PID Controlled Hemofiltration for Poison Control

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Objective

The Maryland Poison Control center handles about 44,000 calls a year regarding people who have been poisoned with substances such as household chemicals, alcohol or opioids, that cannot be easily cleared using current hemofiltration methods. This project aims to improve hemofiltration by utilizing the power of ECMO. In order to accomplish this, the pump must meet the demands of ECMO and hemofiltration while and manage a flow rate of up to 5 Liters per minute (Lpm) through the main pump. The selected design involved programming a microcontroller to adjust the rate at which a roller pump pumps the effluent fluid from the filter based upon the measured flow rates. The device must be durable, capable of running for days, portable, and not too expensive.

Methods

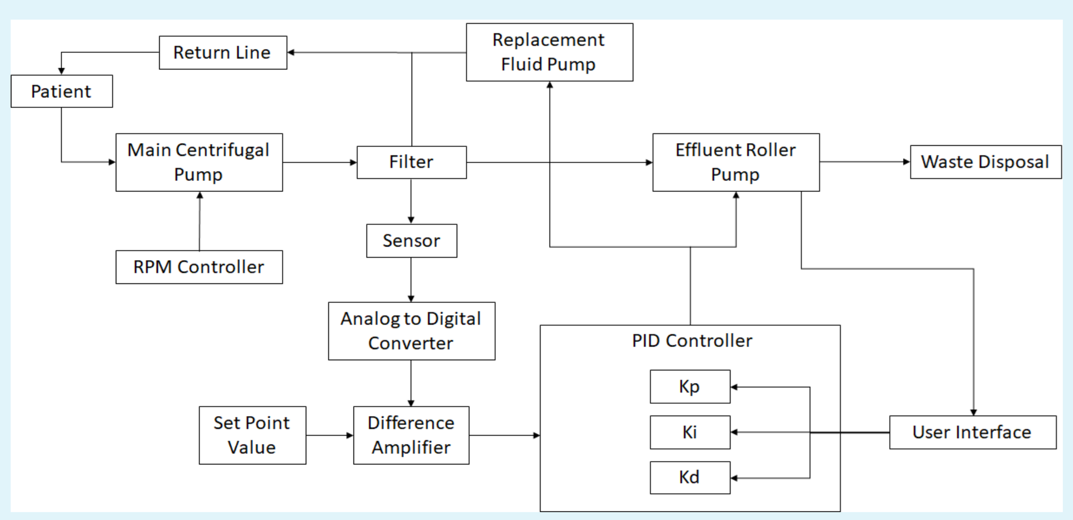

Figure 1. Schematic of set in which the flow sensor is used as an input for the PID controller which feeds a voltage and drives the effluent and replacement roller pumps.

An Arduino Uno will be used to create a PID controller for a pump. The hemocompatible pump was provided by Dr. Wu and has access to required ports for motor speed control. The sensor used to measure the flow rate for the PID controller is an ultrasonic flow sensor that can also be used with blood, allowing the designed system to run with blood. The system design allows it to be compatible with any filter design the cooperating team develops. A circuit will be needed to amplify the current produced by the Arduino since it is only capable of producing low currents that cannot drive a motor. The motor to be controlled in this diagram is the effluent pump which will see less flow than 5 Lpm. The pump being controlled can only achieve a flow rate of around 3 Lpm which should serve our needs.

