Single Infusion Intravenous (IV) Drip Regulator

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Abstract

In this report, we explore the need for a single infusion automated intravenous drip regulator, as well as currently existing solutions and how we differ from them. We will take a deep dive into the multiple subsystems that go into creating an automated drip regulation system, and how we are able to verify that these systems are working as intended, as well as share key data and figures to show our verification. Finally, we take a look at the total cost of the project, including labor and parts and conclude by describing our accomplishments, any future work that needs to be done, and the ethical and safety concerns that we have taken into consideration.

1. Introduction

In order to understand the motivation behind a single infusion intravenous drip regulator, it is necessary to understand the problem, the need for a solution as well as a background of potential existing solutions and why they are ineffective. We will explore these ideas below.

1.1 Objective

Single infusion IV drips are currently manually regulated, or use an electric pump. Electric pumps, also known as infusion pumps, range from $1,800 to $4,500 in cost, might have an annual software subscription license, and require an additional $150-250 annual contract for maintenance if there is no in-house repair department. [4] Hospitals in first world countries have a limited supply of pumps due to the cost. During the COVID pandemic, the FDA issued an Emergency Use Authorization [5] for an increased supply of infusion pumps and accessories. Many hospitals reverted to using gravity IV pumps due to a shortage of infusion pumps. Many third world countries or medical camps have even fewer available. Infusion pumps also require training to learn how to operate.

Our goal is to create a low cost and easy-to-use solution to measure the rate of drips for gravity IV drip systems, and provide an alert when a certain amount of IV fluid has been consumed or if the IV supply has been depleted, and control the rate of flow of IV fluid at a per unit price below $20 once scaled.

1.2 Background

An infusion pump has the ability to deliver fluids in controlled quantities. According to the FDA, there are many types of specialty infusion pumps. An Enteral pump delivers nutrients and medications to a patient's digestive tract. A PCA (patient-controlled-analgesia) pump allows the patient to self-administer a set amount of medication. There are many other varieties as well, but all pumps can neatly be classified into two categories; one category are large stationary bedside pumps and the other is mobile pumps. [6]

Errors in IV administration can lead to harmful patient outcomes. A study was done at a teaching hospital in Brisbane, Australia. All patients received a continuous IV infusion. Of the 687 observations, 124 (18%) had at least one administration error. The most common error was the wrong administration rate. It was concluded that errors could be mitigated with the use of infusion control devices and frequent monitoring of the administration rate. [1]

DripAssist by Shift Labs is a direct competitor. They advertise a IV monitoring system for gravity infusion pumps. The device can count drops, calculate the rate of fluid, and detect a depleted supply of fluid. The DripAssist retails for $480 for a human model and $335 for a veterinary model. This device lacks a pressure controller to automatically adjust the rate of flow.

2. Design

Our project consists of 3 key subsystems, a microcontroller, and a WiFi communication module, and power. First, we have our drip detection subsystem, which consists of an IR LED and a phototransistor as well as a drip chamber (which is pre-built and comes with the default IV infusion system). Here, we measure how much light is being transmitted to the phototransistor through the drip chamber, and when a water drop falls through the amount of light transmitted is reduced due to light scatter. By measuring this change, we are able to determine the number of drops of IV fluid falling into the drip chamber.

Along with the drip detection system is the drip controller subsystem, which applies varying pressure to the tube that is responsible for delivering the IV fluid and therefore controls the rate at which the fluid is administered to the patient. To implement this, we use a servo motor which rotates a threaded rod with a nut on the end. Attached to this nut is a plastic piece that applies pressure to the tube. Between this wall edge of this system and the tube is a force sensor to measure the amount of pressure exerted on the tube. As the servo motor begins to rotate, the nut slides forward, and the plastic piece attached to the nut applies the pressure.

Lastly, we have the statistics subsystem, WiFi module, and microcontroller. The statistics subsystem is responsible for displaying information about the fluid being administered, how much of the fluid is being administered, average flow rate, etc. The OLED focuses on displaying the current flow rate, while the web app displays all the statistics. The WiFi communication module is used to facilitate communication between the statistics module and the microcontroller. Our microcontroller serves as the brain of the entire project and is what each part is connected to to make sure all the subsystems work as intended. Finally, our power subsystem ties everything together to power our system.

2.1 Drip Detection

The drip detection system consists of a phototransistor and LED that are placed around the drip chamber and are able to detect when drip has fallen from the IV bag into the drip chamber. This is used to determine the rate of flow as well as how much fluid has been administered and how much is left.

2.1.1 IR LED and Phototransistor

The IR LED points at the phototransistor which reads how much light is being absorbed. In order to detect a drop, the phototransistor reads lower reading of light when the drop falls due to the diffraction/absorption of light coming from the IR LED to the phototransistor. There is a risk of ambient light from the room affecting the readings from the phototransistor. Since light fixtures rarely emit IR light, we used an IR LED and a phototransistor which only recognizes IR light. This results in minimal noise from other light sources.

