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Automated Peritoneal Dialysis: A Cost Effective Solution

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Abstract: ***Cost is an influential constraint when treatment of kidney disease is considered. Automated Peritoneal dialysis (APD) is a very flexible and healthy method to perform dialysis as compared to other traditional methods like Hemodialysis. Even though, the APD is broadly being used by the end stage renal disease (ESRD) patients to enhance their lifestyle, the cost factor remains as a major disadvantage. To overcome this drawback, a cost effective system is designed for automated peritoneal dialysis (APD) for artificial filtration function of the kidney. Thus the paper is aimed to introduce an APD system which is cost effective and includes all the advantages of the existing systems which can be opted by a larger society to enhance their lifestyle for better living.***

Keywords: Automated Peritoneal Dialysis; Hemodialysis; End Stage Renal Disease (ESRD); Kidney; Cost

1. Introduction

Automated Peritoneal Dialysis (APD) is one of the most evolving techniques as life saving therapeutic options for people suffering from acute kidney diseases. Emerging technologies must forbid the gap between previous and current work; which is the disadvantages must overcome in order to improve the technique for better use. Automated Peritoneal Dialysis (APD) is a process which uses the semipermeable membrane 'peritoneum', lining the abdominal cavity in human body to perform the alternative function of kidney during acute kidney failure. This process includes steps such as- (a) infusion of the dialysate in the cavity, (b) let the solution be present in the cavity for a time span; diffuse the waste from the fresh dialysate in the cavity. (c) drainage of the waste from the body. Apart from the traditional dialysis methods such as hemodialysis and peritoneal dialysis (continuous ambulatory peritoneal dialysis (CAPD), continuous cyclic peritoneal dialysis (CCPD)), Automated Peritoneal Dialysis (APD) provides various controlling, monitoring and regulating techniques in an efficient manner.

The currently available APD systems in market provide all the above techniques (i.e. controlling, monitoring, regulation), but at the cost of expense. The available system are extremely expensive plus the everyday cost of dialysate adds up to the total expense. Also, there are few manufacturers like BAXTER Solutions, MAXIM, etc. but these systems are highly expensive for common man to put in so much of money. Therefore, end stage renal disease (ESRD) patients chose hemodialysis (HD) for their kidney treatment, irrespective of the time, flexibility and many other factors which affect day-to-day life. Because for hemodialysis, patients need to visit dialysis centers three to four times a week. Whereas Automated Peritoneal Dialysis (APD) systems provide that flexibility to patients in order to continue with their daily activities; dialysis using APD is performed each night as the patient sleeps and is finished in the morning. The patient is free to do the day jobs in a much healthy manner.
The APD system discussed in this paper is a proposed model which takes into consideration all the advantages of the existing APD systems in the market. In addition to the advantages, the system is designed keeping in mind the major disadvantage of cost. The system fulfils other constraints such as time, user friendliness, and accuracy, precision because heavy risk cannot be taken when it comes to human life.

2. Methodology

Automated peritoneal dialysis (APD) is a subtype of peritoneal dialysis which is broadly used option for home dialysis. It uses an automated system programmed ably to perform the artificial kidney function. The dialysate fluid is passed in the abdominal cavity and allowed to stay in the cavity for a small amount of time 'dwell time'. The waste is then diffused from the peritoneal cavity by the process of osmosis and diffusion. The entire exchange is carried out by a set of highly operational peripherals such as pump, valve, sensors to sense the parameters and all these peripherals controlled by peripheral interface controller (PIC).

A. Hardware Specifications

i. APD System Configuration

The proposed system of automated peritoneal dialysis (APD) is a Peripheral Interface Controlled system. After comparison of microcontrollers, Peripheral Interface Controller (PIC) was selected because the system is an application specific integrated circuit (ASIC) which highlights on the Automated peritoneal dialysis method specifically.

