need to use special infusion sets, as all brands of infusion sets which comply with the standard of GB8368-2005 can used in the design as shown in Figure 3.35.

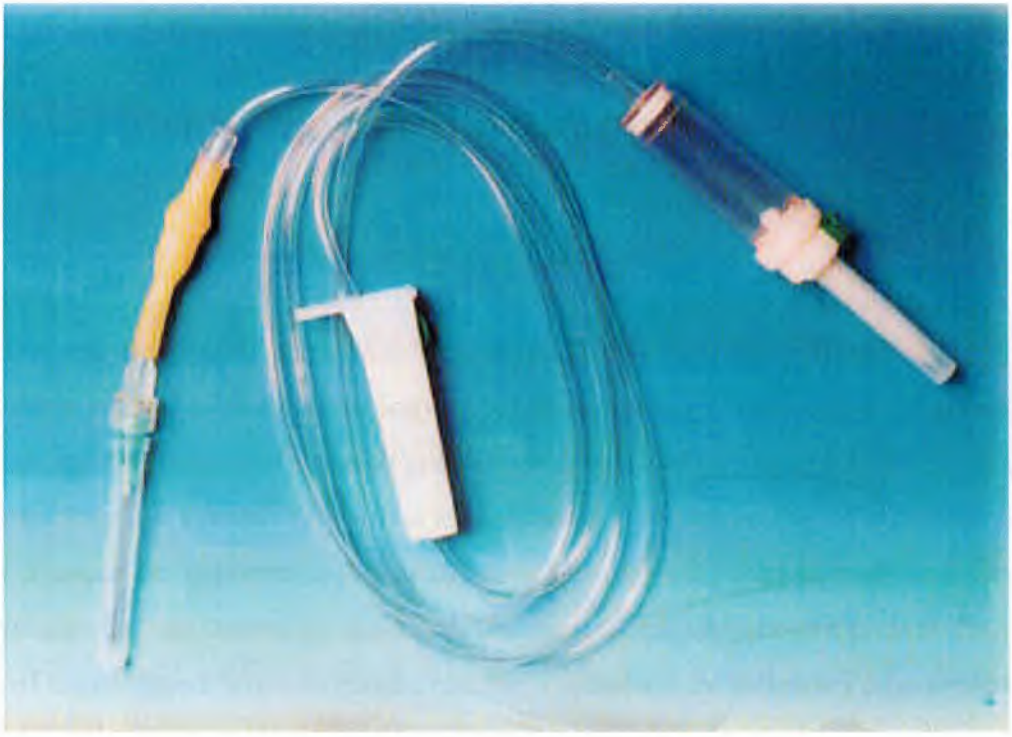


Fig. 3.35: IV Infusion Pump Set.

3.15Summary

This chapter has described the IV infusion pump designed by the author. The complete circuit diagram of various parts of the system have been described in great detail. Precise movement of the peristaltic pump was achieved by using a stepper motor, controlled from a PIC16f887 microcontroller. The Bluetooth interface provided remote monitoring capability to the system.

CHAPTER 4

THE OPERATION OF THE DESIGNED WIRELESS PROGRAMMABLE VOLUMETRIC IV INFUSION PUMP DESIGNED SYSTEM

4.1 Overview

The Wireless Monitoring Programmable Volumetric IV Infusion Pump Systemis a combination of microelectronic technology and modern nursing.It can control the speed, volume and general quantity of infusion precisely and continuously over long hours on a large scale, which completely meets the various requirements of modern clinic of treatment on different occasions.An important outcome of wireless monitoring applied to clinical nursing. One microcontroller can control all actions of the device. This chapter will present the operation of the designed Wireless Programmable Volumetric IV Infusion Pump System.

4.2 Clinical Application Scope

The Wireless Programmable Volumetric IV Infusion Pump Designed System as shown in Figure 5.1,it's not applicable for blood transfusion.Used in clinics, wards and nursing where patients need intravenous infusion at steady speed or continuous & precise infusion, such as ICU, CCU, pediatrics, gynecology and obstetrics, internal medicine, surgery, operating room, first aid room and quarantine department.

