Research Article

A simple prototype for pulsatile blood flow using an adjustable centrifugal pump

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Abstract

Heart-lung machines used in open heart surgeries pump the necessary blood with two different types of pumps integrated into them. These pumps are roller or centrifugal pumps. While roller pumps are preferred more frequently in cardiac surgeries due to their ease of use and relatively low cost, centrifugal pumps are preferred in cases where long-term mechanical cardiac support or long-term oxygenation is required. Centrifugal pumps are suitable for longer-term use due to their advantage of causing less damage to the shaped elements of the heart (thrombocytes, leukocytes and erythrocytes) compared to roller pumps. Other flow types of heart-lung machines are pulsatile and non-pulsatile flows which may influence the side-effects of these machines on human body. While non-pulsatile blood flow pumps blood into the body continuously at a constant pressure, pulsatile blood flow pumps blood intermittently, imitating the heart's beating pattern. Therefore, pulsatile blood flow is more physiological and has many benefits over non-pulsatile flow, such as reducing inflammation that may occur in the body and thus reducing the side effects of the heart-lung machine. Although there are many studies on the pulsatile flow using roller pumps, there is no device in daily use that will provide an adjustable pulsatile flow using a centrifugal pump. There are very few experimental studies on centrifugal pumps providing pulsatile flow in which the frequency and flow rate of the pulsatile flow was often kept constant. Currently, no device that can adjust the desired frequency and flow rate has yet entered the routine use. Thus, the aim of this project is to design a simple prototype of such a centrifugal blood pump that will provide pulsatile blood flow which will be adjusted in terms of frequency and flow rate.

Keywords: *Cardiopulmonary bypass, centrifugal heart pump, pulsatile cpb flow, prototype device*

1. Introduction

The heart-lung (cardiopulmonary bypass) machines used in open heart surgeries ensure the pumping function of the heart. Roller or centrifugal pumps integrated into these devices constitute the driving force that undertakes the heart's function. While roller pumps are preferred more frequently in heart surgeries due to their ease of use and relatively low cost, centrifugal pumps are preferred in cases where long-term mechanical heart support or long-term oxygenation is needed. Centrifugal pumps are suitable for longer-term use due to their advantages of causing less damage to the shaped elements of the heart (thrombocytes, leukocytes and erythrocytes) compared to roller pumps. In addition to the blood flow pattern obtained with these centrifugal or roller pumps, different flow patterns are also applied in the body in order to reduce the side effects of heart-lung machines. The most commonly known of these different flow modalities are pulsatile and non-pulsatile blood flow.

Pulsatile blood flow is achieved by the electric motor operating the pump suddenly accelerating at an increasing speed, providing continuous flow for a certain period of time at the high pressure, then slowing down in a decreasing manner, and providing continuous blood flow for a period of time at the minimum low point without stopping completely, then suddenly accelerating again at an increasing speed, and repeating this process continuously. However, non-pulsatile blood flow provides blood flow at a set constant pressure.

Under normal conditions, heart beating creates a pulsatile flow. Therefore, it is more physiologic to mimic this pulsatile flow pattern during long periods of heart surgery when the heart is stopped. It has been shown that blood pumped with pulsatile flow causes less damage to the body in terms of the functioning of the heart and kidneys than non-pulsatile flow, and that pulsatile blood flow causes less inflammation than non-pulsatile flow, thus reducing the side effects of the heart-lung machine [1, 2]

Roller pumps work by compressing polyvinyl, silicone, or latex tubes placed inside them in one direction by cylindrical rollers. Two small rollers rotating around an axis compress the rubber tube and push the blood inside the tube forward. The flow rate of the pump is proportional to the rotation speed of the rollers and the diameter of the tubing placed inside (Figure 1A). Impeller pumps operate using the same manner with centrifugal pumps using rotating blades. Impeller and basic centrifugal pumps are both classified as centrifugal pumps.