Figure 2.1. Water Absorption with IR Wavelength [8]

Figure 2.1 plots the water absorption spectra. Water has a higher absorption with IR light than with visible light. We used the longest wavelength IR transmitter and receiver pair that we can find, so that the likelihood that this pairing detects water is much greater.

2.1.2 Drip Chamber

The drip chamber is a part that comes with the IV drip system. The drip chamber continues to function the same way as it currently is but now we are also detecting when a drip occurs through it. The main requirement is that the drip chamber is big enough for us to be able to place our two sensors and also big enough to drop a properly sized drop. The verification on how we were able to purchase the current drip chamber is found in section 3.1.2.

2.2 Drip Controller

The drip controller is used to adjust the rate of flow of the fluid by adjusting the pressure on the IV tubing with the use of a servo motor. An additional force sensor acts as a pressure measuring device and as a safety device. This subsystem works closely with the Drip Detection subsystem to achieve the requested rate.

2.2.1 Continuous Rotation Servo Motor

The servo motor is used to adjust the pressure on the roller clamp. By either tightening or loosening the IV tubing, we can increase or decrease the flow rate to the necessary value.

The motor remains at a fixed position and changes the pressure on the tubing appropriately by turning a threaded rod which moves a plastic component in and out, putting pressure or releasing pressure on the tube. This is a continuous rotation servo, so it does not have the ability to keep track of its position.

2.2.2 Force Sensor

The force sensor lies between the tube and the wall of the pressure box. When a force is applied to one side of the tube, the tube has an opposite reaction on the other side. This pressure pressure on the tube estimates the rate of flow and it can be adjusted until it matches a desired range is achieved. The force sensor also acts as an additional safety component to ensure that too much pressure is not applied or no pressure is applied. The former can result in a crushed or deformed tube, while the latter would result in unrestricted flow of liquid. Thus, the force sensor provides an additional check to avoid those two potential problems.

2.2.3 Pressure Box

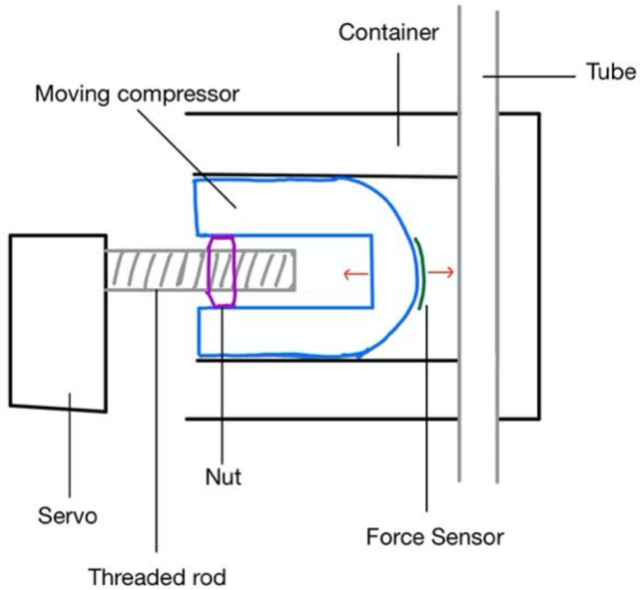

Figure 2.2. Blueprint of Pressure Box

Figure 2.2 shows the chosen blueprint for the pressure box. Essentially, it is a redesign of a traditional roller clamp. The outer frame and the blue part are both made out of delrin to reduce weight. The blue piece is the component that applies pressure to the tube. It does so because it's attached to the nut in purple. When the servo moves the threaded rod, the nut is moved back and forth, which carries the blue part along with it. The threaded rod is 16 threads per inch. This translates to 0.0625 is horizontal movement with a single 360* turn by the servo motor. This mechanism was designed and built with assistance from the ECE machine shop.

2.3 Statistics

The statistics subsystem consists of the OLED Display which is used to display the information about the IV drip such as the flow rate and the web app which will be used to set the flow rate and also view what the current rate is. The OLED screen is required so that the flow rate can be monitored in person without the web app while also allowing the patient to see what the rate should be. The web app is the only place where the flow rate can be set to the desired value.

2.3.1 OLED Display

The OLED display shows the current flow rate that the IV fluid is set to so that it can be viewed easily. Additionally, the OLED screen also shows when a drop has occurred while it is setting the flow rate. This allows the user to check that rate is correct while it is setting it to the appropriate value if there are any doubts.

2.3.2 Web App

The web app is connected to the system through WiFi and is used to set the rate of flow that the IV needs to be administered at. The web app also displays what the current flow rate of the IV fluid is. Additionally, the app will only allow users to input values between 10-60 gtt/min because those are the only values that should be used for safety reasons. If a user tries to input a value outside of this range, the system will reject it and continue holding the rate at whatever value it is.