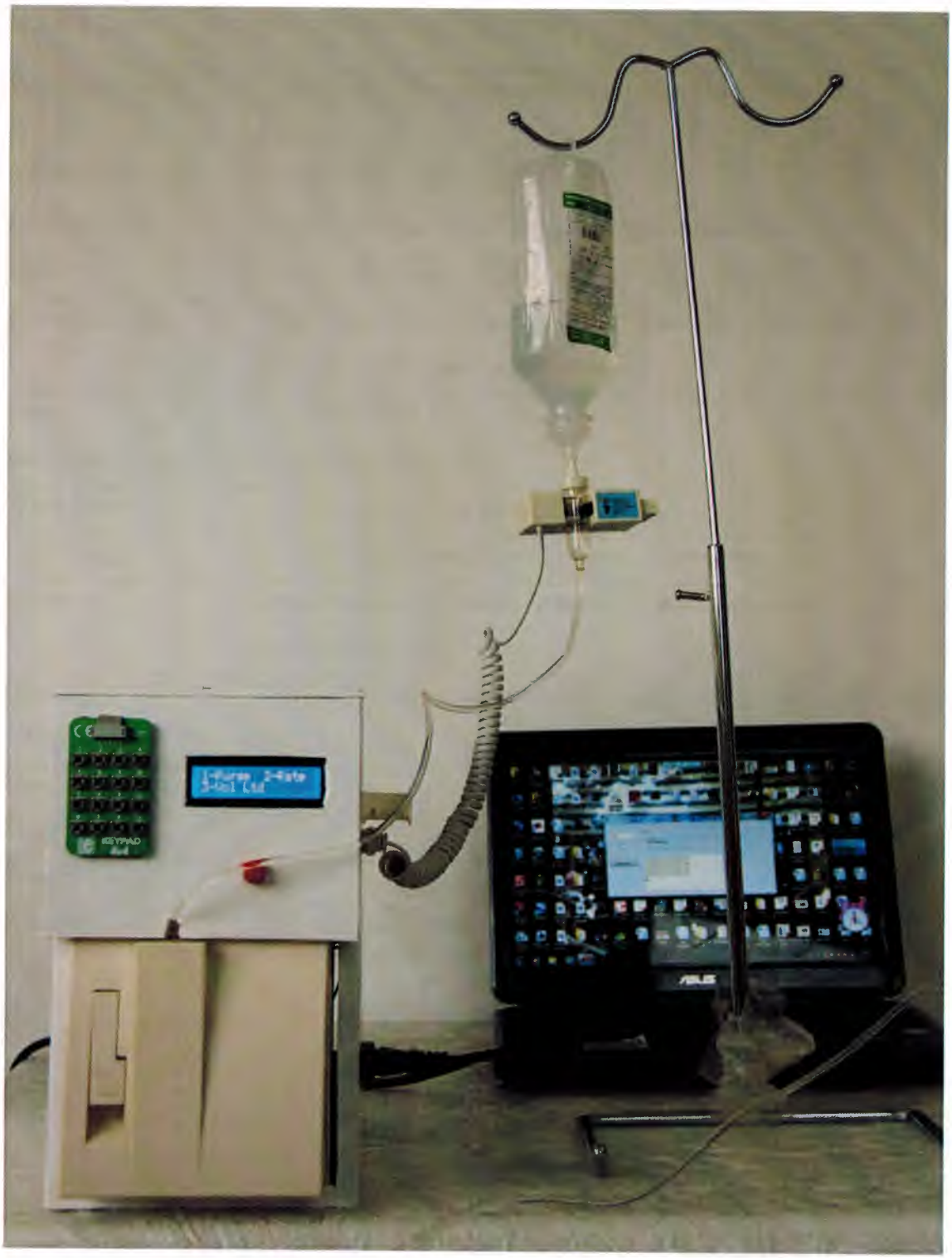


Fig. 4.1: The DesignedWireless Programmable Volumetric IV Infusion Pump System.

4.3 Technical Specification

Product Model	**The wireless Programmable Volumetric IV Infusion Pump.**
AC Power Supply	AC 85-264V, 50/60 Hz.
Battery Type	DC12V, 1800mA/h NI-MH rechargeable battery.
Battery	Can use for more than 3 hours after fully recharge.
Battery Recharge	When connect to AC power, it automatically rechargeand it takes about 15 hours to fully recharge.
Fuse	F 0.8A H/250V
Pump Mechanism	Peristaltic Mechanism.
Work Mode	Continuous working mode.
Rate Range	Preset flow rate range: 5-250 d/min, 20 drop/ml
Alarm	Drop detector, air bubble in the pipe, occlusion detector, door open detector.
Applicable infusion set	All standard infusion set.
Max. size of the Shell	26 cm x 16 cm x 30 cm (Length× Width× Depth)
Weight	2.5 Kg
Bluetooth	SPP, distance 100 m

4.4 Front View

The front view of the designed infusion pump system is shown in Figure 4.2.

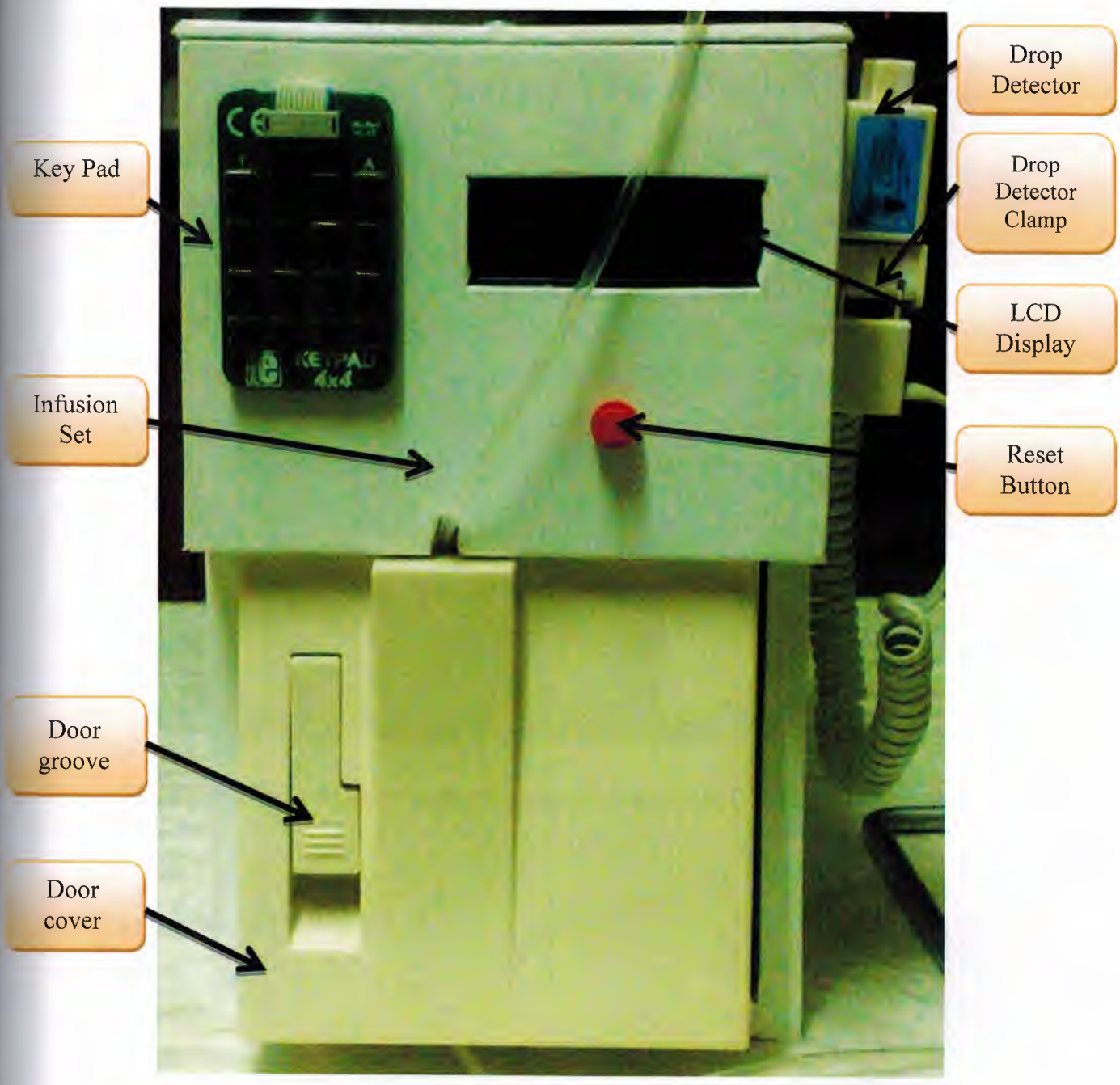


Fig.4.2: Front View of the Wireless Programmable Volumetric IV Infusion Pump System.

4.5 Side View

The side view of the designed infusion pump system is shown in Figure 4.3.