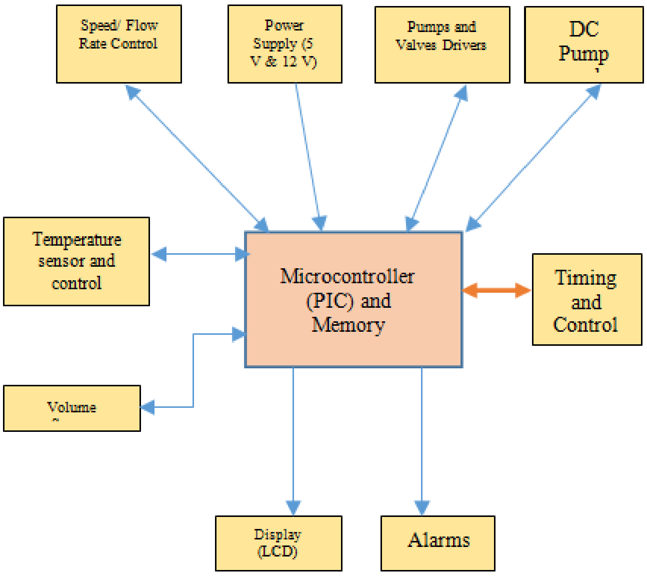

Figure 1: Block Diagram of the APD system

The block diagram consists of PIC which is the heart of the APD system with the peripherals for controlling, monitoring and regulation of the system. The peripherals are: temperature sensor, DC pump control, solenoid valve, DC pump and valve driver circuitry, LCD, volume sensor, power supply.

i. Temperature Sensor: LM35 is used to observe the changes in the temperature of the dialysate solution and send the physical entity to the ADC channel inbuilt in PIC and temperature is controlled with the help of PWM generation.
ii. DC Pump: A submersible DC pump is fitted on an assembly inside the container with dialysate fluid.
iii. Valve: Valve is responsible for the passage of the dialysate in the dialyzer when open. Valve in this system also functions as the flow regulator.
iv. Driver Circuits: Relay Driver circuit is used to drive the DC pump and the solenoid valve.
v. Volume sensor: Calibrated volume sensor is used at the o/p to measure the volume of the drained fluid. Two copper plates are used; a 5V DC is applied to one of the copper plates with a 100 ohms resistor connected to another copper plate and voltage across the resistor is observed.
vi. PIC: Peripheral interface controller (PIC) is embedded with a logical code to control all the above peripherals. Independent PWM generation is an important feature in PIC. Timing and temperature sensor o/p is controlled by the PWM duty cycle. Inbuilt ADC is also a specific feature in PIC; temperature sensor is connected to one of the analog channels of the PIC.

ii. APD Circuit Diagram

The proposed design of Automated Peritoneal Dialysis (APD) system is a PIC based circuitry. PIC is used in this circuit because of its enumerable features, out of which its inbuilt Analog-to-Digital Converter (ADC) channel is one of a kind. A physical quantity connected to any one of the ADC channels can give an accurate digital value of 10 bit resolution. In this proposed circuit, a temperature sensor LM35 is used to sense the temperature of the inlet solution and is connected to one of the analog channel pins.

Liquid Crystal Display (LCD) is used as a 4 bit display and is connected to a PIC port. The control bits of LCD i.e. EN, R/W, RS are also connected to port pins to transfer/receive the data and commands.

The process of pumping the solution in the cavity (artificial kidney in the system designed) is done by a submersible DC pump which is submerged in the solution. The relays and the solenoid valve are either ON/OFF as per the control signals on the port pins of the PIC where they are connected. The pump is ON when the solution is heated to exact 37o C and simultaneously the valve is ON (open).

Temperature control is done by another special feature of the PIC which is its PWM generation technique. PWM can be generated to control and monitor an entity by using the duty cycle and pre-scalar values in formulae and then into code format.

Oscillator and reset circuit is present at the respective pins of PIC.

An additional connection for external storage and data transfer is added in the circuit for future use MAX232 and a DB9 connector for serial communication. MAX232 can be used to transfer the records of the patient to a memory unit so that the doctor or a nurse can analyze the condition of the patient based on the results stored.