2.4 WiFi

The WiFi module communicates over SPI and we used the ESP8266 WiFi module as it kept costs low and was effective. The WiFi module was used to transmit metrics information between the hardware collecting the information and the web app, or OLED displaying the information. This subsystem is able to provide the flow rate submitted on the web application to the microcontroller so that the microcontroller can carry out the rest of the process. Once the flow rate is set and verified by the hardware, this information is sent back to the web application through the ESP8266 and it is displayed on the web application as well.

2.5 Power

The power system accepts a range of 7-14V input. The input voltage is stepped down to 5V and 3.3V with linear regulators. The total current draw was found to be under 1A for both the 3.3V and 5V line. Since we are using AC-DC wall power, and not DC-DC battery power, efficiency was not a priority. Heat sinks are added to the linear regulators as an overheating precaution. Figure 2.3 below is the final power schematic.

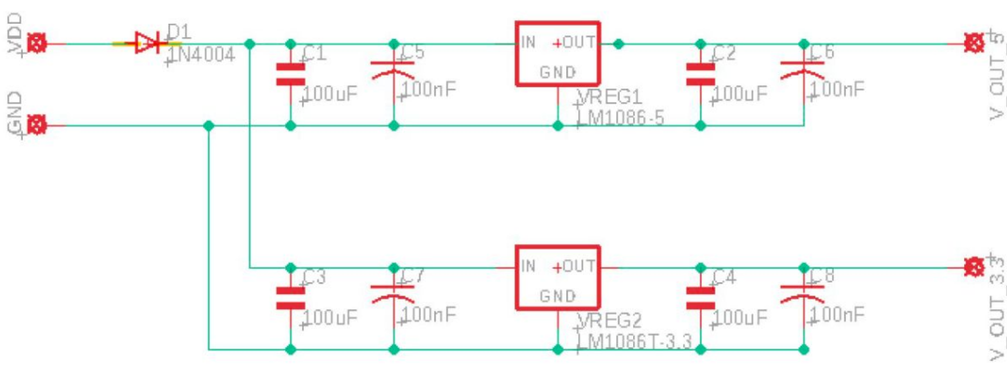

Figure 2.3. Power Schematic

2.6 Microcontroller

The ATmega328 proved to be a low cost, power efficient, and easy to obtain microcontroller. Our software used slightly over 16KB of flash memory, which fit well under the 32KB limit of this microcontroller. However, going forward, we would choose an ATmega168 since with some code optimizations, we could definitely fit it within 16KB of flash memory. Many of the logic pins on this microcontroller are 5V pins. To prevent damage to 3.3V modules, we added a logic level converter with mosfets to step up or down the 5V signal to 3.3V signals.

2.7 PCB

The printed circuit board, PCB, is 80mm in width and 90mm in height. Our initial design for the PCB, as seen in figure 2.4, worked as intended and no revisions were necessary. We did not have any strict specifications for the PCB, except that the traces were thick enough to handle higher current at certain locations. In future iterations, the footprint can be reduced to reduce costs.