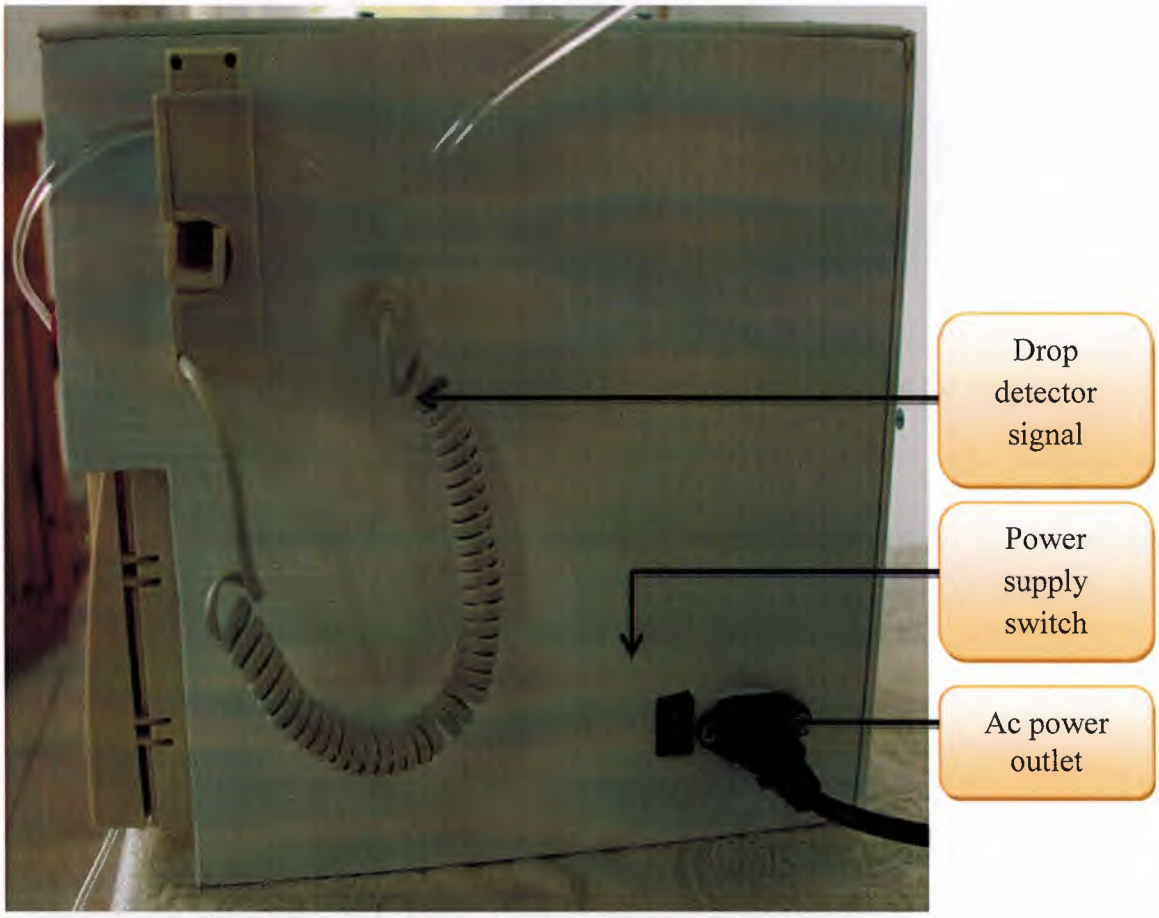


Fig.4.3:Side View of the Wireless Programmable Volumetric IV Infusion Pump System.

4.6 Explanation of the Operation

First Step: Connect to the Power

Connect the power cord into the outlet of the infusion pump and turn on the power supply switch (Turn from "o" to "I",the pump LCD will display the interfaceas Figure 4.4 shown, andthe pump's battery automatically recharging. Applicable power supply is AC 85V-264V, 50/60Hz. The LCD will display the interface as shown in Figure 4.5.

Fig. 4.4:Connect the power cord into the outlet of the infusion pump and turn on the power supply switch.

Fig.4.5: LCD Interface Display.

Second Step: Install IV set

1. Close the flux adjustment valve of the infusion set, and connect it to the infusion bottle or bag, and leave the liquid level in the half of the chamber of the IV set.
2. Open the handle of the door, turn the free-flow protection right as Figure 4.6 shows, and put the IV pipe into the groove straight as Figure4.7 shows.

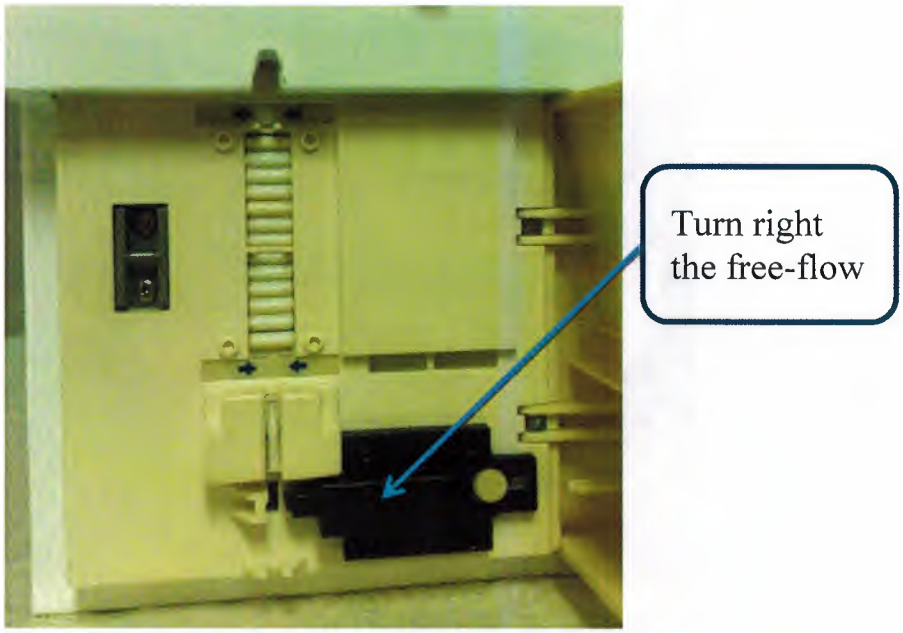


Fig.4.6: Turn the free-flow protection.

Fig.4.7: Put the IV pipe into the groove.

3. Close the door.

Caution: Please keep the IV pipe in the groove when close the door.