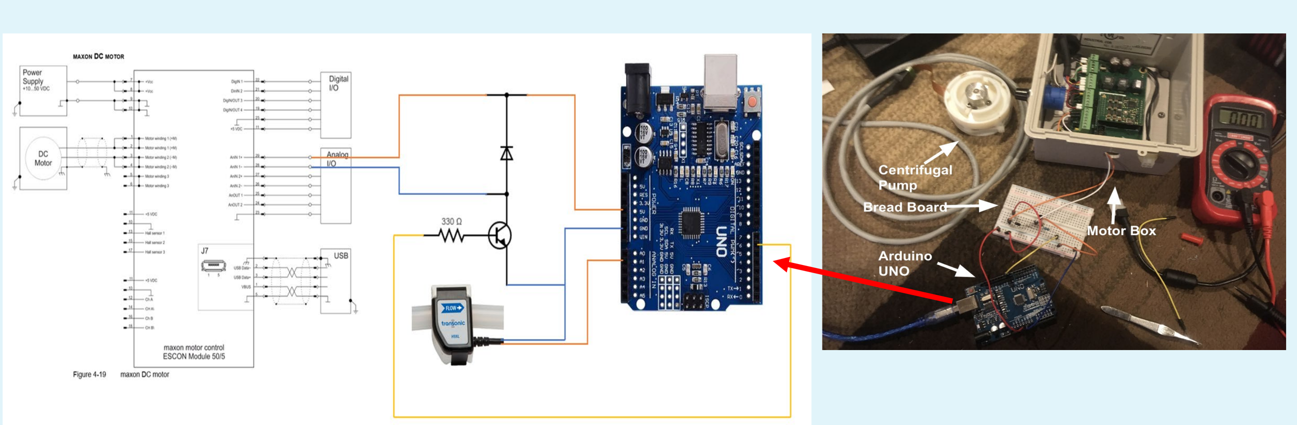

Figure 2. Depiction of connections between the Arduino board and flow rate control system.

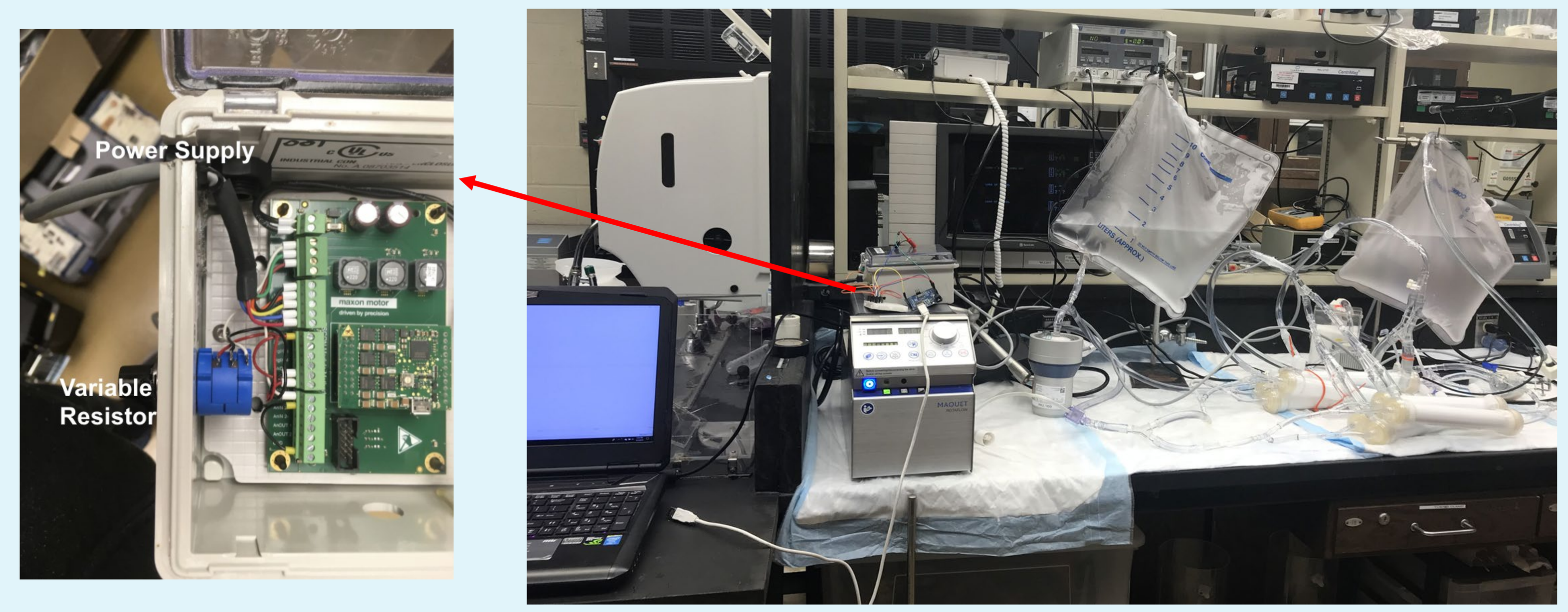

Figure 3. Full hemofiltration system set up with 8 filters in parallel (made by filter team with circuit setup of the motorbox

The pump control system was created using the AutoPID tool box in Arduino along with a small circuit portion to allow the output of the Arduino controller to be amplified to a higher current than the output pins are capable of. The pump control system went through many iterations before it was entirely ready to be put into use. The original setup reached the setpoint after about three minutes of running. This was because the inputs in the PID equation were too low, resulting in a very slowly changing output. The issue was fixed by multiplying the setpoint and voltage read from the sensor by the same value. This amplified the output of the PID controller and did not interfere with reaching the setpoint. A second version of the code was created to allow for monitoring the flow rate and run time from a computer using Arduinos serial plotter. The Arduino fed the output of the PID into a controller for the motor that is provided by Maxon Motors for this specific motor and contains a 120V power supply and motor winding and controls as well as inputs for external commands.