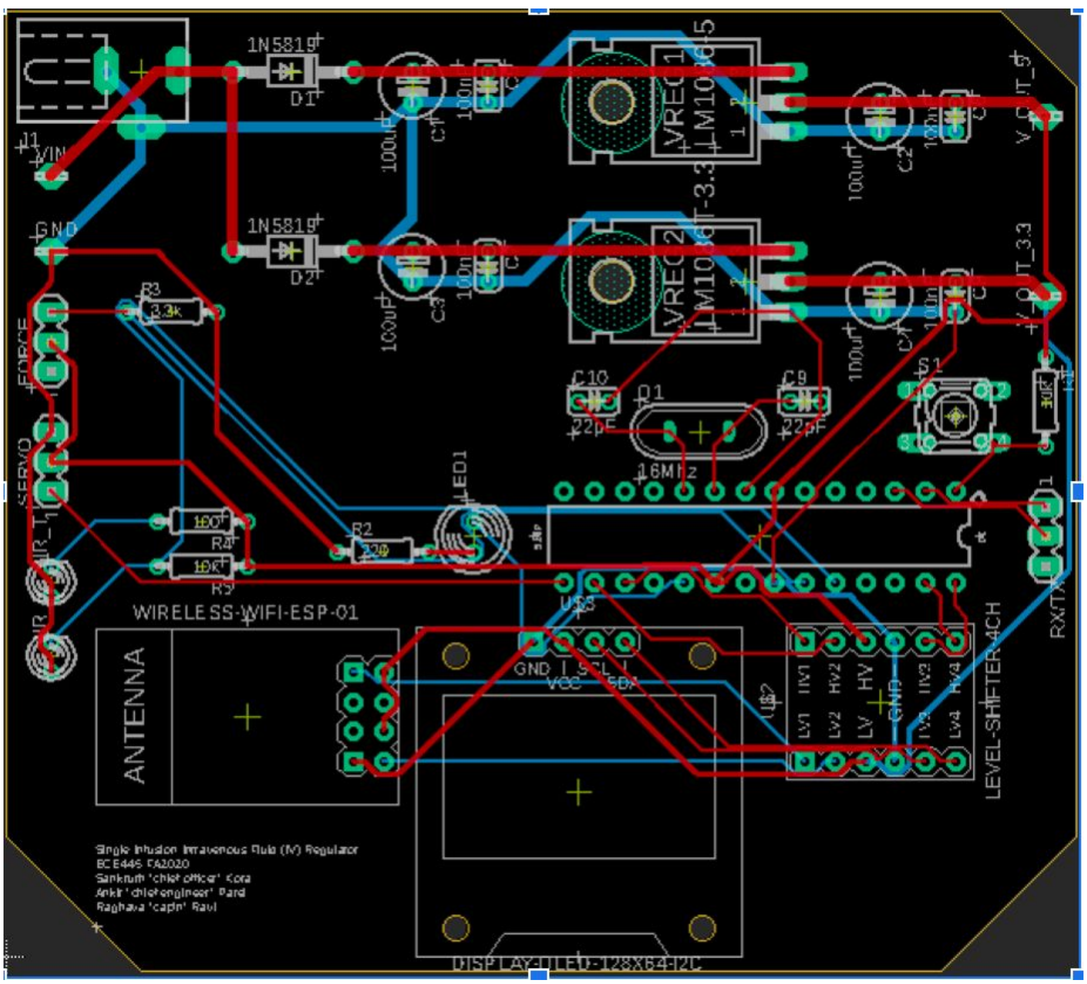

Figure 2.4. PCB Design

3. Design Verification

In this section, we perform a verification of each of our different subsystems and ensure they have met the expected design standards.

3.1 Drip Detection

The drip detection system consists of the IR LED and Phototransistor, and the Drip Chamber components so we verified each of these independently to ensure that the drip detection system works correctly.

3.1.1 IR LED and Phototransistor

In order to verify that our IR LED and phototransistor system worked as intended, our team dropped one mL of water through the system and see if the phototransistor was able to pick up a change in the light consistently.

Figure 3.1 below shows the default phototransistor analog value. As we can see, the default seems to hover around 723. From this default value, we see how the value changes if there is a drop of water falling or not. So, when there is no drop of water falling, we see the values stay consistent and do not change erratically, and when there is a drop of water falling we see a considerable difference in the analog value measured. The fact that there is a significant difference indicates that the IR LED and phototransistor system is working.

Now, we can look for a difference above 30 in our analog values from the current and previous and successfully say that we detected a drop of IV solution.

Phototransistor Analog Value (Previous)	Drop Falling - Value (Current)	Difference (Previous - Current)
723	No - 723	0
722	No-723	-1
723	Yes - 684	39
724	Yes - 680	43
723	No- 723	0
723	Yes - 682	37

Figure 3.1. Phototransistor Drop Measurements

3.1.2 Drip Chamber

To verify that our drip chamber had the correct measurements, we took a tape measure and measured around the circumference to ensure that the part we ordered was in line with our expectations. We measured a value of **0.18 inches** for the diameter.

We also had a requirement that our drop sizes are between 10-20 mL. This requirement is no longer as important since our drip detection system was capable of measuring drops of mL smaller than that (1mL). So, the true requirement was whether the drop size was big enough for the IR LED and phototransistor to detect it, and as we can see by the data above, the drop size is big enough. Therefore, both these requirements, for the purpose of our project have been successfully met.

3.2 Drip Controller

The two main electronic components of the drip controller system were verified with in-depth tests. The physical component was verified with the use of mechanical measurements.

3.2.1 Continuous Rotation Servo Motor

5V was provided to the servo motor and pulses of 1500 µs +/- 500 µs were sent. The current measured at each of these pulses was under 200mA, which falls within the design constraint. It was also important to validate that the pulses matched the manufacturer specifications. Our tests with sending different pulses found the range from the steady-state of the servo was larger than expected. Figure 3.2 below charts various pulses sent, the time they were sent for, and the distance movement as measured by a caliper. The pulses below are the actual values used in our software.

Pulse Width (us)	Time (ms)	Distance (in)
1470-1550	-	0.000
1200	500	0.212
1400	1000	0.136
1560	1000	0.128
1800	500	0.233

Figure 3.2. Servo Motor Pulse Width and Distance Measured

Note that the distance movement is not perfectly equal. This was a design decision. In the event that the movement was equal in each direction, there is potential for the servo never reaching the required point and forever trying. With inequivalent distances, the motor can always converge to a point.