Power Supply: 4 different power supplies are designed in the circuit- (a) a regulated 5V power supply for PIC & LCD by using 7805 IC, (b) a regulated 12V for DC Pump from IC 7812, (c) an unregulated 12V for relay function, (d) 5V DC power supply for calibrated volume sensor to measure the volume of the waste drained from the artificial kidney, (e) 230V supply from the transformer to on/off the solenoid valve.

iii. Mechanical Assembly of APD model

Figure shows the mechanical assembly of the designed automated peritoneal dialysis (APD) model.

Figure 2: Mechanical arrangement of the APD system

The dialyzer is mounted on the frame in accordance with gravity. Peripherals are connected in specified parts of the assembly. Following sensors are attached to monitor and control the various patient parameters:

i. Level Sensor- check the level of the solution contained in the container and send control signal to the PIC for further control operations,
ii. Water Heater- Heats the solution and the temperature is controlled by the PIC PWM technique,
iii. LM35- temperature sensor IC LM35 is kept isolated from the solution in a small assembly,
iv. DC Pump- to pump the solution in the artificial kidney when it receives signal from PIC.
v. The solenoid valve is mounted on the frame. It is responsible to either allow or disallow the flow of solution in the artificial kidney.
vi. The output container is kept exactly below the artificial kidney. The output container is used to measure the volume of the drained solution in order to obtain results. A calibrated volume sensor is used which consists of two copper plates submerged in the drained waste solution container and a power supply of +5V DC is applied to the resistor connected to the copper plates.
vii. LCD is mounted in a slot given on the frame for an easy observation.

B. Algorithm and Flowchart

a) Algorithm

An algorithm and flowchart are very much essential in defining any process in an effective way. It expresses the instructions in a sequential manner or conditional manner as per the computations. Diagrammatic representation of an algorithm eases the understanding of the processes especially in ASIC designs as in the APD system.

PIC is a very user friendly Microcontroller when it comes to programming especially because of its special features such as an ADC channel of 10 bit resolution available on the port pins of Port A itself. The logical coding is done in mikro C which is a feature rich and powerful tool for PIC programming. PIC and C programming fits well; C programming is appreciated for its high-efficiency outputs.

i. The system when connected to a switch will trigger the power supply on the board which in turn will turn on the PIC. The PIC issues a pulse indicating that the machine is ON.
ii. The level and temperature of the dialysate is monitored and controlled by level and temperature sensors respectively.
iii. The dialysate (37o C) is then passed into the abdomen cavity when the valve and pump are turned ON.
iv. The fluid remains in the cavity for a certain amount of time called the 'dwell time': during the dwell time diffusion of waste takes place (as explained in the previous sections). This time fixed for a patient but it can vary for children, adults and senior citizens depending upon their capability of exchanges.
v. The volume of the drained solution is measured by the volume sensor, and if the target volume of 25% is not achieved, the dialysate is again passed into the dialyzer.
vi. When the target volume of 25% is achieved, the system indicated completion of one exchange.