4. Put the chamber of the IV pipe into the drop detector as Figure 4.8 shows.

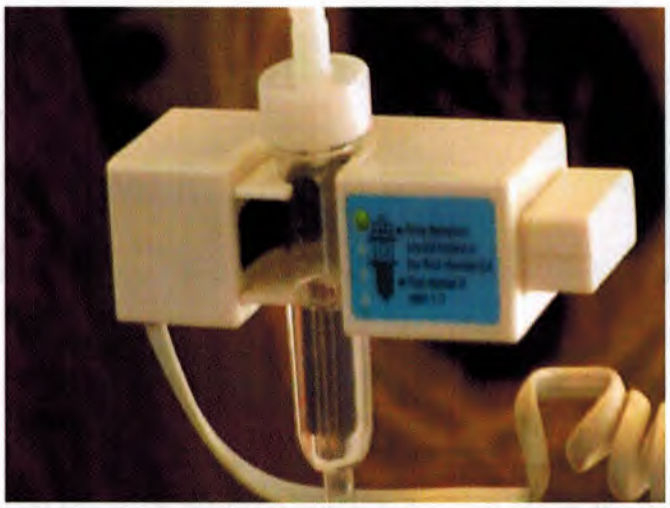


Fig.4.8: The chamber of the IV pipe into the drop detector.

Caution: must turn the drop detector left and then put the chamber of the IV pipe into it.

Caution: Put the drop detector on the three quarters of the chamber.

Caution: ensure the liquid level in the chamber doesn't cover the clamp of infrared sensor. This detector can't work in the environment which the sun can directly shine.

Third Step: Setting of IV Parameter

1. **Set the wireless connection between the infusion pump and the nurse station.**

As shown in the Figure 4.9, the nurse must choose the communication port of the IV infusion pump where the nurse station monitor will connected wirelessly with the IV infusion pump by using the Bluetooth technology and then choose the connect option to complete the connection .

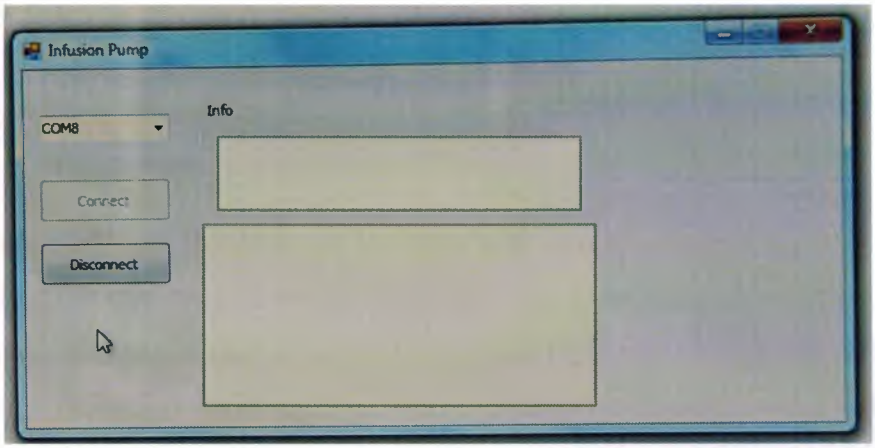


Fig.4.9: Nurse Station Monitor.

2. Purge Function

This function very important in the IV infusion pump because it clears the infusion set from the air bubble inside the tube by fast rate infusing until the nurse sure that no air bubble in the tube and the tube full by the fluid the nurse must press the (1) to start the purging and to stop this function press (#) key as shown in Figure 4.10.

Fig.4.10: LCD Message of the Purge Function.

After the (#) key pressing the LCD display will back to the main menu. During the purging action the air bubble detector is inoperative.

3. Dose Rate Function

This function is used to set the dose rate in (Drop/min) which is determined by the nurse or the doctor. The flow rate ranges from 5to250 d/min. The nurse must choose the (2) key and then enter the determined number of drops as shown in Figure 4.11 , and then press (#) key to back to the main menu. In case of an error happen through the dose rate value writing the (*) key will canceled the entered number.

Fig.4.11: LCD Message of the Dose Rate Function

4. Dose Volume Function

This function is used to set the dose volume in(ml), which is determined by the nurse or the doctor. The nurse The nurse must choose the (3) key and then enter the determined number of ml value as shown in Figure 4.12, and then press (#) key to back to the main menu. The limited volume must start from 1ml. In case of an error happen through the ml value writing the (*) key will canceled the entered number.

Fig.4.12: LCD Message of the Dose Volume Function.

5. Start The Infusing

After setting the dose rate and the dose volume, to start the infusion process the nurse must press the (a) key as shown in Figure 4.13, then there are two option will display (*) to start the infusion and (#) to canceled and back to the main menu. When start the infusion the LCD message as shown in Figure 4.14. When the infusion start the nurse station monitor will display message as shown in Figure 4.15.

Fig.4.13: LCD message of the start drug infusion option.

Fig.4.14: LCD message when drug infusion start.

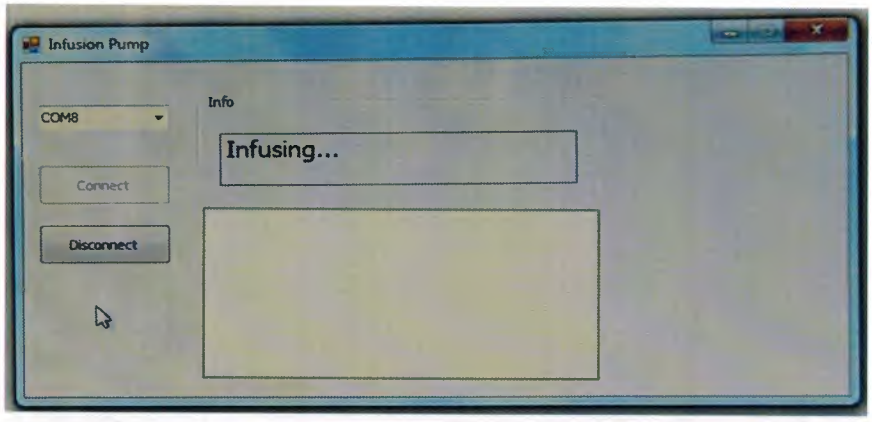


Fig.4.15: Nurse station monitor display message.

Fourth Step: IV Infusion Pump Alarm

Drop Detector Alarm

The drop detector alarm detects if there is a problem in the drop rate flow and it tends an error signal to the MCU to inform this error condition. The MCU will then immediately stop the pump motor and send a signal to the audible alarm and send a message to the LCD display of the device as shown in Figure 4.16, and to the nurse station monitor to inform the nurse that there is an error. The error message is sent with date and time stamping, and in addition an audible alarm is output from the device asshown in Figure 4.17.