3.2.2 Force Sensor

The force sensor's range was categorized by applying a steady pressure by using the servo motor. It was found that when no pressure was applied, the force sensor output a value of 29.8g. This is due to the pressure acting on the force sensor while sandwiched inside the pressure box. This value is the baseline force. The point at which the tube was completely crushed was 55g. This value serves as a limit that triggers a system shutdown if reached. At this point, the tube us completely crushed, and possibly deformed. These tests provided a range of force values that we needed to be able to measure accurately, so we worked on achieving the maximum sensitivity that can cover this entire range of values.

$$V_{out} = V_{CC} * \frac{R}{R + R_{FSR}} \tag{3.1}$$

Equation 3.1 provides the relation that voltage is inversely proportional to the force sensor resistor's (FSR) resistance. When no force is applied, the resistance of the FSR will be high (around 10 MΩ). With a 10 kΩ pull down resistor and Vcc = 5V, Vout = 0.005V. When the FSR is pressed, its resistance will change to a minimum of 200Ω, resulting in a Vout = 4.9V. The advantage of our circuit is that the value of the pull down resistor can be changed to change the circuit sensitivity in favor of a narrower force sensitivity range. As per our measurements, a range under 1kg is required for the IV tubing, so maximized sensitivity over range. Ultimately, we chose to go with a 100k resistor. Figure 3.3 charts voltage with force.

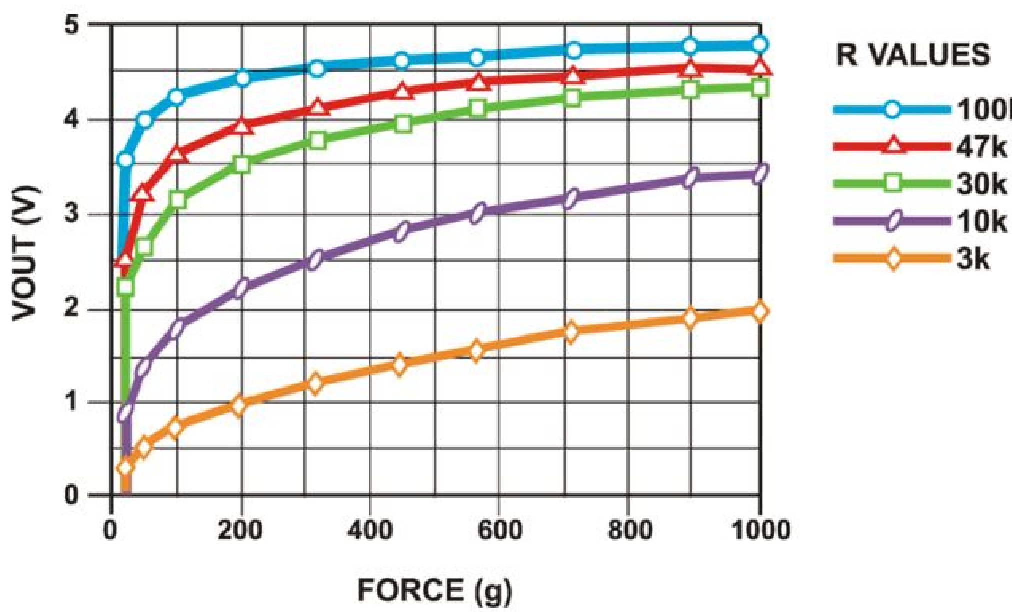

Figure 3.3. Force Sensor: Voltage Measurement with Force

3.2.3 Pressure Box

The pressure box was the last component verified. The requirements were quite simple. It should be able to accept a tube, which it does, and then allow the tube to be squeezed and have the force sensor measure it. The initial design of this component did not allow the tube to be compressed enough since there was too much empty space behind the tube that the tube expanded into . This allowed liquid to continue to flow through. The second revision fixed this, but the force sensor did not make proper contact with the tube, so pressure was not properly detected. The final revision fixed both of these issues and satisfied the requirements.

3.3 Statistics

As previously mentioned, the statistics subsystem consists of two components which are the OLED Display and web application. In order to verify that the OLED works, we tested it independently, but to test the web app works we used the WiFi communication module to work as well as the microcontroller.

3.3.1 OLED Display

The verification process for the OLED Display required us to display text on the screen and make sure that it was readable from a distance of about 10 feet. To do this, we first connected the OLED with the microcontroller and were able to send text that needed to be displayed on the screen. The next step required the WiFi module and web application to work and this was where we would verify that the rate inputted on the web application was the rate that would be displayed on the screen within 2 seconds. This step was met in our project as we were able to hit submit on the web application and almost instantly get the requested rate to display on the screen. The last aspect the OLED was used for was to count the number of drops in a 15 second window and increment the counter each time a drop was detected. This was verified with the help of the IR LED and phototransistor as they were used to detect the drop and once a drop was detected, it would increment the counter and send that information to the OLED screen. During the demo, we were able to show this by adjusting the flow rate and having the counter change values as drops were detected while the flow rate was being set. Once again, this was instantaneous as the number was changing at the same time a drop was falling in the drip chamber.