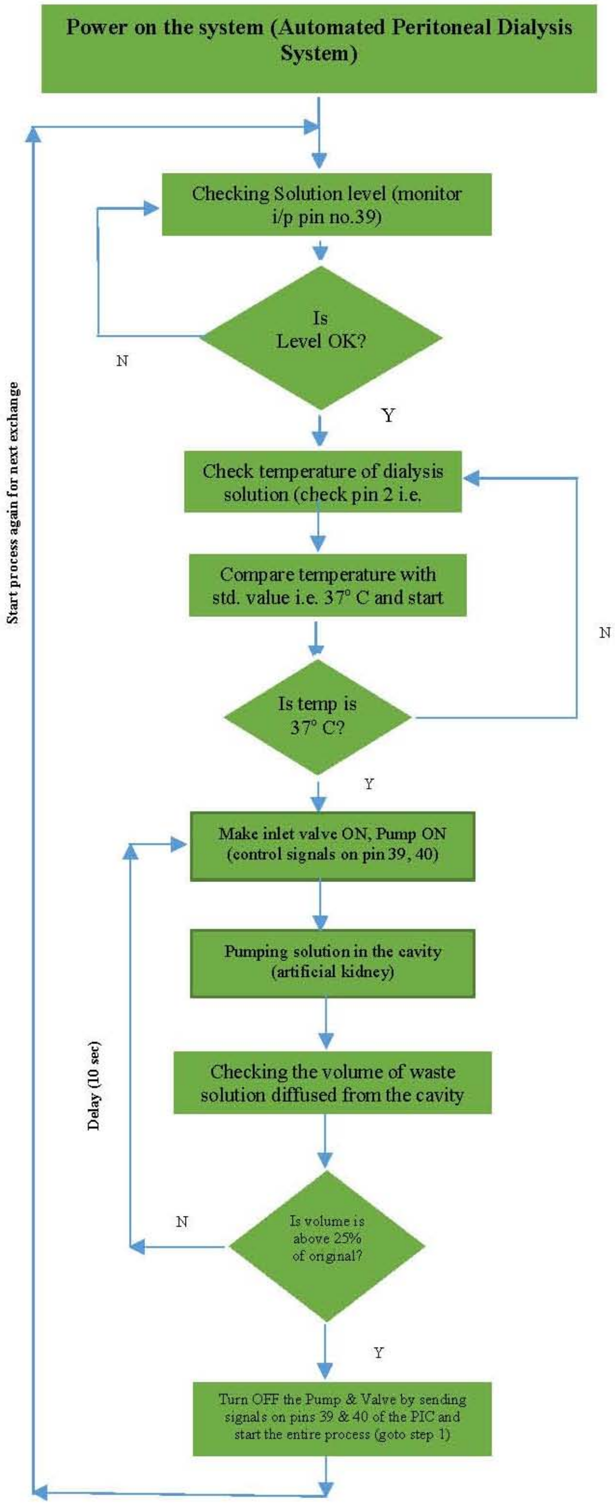

Figure 3: Flowchart of automated peritoneal dialysis (APD) system

b) Flowchart for Automated Peritoneal Dailysis System

The flow of logic written in mikroC is represented in the form of flowchart. A time span loop of 10 seconds is used for the dialysate fluid to pass in the dialyzer and then the volume sensor monitors the volume of the drained fluid.

3. Results and Conclusion

a) PWM Generation

An independent PWM generation is achieved in the system to control the temperature with the help of temperature sensor LM35. Five PWM levels were achieved for temperature changes of .2 i.e. 36.2, 36.4, 36.6, 36.8, 37.0. Duty cycle of 100%, 80%, 60%, 40%, 0% respectively were generated for the above temperature variations.
Pulse Width Modulation can generate signals with varying frequencies and duty cycle with respect to time. Generation of PWM takes following steps:

i. Calculate maximum frequency
F(PWM)= F(OSC)/16832 (1)
ii. Calculate period register 2 (PR2) register value
iii. Calculate duty cycle and load the values in CCPRXL, CCPXCON registers associated with PWM generation
iv. Write T2CON register to enable timer2

To decide duty cycle:

PWM duty cycle= (CCPR1L, DCB1B1, DCB1B0)* TOSC* TMR2 prescale value (2)

If PR2 =171 then the duty cycle required is 20%; therefore load CCPRXL =34

The 5th and the 4th bits of CCP1CON (DCB1B0, DCB1B1) are loaded with the LSBs of PWM duty cycle (i.e. 34 in this case). Thus the duty cycle values calculated for this specific system are 0%, 40%, 60%, 80%, 100% for 37oC, 36.8oC, 36.6oC, 36.4oC, 36.2oC and less respectively.