Fig.4.16: Drop detector LCD message.

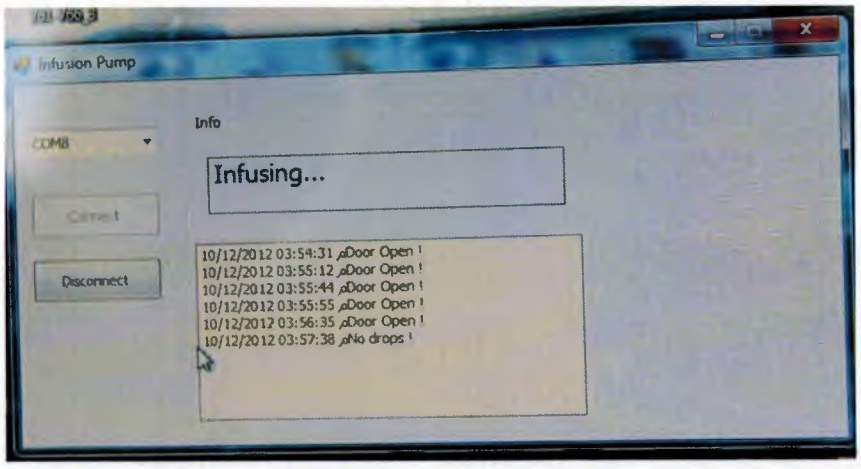


Fig.4.17: Nurse station monitor display message in case of no drop detector.

To stop the audible alarm the nurse must press (c) key and the LCD display will back to the main menu. In this case the nurse must firstly disconnected the IV set from the patient because the Probability of air bubble presence and then solve the abnormal situation and repeat 2,3,4,5 of the third step.

Air Bubble Detector

This detector is sensitive to the air bubble inside the tube of the system.The sensitivity of the air sensor is 100% the minimum single airbubble is 0.05ml. The air bubble presence caused by the leak in the tube's wall through a punch. When the sensor sense the air bubble the detector will send a signal to the MCU that there is abnormal situation and the MCU will

immediately stop the pump motor and send a signal to the audible alarm and send a message to the LCD display of the device as shown in Figure 4.18, and to the nurse station monitor inform the nurse that there is an error with the time and date of the error message with audible alarm as shown in Figure 4.19.

Fig.4.18: Air bubble detector LCD message.

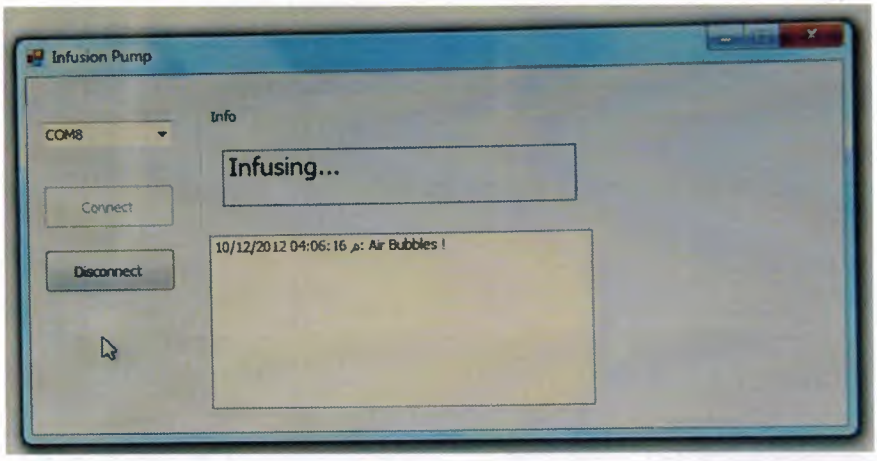


Fig.4.19: Nurse station monitor display message in case of air bubble detector.

To stop the audible alarm the nurse must press (reset) button and the LCD display will back to the main menu. In this case the nurse must firstly disconnected the IV set from the patient because the air bubble presence inside the IV set tube and then solve the abnormal situation and repeat 2,3,4,5 of the third step.

Door Detector

This detector is sensitive to opening the door of the device after starting the infusion or through the infusion of the fluid. When the door was open the detector will send a signal to the MCU that there is abnormal situation and the MCU will immediately stop the pump motor and send a signal to the audible alarm and send a message to the LCD display of the device as shown in Figure 4.20, and to the nurse station monitor to inform the nurse that there is an error. As previously, the error message is sent with date and time stamping,and in addition an audible alarm is output from the device asshown in Figure 4.21.

Fig.4.20: Door open detector LCD message.

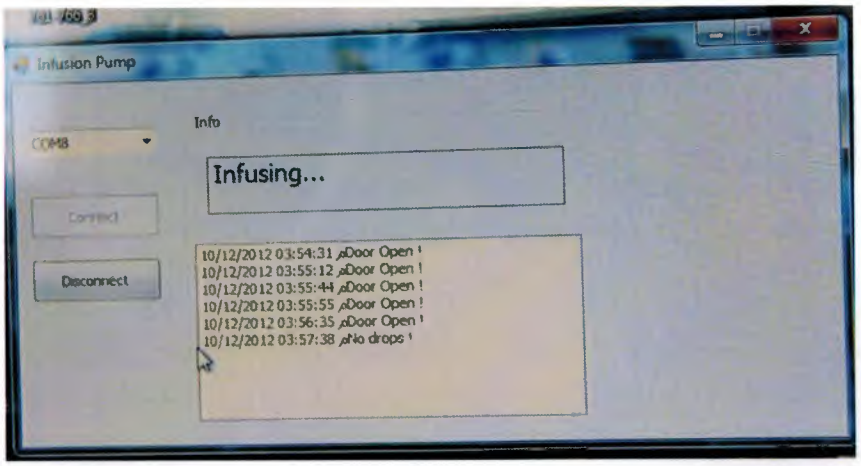


Fig.4.21: Nurse station monitor display message in case of door open detector.

To stop the audible alarm the nurse must just close the door and the LCD display will back to the main menu. In this case the nurse must repeat just 3, 4, 5of the third step.

Fifth Step: Cleaning and Sterilizing

1. Turn off the pump and disconnect it with AC power supply beforemopping it.
2. Clean the pump and drop detector with damp rag. Open thedoor to clean, and avoid the pump getting wet.
3. Do not use something like xylene, acetone or something analogous, these chemicals will cause damage to the plastic module.
4. Use the cotton moistened with 75% alcohol to sterilize the pump.