Results

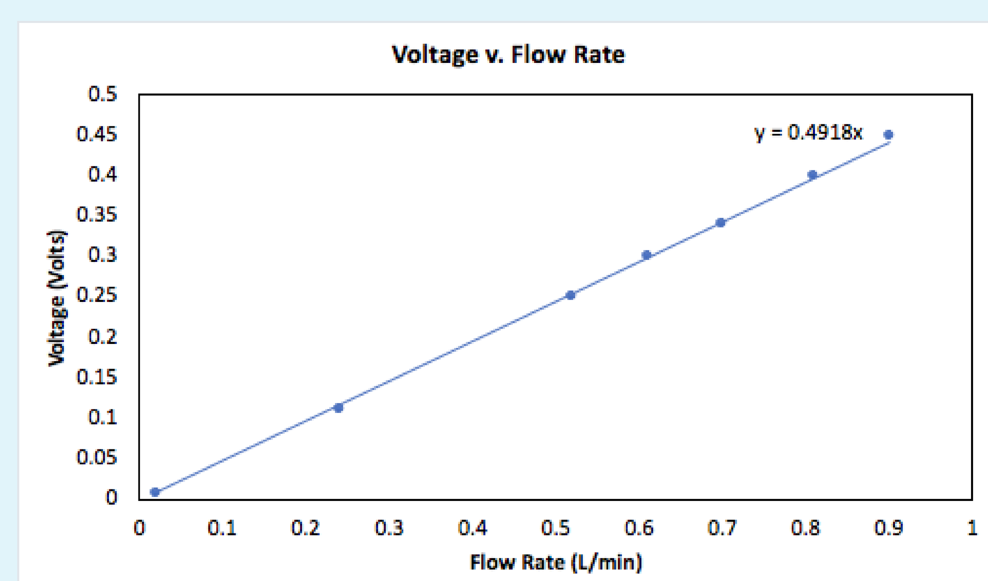

Figure 4. Flow rate vs the read voltage

A relation between the voltage output from the sensor to the read flow rate was established by generating a trend line through various recorded points. The relation was found to be approximately 0.1V for every 0.2 Lpm of flow. This relationship was needed to convert the desired setpoint to a voltage that could be compared to the voltage being read by the flow sensor. The code feeds a PWM signal to the motor control box that can be used to increase the flow as needed based upon what is read from the sensor.