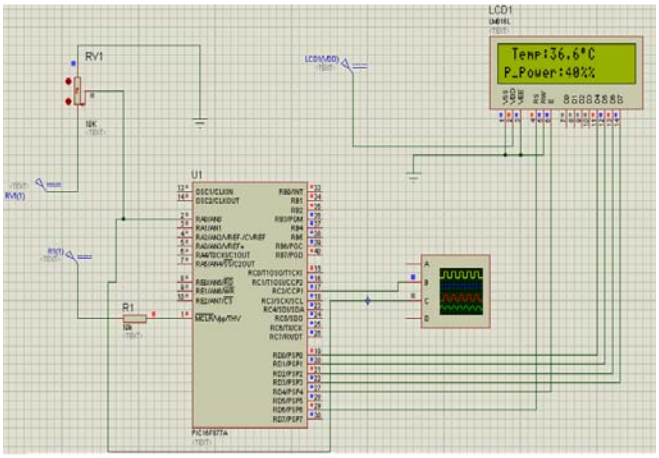

Figure 4.a: Temperature with respective PWM

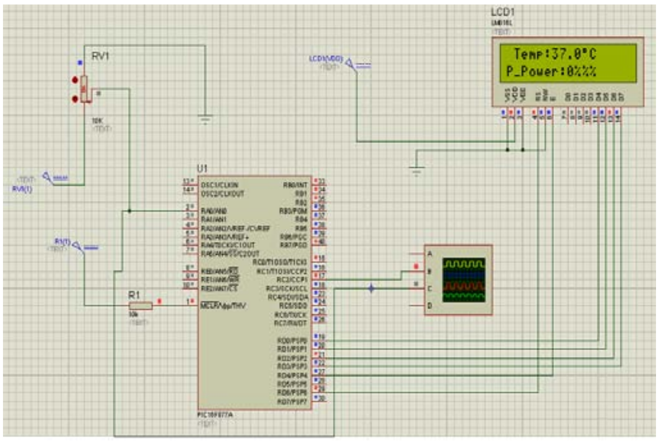

Figure 4.b: Temperature with respective PWM

Figures (a) shows the dialysate temperature of 36oC and the PWM generated for this temperature is 40% duty cycle which indicates the target temperature is not reached yet. Figure (b) shows the target temperature i.e. 37oC is reached; therefore the duty cycle is 0% indicating the temperature is achieved.

b) Working with patient

While working with patients, a catheter is inserted in the abdominal cavity of the patient which is attached to the tubing of the system. The exchanges in automated peritoneal dialysis takes place as the patient sleeps at night. The patient attaches himself to the system and turns on the mains to start the exchanges.

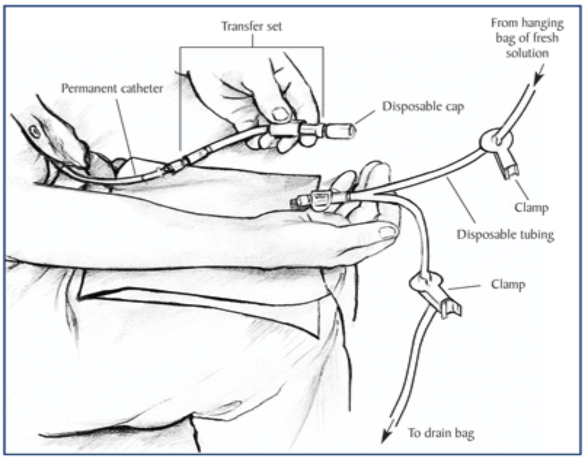

Figure 5: Connection of catheter for preparation of APD

c) Experimental procedure

The peripherals were mounted on the mechanical assembly in a proper sequence. The dialyzer was attached in accordance with the gravity. The time required for the fluid to drain from the dialyzer is more as the process is a slow process. The waste solution is dripped from the dialyzer at a timely basis.

The volume is monitored and measured to obtain the desired 25% of the volume. When the 25% i.e. target volume is achieved the system automatically resets to first step.

Thus the system worked as per the logic provided. All the simulations functioned properly and expected function of the automated peritoneal dialysis system was achieved.

4. Conclusion

Cost was the major constraint over which the system was designed. The available systems in market are extremely expensive for a common man even for the treatment of kidney disease. This automated peritoneal dialysis system helps the common man to choose economical way for his/her treatment of kidney disease. Because of the use of PIC as the controlling and monitoring unit in the system, the cost has reduced to great levels plus the functionality of the system is not hampered. The system works very effectively.

5. Future Scope

In this paper, cost of the system was taken into consideration and the system was designed as per the major constraint. Reduction in size i.e. a more compact design can be achieved with automation in the discussed system. If the size is widely reduced, the flexibility will greatly improve for working patients.

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