3.3.2 Web App

The verification process for the web application largely depended on the WiFi module working properly because the information such as the flow rate needed to be transmitted from the web app to the microcontroller through the ESP8266 module. The web page consisted of a text box where the user would input the desired flow rate and then hit the submit button. Once the submit button was clicked, the web page would send a request to the server. The microcontroller would process this request and verify that the correct flow rate was sent by displaying the information on the OLED screen. Once the whole system was working, this flow rate was used to move the motor so that the actual flow rate of the IV fluid would change. As shown in the demo, this was working as expected in our project. Another aspect of verification for the web app was to make sure that it worked with multiple browsers so we tested this out by submitting rates through Chrome, Safari, and Firefox and were able to get the correct values all the time. The last part was to make sure that only valid flow rates would be processed so that meant values between 10-60 gtt/min. The verification for this was simple as we would input a value outside this range and the web app would just reject the value and tell the user to input another value.

3.4 WiFi

In order to get the WiFi module to work the way we needed there were a few steps that needed to be taken starting with putting the module in the correct mode. We were able to accomplish this by using the serial monitor and checking what the response was when the device was connected. The next step was to verify that the device was able to connect to a WiFi network that was compatible with the ESP8266. This was done by using a hotspot from our phones and checking if a connection was established between the two. Lastly, we needed to make sure that the module could start a web server and that it could be accessed with the IP address provided. This requirement was met as we were able to type in the IP address given by the ESP8266 into a web browser and the web page would load up very quickly. To make sure that the web page and communication module were working properly, we would send a flow rate through the web app and make sure that the same value reached the microcontroller by displaying it on the OLED screen and by adjusting the motor as necessary.

3.5 Power

The main requirements of the power subsystem were that it could supply a max of 1.5 A at 3.3 V and 1.5 A at 5 V and that the voltages were smooth both without and with a load. A 2 Ω 10 W and a 3.3 Ω 10 W resistors were connected to the output for the power subsystem. The current across both were measured with an oscilloscope and it was found that the peak current was 1.5A, which satisfies the requirement. Load testing was done using various resistors to achieve the load specified in the table below. As figure 3.4 shows, there was minimal voltage drop even under heavy loads.

Expected:	3.3 V	5 V
No Load:	3.39 V	5.03 V
1A Load:	3.27 V	4.99 V
1.5A Load:	3.23 V	4.96 V

Figure 3.4. Expected v. Measured Voltages of Power Subsystem

Figure 3.5 displays the smoothness of the 5 V voltage signal. The average peak to peak amplitude was minimal enough to satisfy our requirement of a smooth voltage signal. The signal for 3.3 V was similar.

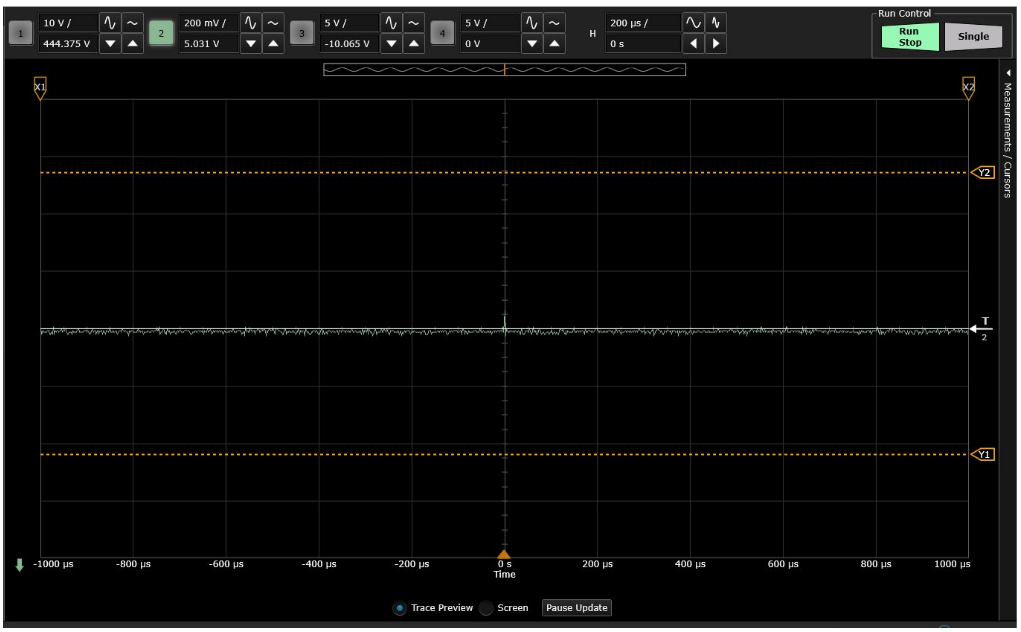

Figure 3.5. Oscilloscope Output for 5 V Supply

3.6 Microcontroller

The ATmega328 needed to be able to transmit data over I2C and SPI quickly enough to allow for instant changes to the Statistics subsystem. We created a USP SPI bridge and sent 500KB of information, which was determined to be more than enough than our initial estimate of 3MB, and received this information on the microcontroller in under 0.5ms. This speed is fast enough to provide a live update of the statistics

4. Costs

4.1 Parts

The total cost of the parts is **$92.36**. A breakdown is in figure 4.1.