Figure 1: A. Roller Pump, B. Impeller pump, C. Centrifugal pump

Roller pumps, which are frequently used in open heart surgeries can provide both non-pulsatile and pulsatile blood flow with the function of cardiopulmonary bypass (CPB) device. Using non-pulsatile blood flow in roller pumps is more advantageous in terms of ease of use. In fact, although non-pulsatile blood flow manages to meet the nutrition of the body's tissues, organs and cells at a certain level, it is not physiological. Centrifugal pump devices that provide pulsatile flow suitable for human physiology by adjusting the frequency and flow rate are not commercially available in routine use today. In the limited experimental studies conducted on this subject, only centrifugal pump devices that provide pulsatile blood flow at a fixed frequency and flow rate have been used [3,4]. In this project, a heart support pump device prototype operating on the centrifugal principle is made pulsatile with an added software and mechanism, in which the frequency and flow rates of this pulsatile flow can be increased or decreased.

2. Materials and Methods

The basic design of centrifugal pumps consists of blades placed in a flat plastic cone housing in a plastic mold (Figure 1B and 1C). The blades are magnetically connected to an electric motor. With this magnetic connection, the drive magnet in the console rotates the pump at an equal speed. When the centrifugal pump is operated, the blades rotate with the force of rotational power of the motor that create a vortex with the kinetic energy. This vortex draws the blood or liquid with negative pressure. With the adjustments made during the rotation of the pump blades, the pump automatically regulates its flow rate according to the desired value by increasing and decreasing its speed.

The prototype device developed in this study has the same mechanism of a centrifugal pump. The non-pulsatile continuous blood flow created by the centrifugal pump is made pulsatile with a mechanism and software added to this centrifugal pump. The centrifugal force-powered motor draws the liquid in. Then, as a result of the adjustment of the desired pulsatile flow, the water flow sensor measures the desired liquid flow values with the software and releases the liquid at these values. Thus, blood is pumped to the patient at the desired pulsatile blood flow values and this flow can be increased or decreased when needed. A software has been developed that allows the centrifuge mechanism to provide pulsatile blood flow. The frequency of pulsatile flow will be increased or decreased by this software which will simultaneously adjust the flow values compatible with this frequency. The centrifugal pump system of this adjustable pulsatile flow pump is constructed using a simple water pump.

In this project, the materials used to create the prototype created and their properties are explained in detail below (The suitability of the materials used was confirmed by the Department of Electrical and Electronics Engineering in Muğla Sıtkı Koçman University).

- Arduino UNO: It is the microcontroller card of the created prototype. The software of the circuit written via the Arduino IDE application is programmed and run with this card (Figure 2).

Figure 2: Arduino UNO Card

- Motor: Since it is not possible to work with a real centrifugal pump motor used in heart-lung (cardiopulmonary) bypass machines, a water pump motor was used in this project (Figure 3). Then the necessary code and electronic circuit mechanism were connected to this motor. The motor provides pulsatile flow to the centrifugal pump using the developed software. The motor pumps the water at the systolic value, i.e. high flow value, set according to the heart's beat frequency for a certain period of time, and then pumps the water at the diastolic value, i.e. low flow value, set again for a certain period of time. Thus, this process is repeated and water is pumped by the motor at the desired systolic and diastolic flow values.

Figure 3: Motor of the water pump used to provide pulsatile flow.

- Motor Driver: It provides control of the necessary commands such as electrical resistance, speed and start-stop of the motor used in the prototype created (Figure 4).

Figure 4: Motor Driver

- Water Flow Sensor: It measures the water flow given out by the engine. Thus, it measures the water delivery information at the desired current values (Figure 5).

Figure 5. Water Flow Sensor

Construction stages of the prototype mechanism

- The water flow sensor and motor driver were connected to the water pump (Figure 6).

Figure 6. Connection of the Water Flow Sensor and Motor Driver to the Pump

- The Arduino UNO Board was connected to the constructed mechanism (Figure 7).

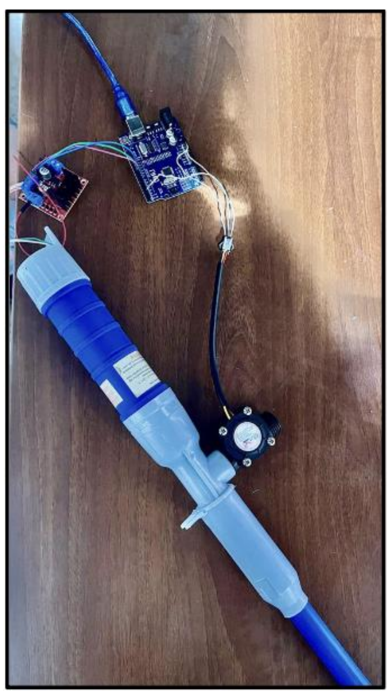

Figure 7. Connection of Arduino UNO Board

- The circuit was arranged, placed in a box and fixed to the pump (Figure 8).