4.7 Programmable Feature

The "Ready for PIC" boardcomes with PIC16F887 microcontroller which is preprogrammed with an UART boot loader firmware and thus eliminates the need of an external programmer. The on-board USB-UART module allows the serial data transfer between the PIC and a PC using an USB cable.Therefore, additional feature can very easily be added to the system, the program can easily modified through the USB-UART of the PIC development board.

CHAPTER 5

RESULTS, CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 Results

Many nurses and health officials are expected to deliver IV drugs regularly. The pharmacy staff at hospitals usually prepare the drug solutions and may also suggest suitable infusion pump rates for the patients. Although experienced nurses can calculate and adjust the drip rates manually, in practise it is difficult to adjust the drip rate correctly and accurately when classical manual roller clamp type infusion systems are used.

Nurses and health officials learn long and tedious equations in their training for calculating the drip rates for a given patient. The problem is that because the drug delivery system is manual it is difficult to set the required delivery rates accurately. This process may take considerable time of the nursing staff as it is usually based on a trial and error method.

The drug delivery system designed by the author can deliver drugs in the form of liquids in the range of 5 to 250 drops/min. The volume of the delivered drug can be set around 20 drops/ml.

The accuracy of the drug delivery was tested by setting the drops/min to 10, 50, 100, and 200 and then counting the number of drops delivered in an interval of 1 minute. The accuracy was found to be better than 10% in all cases, where the number of drops counted in a minute were 10, 47, 95, and 191 respectively. Similarly, the drops/ml was set to 20 drops/ml and the volume of 100 drops was measured to be accurate to about 4.8 ml, giving an accuracy to better than 5%. The operation of the air bubble detector was measured by allowing small amount of air inside the system and it was noticed that the bubble detector alarm was triggered to indicate the presence of air inside the system. The door detector mechanism was tested simply by opening the door while the infusion was in progress. As soon as the door was

opened it was noticed that an audible alarm was generated by the system. Also, a message was sent to the nurse's computer to warn that the door has been opened.

The drug delivery accuracy of standard classical roller clamp manual infusion systems is reported to be around ±25% [64] which is much less than the accuracy of the automatic system designed by the author. Classical drug delivery systems require vigilant observations at frequent intervals to verify the accuracy of the drug delivery rate [64]. The system designed by the author on the other hand is automatic and does not require any observation after it has been setup correctly.

The system provides several safety mechanisms with audible alarms. Such safety features are not existent in conventional IV drug delivery systems. For example, if the drug delivery stops for whatever reason while using the conventional manual systems, the nurse is not aware of this important situation and as a result the patient will not receive the drug. The system developed by the author on the other hand provides audible alarm as well as sends a message instantly to the computer of the nurse in charge using the Bluetooth communications equipment so that the problem can be rectified as soon as possible.

The designed drug delivery system has been tested successfully at the Mosul District Hospital in Iraq on real patients. The detail of these tests and results are given in Appendix A.

5.2 Conclusions

The designed microcontroller based automatic and intelligent drug delivery system has been implemented successfully using a standard microcontroller development system and standard off the shelf electronic parts. The cost of the overall system is very low. Because the system is programmable, its functions can be extended by modifying the program as required. Tests carried out at the Mosul District Hospital with real patients receiving IV drugs have indicated great success as drugs were delivered to patients with high accuracy. The system has been accepted at the Mosul District Hospital to be used at bed sides to replace the existing classical manual mechanical roller clamp based systems.

The designed system has the great advantage that the state of the drug delivery can easily be monitored remotely by the nursing staff using their computers, away from patients' bed sides. For example, the classical manual drug delivery systems do not give any kind of warning if the drug delivery stops for whatever reason. In addition to delivering drugs with great accuracy, the system also offers safety features not found on classical manual drug delivery systems.

5.3 Future Improvement

Although the designed system is working satisfactorily, there are interesting points that can be implemented in the future, among them are:

- Various biosensors, such as glucose sensor, can easily be added to the system to enhance its features and make the system close loop system.

- The system can be programmed for special diseases. For example, the specific protocols for chemotheraphy drugs are determined according to patient body data such as the age and the weight of the patient. The protocol of the drugs with their names can be entered and then the system can automatically deliver the required amount of drug to the patient. This would be very important addition to the system, in order to reduce the human error.

- The nurses' computer is currently used to monitor the state of the drug delivery system where various fault conditions are sent to the computer using the Bluetooth technology. The system can be improved by the addition of control features such that the operation of the system can be controlled remotely from nurses' computers. For example, the drug delivery parameters, such as the drops/min could be set remotely from nurses' computer. With the addition of this remote control feature the system hardware will be simplified considerably as there will not be need to use a keypad or an LCD.

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APPENDIX A

The designed drug delivery system has been tested at the Mosul Health District Hospital in Iraq on real patient by using the normal saline (0.9 Sodium Chloride) as artificial situation at various doses according to the designed drug delivery system specification. The manager of the Nursing Department, Mr. A.H. Salih [60], has reported the success and the acceptance of the device for use in the hospital as it offered many advantages compared to the existing traditional drug delivery system. The fact that the system offers remote monitoring has been reported to be most important feature of the designed system. Nurses could monitor the states of the drug delivery system from their places of work, without having to go to the bed sides of patient.

The safety features and alarm reporting feature have also been like by the hospital staff as they could get on with other duties and not go frequently to check the state of the drug delivery system. The General Directorate of the Mosul Health District Dr. M.F. Kashmoola [61], expressed wish and recommended that commercial versions of the designed system should be developed for use in government hospital throughout Iraq.

The designed drug delivery system has been tested at the Oncology and Nuclear Medicine Hospital on real patient by using the normal saline (0.9 Sodium Chloride) as artificial situation at various doses according to the designed drug delivery system specification. Dr. K.M. Ali [62], the Head of Oncology and Nuclear Medicine Hospital, at the Mosul Health District in Iraq, said that the device provide protection of the nursing staff in case of chemotherapy which delivered by using the IV infusion pump during long time to the cancer patient, where compared with the traditional IV infusion pump the designed wireless programmable volumetric IV infusion pump system will reduce the contact of the nursing and medical staff with the patient through the wireless remote monitoring of the drug delivery state in the nurse station.