Part	**MFT**	**Price**	**QTY**	**Total**
60 DPM NEEDLELESS IV ADMIN SET	BoundTree	$6.99	1	$6.99
IV bag - 500ml	Allivet	$7.99	1	$7.99
ATmega328	Atmel	$4.25	1	$4.25
Continuous Digital Servo Motor	YANSHON	$11.99	1	$11.99
Infrared Emitter 940nm - NTE30132	NTE	$0.50	1	$0.50
Infrared Phototransistor 940nm - NTE30133	NTE	$0.5	1	$0.50
Capacitors, diodes, ICs, resistors, buttons, switches, misc	-	-	-	$10
0.96 Inch OLED Module	UCTRONICS	$6.99	1	$6.99
ESP8266 ESP-01S WiFi Serial Transceiver	DIYmall	$5.49	1	$5.49
FlexiForce Pressure Sensor	FlexiForce	$24.95	1	$24.95
Linear Voltage Regulator LM1086CT-5.0	Texas Instruments	$1.86	1	$1.86
Linear Voltage Regulator LM1086CT-3.3	Texas Instruments	$1.86	1	$1.86
12 V 5 A power Supply	LEDMO	$8.99	1	$8.99
Total				**$92.36**

Figure 4.1. Cost Breakdown

4.2 Labor

Our costs to develop this system comes out to 45 dollars an hour for 10 hours a week assuming three people are working on it. This semester includes about 75% of our final design, since it does not include the ability to maintain pressure for potentially multiple IV lines. With the above estimates, we expect our project to cost, without the parts, approximately:

3 * $45/hr * 10hr / week * 16weeks/0.75 = **28,800 dollars**

5. Conclusion

5.1 Accomplishments

Our project successfully accomplished the goals that we set. We were able to set a drip rate using a web application on our phone. After submitting a drip rate, we saw our motor start to immediately adjust the pressure in the tube and count the number of drops and automatically adjust itself to find the correct drip rate. After finding the correct drip rate, we were able to display all the necessary information on the OLED display such as the current drip rate, the amount of force being exerted on the tube etc.

Our error handling was also successful. In the event that we need to completely shut off IV delivery, our motor can apply max pressure to prevent any fluid from dripping, which was verified by seeing that the drip detector did not count any drops. Also, in the event of a power outage we demonstrated that we could maintain the same pressure and therefore would not lose track of a patient's drip rate. These critical decisions allowed us to hold the patients' safety to the highest standard.

5.2 Ethical Considerations

Automating the way IV fluid is delivered to the patient does pose certain, manageable safety hazards. Some of these hazards occur when a battery dies or when a motor fails. When it comes to part failure, we run the risk of creating an unconstrained flow of liquid into a person's body. In instances, when these occur we have an emergency "shut-off" that immediately cuts off all distribution of IV fluid, and notifies the nurse by sending a push notification through the web app, as well as lighting a certain LED in the OLED panel to physically indicate this. The shutoff is triggered either when the motor is unresponsive or when the force sensor detects a force beyond the ideal range.

There are times when internet connection at hospitals become unreliable due to geographical location, inclement weather or other unforeseeable issue. In these cases, the nurse can still manually adjust the clamp, as is the current default method.

In terms of ethics, there may be ethical concerns that we, as the developers of this product, may have access to the medical data of patients but we do not be storing any of this data ourselves in order to comply with HIPAA privacy rules and regulations.

According to the IEEE Code of Ethics #1 [10], we see that it is important "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment". To make sure that we align with these codes of ethics we will share information regarding our parts lifetime to try to predict any upcoming failures so that we can always hold the people's safety and health with the utmost importance.

Looking at the Food and Drug Administrations Identification of an Intravascular administration set [11], it is clear that we are still within the specified guidelines and are only modifying the way it is administered. Because we are not changing the actual physical properties of how an intravascular administration set works and the components that go into it, we are still within the FDA guidelines.

5.3 Future Work

For future work, we are looking into adding more security features to the WiFi subsystem. At the moment, the Wifi subsystem only works on WPA2 networks, but many hospitals use a closed WPA2 Enterprise network for staff and devices. Adding this extra layer would also provide the extra security that the network has. Another feature is a login method so that only IV-administration trained and certified medical staff can control IV drips. This could also be used to only allow relevant staff to have access to a patient's IV regulator.

The pressure box also showed mechanical challenges along the way. At times, the servo would bind up due to threads seizing. A redesign of the pressure box to use a positional servo and to more closely follow the methodology of a traditional roller clamp would allow us to reduce some mechanical issues and also reduce costs.