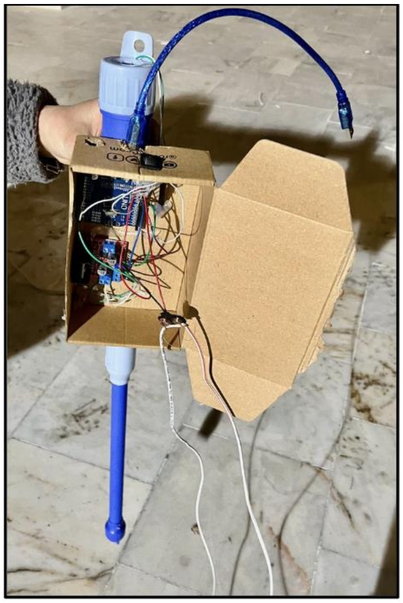

Figure 8. Arranging and Fixating the Circuit

- The prototype was completed (Figure 9).

Figure 9. Finished Prototype

- The software of the mechanism that provides adjustable pulsatile water flow to the centrifugal pump system, made with Arduino IDE, is given below:

```
#include <LiquidCrystal.h>
const int motorSpeedPin = 9;
const int motorDirection1 = 10;
const int motorDirection2 = 11;
const int flowSensorPin = 2;
LiquidCrystal lcd(8, 7, 6, 5, 4, 3);
void setup() {
pinMode(motorSpeedPin, OUTPUT);
pinMode(motorDirection1, OUTPUT);
pinMode(motorDirection2, OUTPUT);
pinMode(flowSensorPin, INPUT);
lcd.begin(16, 2);
}
8void loop() {
runPump(6, 3000);
runPump(5, 3000);
}
void runPump(int targetFlowRate, int duration) {
int startTime = millis();
while (millis() - startTime < duration) {
int flow = readFlowRate();
int motorSpeed = map(targetFlowRate - flow, 0, 6, 0, 255);
digitalWrite(motorDirection1, HIGH);
digitalWrite(motorDirection2, LOW);
analogWrite(motorSpeedPin, motorSpeed);
lcd.clear();
lcd.print("Flow: ");
lcd.print(flow);
lcd.print(" L/min");
delay(100);
}
digitalWrite(motorDirection1, LOW);
digitalWrite(motorDirection2, LOW);
analogWrite(motorSpeedPin, 0);
int readFlowRate() {
}
```

3. Results

In this study, a software and mechanism that creates pulsatile flow has been added to a water pump that works with the centrifugal pump principle. A system has been created where the centrifugal pump draws water in and then releases it with pulsatile flow. In the created system, the current values of the centrifugal pump can be increased and decreased as intended. As a result of this project according to the obtained data, the motor used in this prototype provided pulsatile flow to the centrifugal pump in requested systolic and diastolic values. It is observed that these flow values can be increased and decreased by the person using the centrifugal pump.

4. Discussion and Conclusions

The aim of the project is to produce a pulsatile centrifugal pump system that can be used in cases of long-term surgery or long-term heart-lung support by adding a pulsatile flow with adjustable frequency and amount to the centrifugal pump system used in heart-lung (cardiopulmonary) bypass machines. The pulsatile centrifugal pump system has advantages such as reducing inflammation that may occur in the body, improving the functioning of various organs during heart-lung machine support and reducing the side effects that may occur with the heart-lung machine [5]. The goals of the project include the ability of the doctor to change the pulsatile flow values provided by the centrifugal pump by increasing or decreasing as desired. Thus, in this project, a mechanism was created in line with the goals to be achieved and the software was written and added to the centrifugal pump. According to the comments made in line with these findings, it was observed that the goal was achieved in the project. The goal was achieved by preparing a suitable mechanism and writing the software in order to provide pulsatile flow to a water pump operating on the centrifugal pump principle. As aimed in the project, the centrifugal pump prototype pumped the water with pulsatile flow according to the values entered. The person using the pump was able to increase or decrease the systolic and diastolic flow values according to how they desire. Hence, a real heartbeat pattern was imitated in the centrifugal pump, the prototype was modeled and the goal was achieved at the end of the project.

5. Acknowledge

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