APPENDIX B

SOURCE CODE

1. Source Code In micro C " The Program of PIC16f887"

```
// LCD module connections
sbit LCD_RS at RD2_bit;
sbit LCD_EN at RD3_bit;
sbit LCD_D4 at RD4_bit;
sbit LCD_D5 at RD5_bit;
sbit LCD_D6 at RD6_bit;
sbit LCD_D7 at RD7_bit;

sbitLCD_RS_Direction at TRISD2_bit;
sbitLCD_EN_Direction at TRISD3_bit;
sbit LCD_D4_Direction at TRISD4_bit;
sbit LCD_D5_Direction at TRISD5_bit;
sbit LCD_D6_Direction at TRISD6_bit;
sbit LCD_D7_Direction at TRISD7_bit;
// End LCD module connections
char yesno[]="(*)Yes,(#)No";
unsigned short key;
unsignedint steps;
unsigned short drops;
unsignedint volume;
unsigned short droprate;
// Keypad module connections
```

```
char  keypadPort at PORTB;
// End Keypad module connections
sbit mot at RA5_bit;
sbitmot_io at TRISA5_bit;

sbitmotEn at RA3_bit;
sbitmotEn_io at TRISA3_bit;

sbit door at RC0_bit;
sbitdoor_io at TRISC0_bit;

sbit bubble at RA0_bit;
sbitbubble_io at TRISA0_bit;

sbitdrpdetct at RA1_bit;
sbitdrpdetct_io at TRISA1_bit;

voidToneA() {
Sound_Play( 880, 50);
}
voidToneC() {
Sound_Play(1046, 50);
}
voidToneE() {
Sound_Play(1318, 50);
}
```

```
unsigned short keypad()
{
unsigned short kp;                    // Reset key code variable
kp=0;
  // Wait for key to be pressed and released
kp = Keypad_Key_Click();          // Store key code in kp variable
  // Prepare value for output, transform key to it's ASCII value
switch (kp) {

case  0: kp=255; break;//Null
case  1:  break; // 1       // Uncomment this block for keypad4x4
case  2:  break; // 2
case  3:  break; // 3
case  4: kp = 12; break; // A
case  5: kp = 4; break; // 4
case  6: kp = 5; break; // 5
case  7: kp = 6; break; // 6
case  8: kp = 13; break; // B
case  9: kp = 7; break; // 7
case 10: kp = 8; break; // 8
case 11: kp = 9; break; // 9
case 12: kp = 14; break; // C
case 13: kp = 10; break; // *
case 14: kp = 0; break; // 0
case 15: kp = 11; break; // #
case 16: kp = 15; break; // D
```

```
    }
return(kp);
   }
//////////Calibration Code {It is active just in case of calibrate the device}
/*void run_ml(unsigned intstep,unsigned short drop) //// This function is calibrate the step of the motor and the drops to get 1 ml
{
inti,y;
for (y=0;y<drop;y++)
{ motEn=1;
for (i=0;i<step;i++)
        {
mot=1;
delay_us(100);
mot=0;
delay_us(100);
        }
motEn=0;
delay_ms(1000);
    }
} */
/*void calibrate() ////// This function is set the parameter of the device 'motor step' and save it in the EEPROM
{
unsigned short drop;
unsignedintstep,x=1,i;
short count;
```

```
s:step=0;
count=0;
Lcd_Cmd(_LCD_CLEAR);              // Clear display
Lcd_Out(1,1,"step/drop ?");
Lcd_Cmd(_LCD_SECOND_ROW);
Lcd_Cmd(_LCD_UNDERLINE_ON);
do{
key=keypad();
if (key<10 && count<5)
if (step>0 || key>0)
        {
        x=1;
for (i=0;i<count;i++) x=x*10;
step=step*x+key;
count++;
Lcd_Chr_Cp(key+48);
        }
if (key==10)
if (count==0)
return ;
else
goto s

   }
while(key != 11);
```

```
d:   drop=0;
count=0;
Lcd_Cmd(_LCD_CLEAR);              // Clear display
Lcd_Out(1,1,"drop/ml ?");
Lcd_Cmd(_LCD_SECOND_ROW);
Lcd_Cmd(_LCD_UNDERLINE_ON);
do{
key=keypad();
if (key<10 && count<2)
if (drop>0 || key>0)
        {
        x=1;
for (i=0;i<count;i++) x=x*10;
drop=drop*x+key;
count++;
Lcd_Chr_Cp(key+48);
        }
if (key==10)
if (count==0)
return ;
else
goto d
   }
while(key != 11);
run_ml(step,drop);
Lcd_Cmd(_LCD_CLEAR);              // Clear display
```

```
Lcd_Cmd(_LCD_CURSOR_OFF);        // Cursor off
Lcd_Out(1,1,"Save ?");
Lcd_Out(2,1,yesno);
do{
key=keypad();
  }
while (key!=10 && key!=11);
if(key=10)
  {
if (step !=0)
  {
steps=step;
  step1=steps/255;
  step2=steps%255;
EEPROM_Write(1,step1);
EEPROM_Write(2,step2);
  }
if (drop !=0)
  {
drops=drop;
EEPROM_Write(3,drops);
  }
  }
} */
////////// End of calibration code
```

```
voiddoor_open() ////// This function is to set the door detector alarm and message
{     do
      {
ToneC();
//       dor=1;
Lcd_Cmd(_LCD_CLEAR);
Lcd_out(1,1,"Door Open!");
delay_ms(1000);
key=keypad();
      }
while (key!=14 && door );
Lcd_Cmd(_LCD_CLEAR);
}

voidair_bubble() ///////// This function is to set the air-bubble alarm and message
{
do{
ToneE();
 //bub=1;
Lcd_Cmd(_LCD_CLEAR);
Lcd_out(1,1,"Air Bubbles!");
delay_ms(1000);
key=keypad();
 }
```

```
while (key!=14);
}

voidnodetect()          //////// This function is to set the drop flow detector alarm and message
{
do
{
ToneC();
Lcd_Cmd(_LCD_CLEAR);
LCD_Out(1,1,"No drops!");
delay_ms(1000);
key=keypad();
}
while (key!=14);
}
void purge() ///// This function is set the purging action.

  {
int i;
motEn=1;
Lcd_Cmd(_LCD_CLEAR);
Lcd_Cmd(_LCD_CURSOR_OFF);
Lcd_Out(1,1,"Press # to stop");
do{
for(i=0;i<1000;i++)
    {
```

```
mot=1;
delay_us(100);
mot=0;
delay_us(100) ;
    }
key=keypad();
if (door)
   {
    UART1_write(0x00);
door_open();
    }
}
while(key!=11);
motEn=0;
  }

void run() /////// This function is set the operation of the system after start the drug infusion
{
unsignedint detector;
bit detect;
unsigned short drps ;
inti,y,z=0,d,digit;
unsigned short mxdrp;
unsignedint ml;
Lcd_Cmd(_LCD_CLEAR);
Lcd_Cmd(_LCD_CURSOR_OFF);
```

```
d=(250/droprate)*240;
mxdrp= droprate/5 + 3;
drps=0;
while(volume>z/drops)
{
for (y=0;y<droprate;y++)
{ motEn=1;
for (i=0;i<steps;i++)
        {
mot=1;
delay_us(100);
mot=0;
delay_us(100);
detector=ADC_Read(1);
if(detector<750) detect=1;
        }
        UART1_write(0x03);
LCD_Out(1,1,"Infusing...");
drps++;
motEn=0;
if (door)
    {
    UART1_write(0x00);
door_open();
    }
if (!bubble)
```

```
    {
    UART1_write(0x01);
air_bubble();
    }
Vdelay_ms(d);
if(!detect &&drps>mxdrp)
    {
     UART1_write(0x02);
nodetect();
    }
if(detect)
    {
drps=0;
detect=0;
    }
key=keypad();
if (key==13) return;
    }
    z=z+droprate;
ml=z/drops;
digit=ml;
Lcd_Cmd(_LCD_RETURN_HOME);
Lcd_Cmd(_LCD_SECOND_ROW);

void rate() ///////// This function is set the setting of the drug rate
{  unsigned short drate,count,x,i;
```

```
dr:  drate=0;
count=0;
Lcd_Cmd(_LCD_CLEAR);
Lcd_out(1,5,"Drop/min");
Lcd_Cmd(_LCD_FIRST_ROW);
Lcd_Cmd(_LCD_UNDERLINE_ON);
do{
key=keypad();
if (key<10 && count<3)
if (drate>0 || key>0)
        {
        x=1;
for (i=0;i<count;i++) x=x*10;
drate=drate*x+key;
count++;
Lcd_Chr_Cp(key+48);
        }
if (key==10)
if (count==0)
return ;
else
gotodr
   }
while(key != 11);
droprate=drate;
}
```

```
voidvol() //////// This function is set the setting of the drug volume
{
unsignedintvolum;
unsigned short count,x,i;
vl: volum=0;
count=0;
Lcd_Cmd(_LCD_CLEAR);
Lcd_out(1,6,"ml");
Lcd_Cmd(_LCD_FIRST_ROW);
Lcd_Cmd(_LCD_UNDERLINE_ON);
do{
key=keypad();
if (key<10 && count<4)
if (volum>0 || key>0)
      {
     x=1;
for (i=0;i<count;i++) x=x*10;
volum=volum*x+key;
count++;
Lcd_Chr_Cp(key+48);
      }
if (key==10)
if (count==0)
return ;
else
```

```
gotovl
   }
while(key != 11);
volume=volum;
}

void main() {
// Initialize Keypad
ANSEL  = 0x42;                    // Put RA1 and RE1 as analog
 ANSELH = 0;
Keypad_Init();
 UART1_init(115200);          // Initialize UART1 module
delay_ms(100);
//parameterinit.
volume=0;
droprate=0;
steps=1100;
drops=20;

 ///// i/o settings
mot_io = 0;
mot=0;
motEn_io=0;
motEn=0;
door_io=1;
bubble_io=1;
```

```
drpdetct_io=1;
 ////////end i/o settings
/*step1=EEPROM_Read(1);
 step2=EEPROM_Read(2);
steps=step1*255+step2;
drops=EEPROM_Read(3);*/
Sound_Init(&PortE,2);
ToneA();ToneA();
do
{
Lcd_Init();                    // Initialize LCD
Lcd_Cmd(_LCD_CLEAR);
Lcd_Cmd(_LCD_CURSOR_OFF);

do {

if (door)
  {
 UART1_write(0x00);
door_open();
  }
Lcd_Out(1,10,"2-Rate");
Lcd_Out(2,1,"3-Vol Ltd");
key=keypad();

 } while (key == 255);
```

```
switch (key)  {
case 1:purge();break;
case 2:rate();break;
case 3:vol();break;
case 12:
while (droprate==0) rate();
while (volume == 0)vol();
Lcd_Cmd(_LCD_CLEAR);
Lcd_Cmd(_LCD_CURSOR_OFF);
Lcd_Out(1,1,"Infuse?");
Lcd_Out(2,1,yesno);
do{
key=keypad();
        }
while (key!=10 && key!=11);
if(key==10) run();
break;
  }
}
    }
while(1);
}
```