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Appendix A: Requirements and Verifications Table

Requirements	Verification	Verification Status (Y/N)
DRIP DETECTION *IR and Phototransistor* 1. Emitter and detector must have matching wavelengths. 2. Infrared wavelength system, between 700nm to 1mm, to avoid light bleed from ambient light. 3. Fast enough response time to detect a falling drop of water. *Drip Chamber* 1. Drop sizes are between 10 to 20 mL. 2. The drip chamber size is between 0.13 inches to 0.27 inches in diameter	*IR and Phototransistor* 1. Power the IR emitter with 5 V of 20 mA continuous forward current for a peak wavelength of 940 nm. Add a resistor for a 1.2-1.5 V drop. Provide the detector with 5 V emitter-collector voltage and 20mA. Saturation voltage for the detector, a transistor, is 0.4 V. Point the two devices towards each other to see if the detector emits a non-zero voltage. 2. Repeat steps for Verification 1. Test the receiver under various room-condition light sources and check for a very low to no signal. 3. Repeat steps for Verification 1. Check for a lower reading by dropping water between the transmitter and receiver. Detector has a 30 µs rise and fall cycle, which should be satisfactory to detect a drop of water falling at 10m/s. *Drip Chamber* 1. Measure output of a drip chamber to ensure that each drop is between 10 to 20 mL 2. Measure the circumference of a drip chamber and divide by pi to ensure the diameter also fits the requirements	Y
DRIP CONTROLLER *Servo Motor* 1. Input: 5 V at 210 mA operating current 2. Ability to control rate and	*Servo Motor* 1. Provide 5V to the motor. Send pulses of width 1500 µs +/- 500 µs. Measure operating current draw across the motor with an oscilloscope. 2, 3. Use an oscilloscope to set custom pulse-width	Y

direction of rotation. 3. Pulse width range 500-2500 µs with neutral position at 1500 µs *Force Sensor* 1. Must be able to measure force exerted between the pressure box and tube (0 lb - 10 lb). *Pressure Box* 1. Make sure that we can place the tube between the pressure box 2. Squeeze the tube using the pressure box and make sure the tube doesn't get damaged as pressure increases	controls and measure rate of rotation at different widths. Check that a pulse-width of 1500 µs stalls the motor. Check that a range between 500-1000 µs turns the motor clockwise and a range of 1000-2000 µs turns it counterclockwise. 1. A. Place the sensor on the pressure box and make contact with the tube. B. Continue to increase the pressure on the tube from the pressure box by sending a 500-1000 µs pulse width to move the motor clockwise. C. Measure the output signal amplified by the op-amp in terms of voltage_out *Pressure Box* 1. A. Attach the pressure box to the tube by placing it around the tube. B. Hold the tube to one side of the pressure box. 2. A. Exert force on the tube using a servo motor to push the delrin piece into the tube. Use a very slow rate to turn the motor - a pulse within 1000 +/- 500 µs. B. Check that the tube still allows liquid to flow properly and isn't broken. C. Find maximum pressure that causes permanent damage to the tube.	
STATISTICS *OLED Display* 1. Receivers the data from the data bus and updates information on the display every 200 ms and is visible from 10ft away *Web App* 1. Viewable from a personal computer on popular browsers (Chrome, Mozilla) 2. Can modify drip rate of	 *OLED Display* 1. A. Set the flow rate on the app and send it to the data bus. B. Check how long it takes for the display to update the rate C. Measure 10 ft from the OLED and check that it can be read easily *Web App* 1. Viewable from a personal computer on popular browsers (Chrome, Mozilla)	Y

system 3. Can display statistics from drip controller	2. Can modify drip rate of system 3. Can display statistics from drip controller	
WIFI 1. Must be able to communicate over WiFi 2. Minimum WiFi connection speeds of 3 Mbps	1, 2. A. Connect to the ESP8266 over SPI protocol and UART protocol. B. Send an HTML page of 6 Mb over specified protocol C. Connect to network with a laptop D. Check that data loads in web app within 2 seconds	Y
POWER 1. Input 7-14 V within -40 °C to 125 °C operating temperatures of linear regulators. 2. Outputs around 1.5 A at 3.3 V and 5 V 3. Constant, smooth DC 3.3 V and 5 V voltage at 0A and 1 A each	1. Input 12V and measure output voltages. The main concern is the heat dissipation for the 3.3 V linear regulator due to a larger power loss than the 5 V linear regulator. We use a temperature sensor to check that the 3.3V regulator remains under 125 °C with the heatsink. 2. Use an oscilloscope to measure voltage and output current. 3. Check voltage drop, and measure noise both under a load and not under a load. We chose 1 A for load testing each voltage level since we do not plan to exceed this amount of current draw with our circuit. For testing under a load, we will use a resistor that will result in a 1 A drop. We will note the change in the voltage compared to not under a load. This will be done for each voltage level.	Y
MICROCONTROLLER 1. Can receive and transmit over SPI at around 3Mbps or faster	1. Create a USP SPI bridge and send information (3MB) to the microcontroller and also send this information back to the computer and confirm that the total time taken is 2 seconds or less.	Y