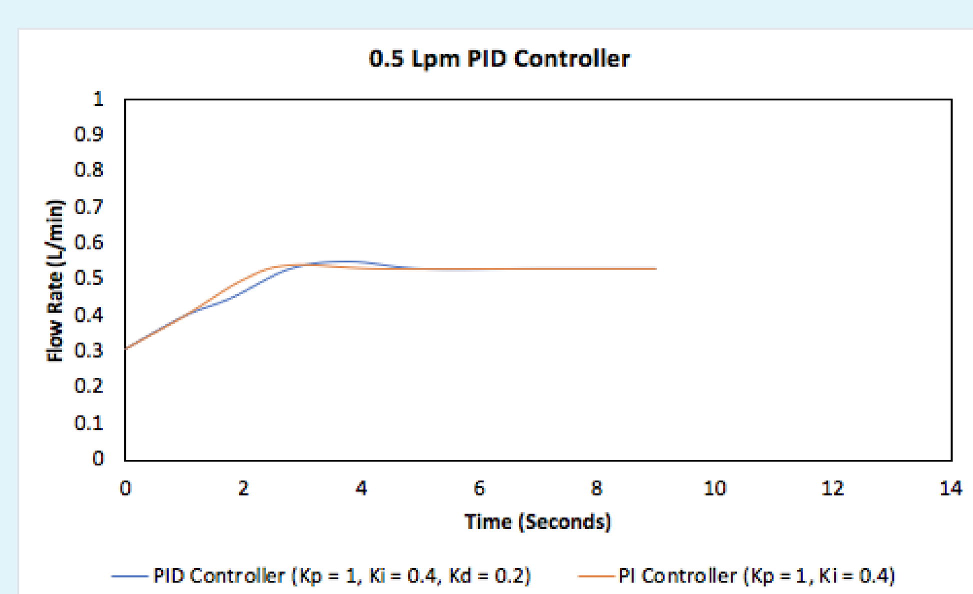

Figure 5. Change in flow rate over time using PI control at 0.5 Lpm

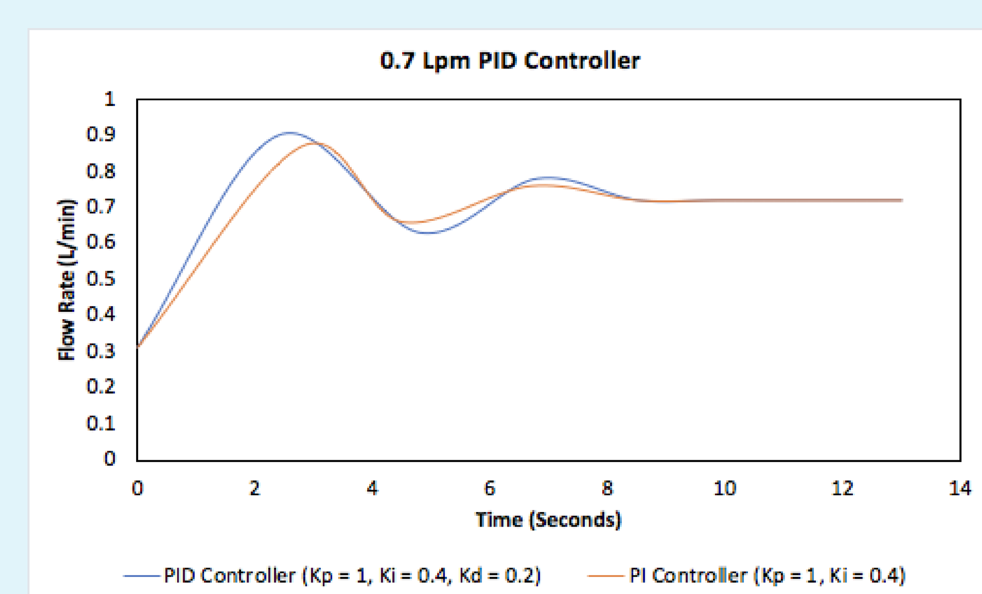

Figure 6. Change in flow rate over time using PI control at 0.7 Lpm

It was found that the PI controller was favorable in both cases of flow rates. The PI controller resulted in less overshooting and a faster response in the case of the 0.5 Lpm trial. The controller was observed to cause more overshooting at higher flow rates. More combinations of controller setting could be tested later on to lessen overshooting. The trials were done with a lower flow rate than intended in the actual design is capable of being scaled up to accommodate a flow of 5 Lpm through the main pump and up to 3 Lpm through the effluent pump.

Ethical Implications

Hemofiltration using the technology of traditional ECMO to filter blood at rates higher than currently possible, is novel, but poses minimal threat to the public. The technology is already available and widely accepted in the medical community. Potential risks of the system include air entrapment in the circuit, blood loss, and hemodynamic instability in case of device malfunction and must be addressed when advancing the design for clinical use.

Conclusions

A feedback controller was built to maintain consistent flow rates for hemofiltration and similar applications. The controller can respond to changing conditions and maintains its function across multiple hemofiltration systems. One of the systems tested involved parallel filters engineered by another capstone team, so this controller may be especially useful when implementing novel hemofiltration devices. Its sensing function enables instant, automated tuning when, normally, a medical professional would have to manually adjust settings. This may be of great value for the other team's parallel filter mechanism, which was designed in part to treat drug overdoses. It will be critical in such unpredictable situations where time is of the essence.

Future Work

In the future the system should be tested in actual blood or a blood mimetic since tests with the controller were only done on saline solutions and water. The results of this test can be used to further determine how the system will interact in a hospital setting on a patient. Finally, a user interface could be added to the controller to create a system that is easier to manipulate. This would also allow for plotting of the flow rates at each point in the system for easy analysis of the performance of the controller.

References

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