2. Source Code in VisualBasic " The Program Of the RN41-1Bluetooth Click Board"

```
using System;
usingSystem.Collections.Generic;
usingSystem.ComponentModel;
usingSystem.Data;
usingSystem.Drawing;
usingSystem.Text;
usingSystem.Windows.Forms;
usingSystem.IO.Ports;
usingSystem.Media;

namespaceInfusion_Pump
{

public partial class frmmain : Form
   {
publicfrmmain()
      {
InitializeComponent();
      }

private void frmmain_Load(object sender, EventArgs e)
      {
string[] strports = SerialPort.GetPortNames(); // to get the serial ports in the device
foreach (string s instrports) // adding the serial ports to the combobox
```

```
        {
this.cbxCom.Items.Add(s);
        }
    }
private void btnconnect_Click(object sender, EventArgs e)
    {
        serialPort1.BaudRate = 115200;
        serialPort1.PortName = cbxCom.Text;
try
        {
serialPort1.Open();

tmrmain.Enabled = true;
btnconnect.Enabled = false;
btndisconn.Enabled = true;


        }
catch (Exception error)
        {
MessageBox.Show("No Device");
        }
    }

private void tmrmain_Tick(object sender, EventArgs e)
    {
byte[] rec = new byte[1];
```

```
if (serialPort1.BytesToRead > 0)
        {
serialPort1.Read(rec, 0, 1);
switch (rec[0])
            {
case 0: lsblog.Items.Add(Convert.ToString(DateTime.Now)+": Door Open !");
SystemSounds.Exclamation.Play();
break;
case 1: lsblog.Items.Add(Convert.ToString(DateTime.Now) + ": Air Bubbles !");
SystemSounds.Exclamation.Play();
break;
case 2: lsblog.Items.Add(Convert.ToString(DateTime.Now) + ": No drops !");
SystemSounds.Exclamation.Play();
break;
case 3: Lblstatus.Text = "Infusing..."; break;
            }
        }
    }

private void btndisconn_Click(object sender, EventArgs e)
    {
try
        {
tmrmain.Enabled = false;
serialPort1.Close();
btnconnect.Enabled = true;
```

```
btndisconn.Enabled = false;
            }
catch (Exception ex)
            {
MessageBox.Show("error");
            }
        }
    }
}
```