Cover Page

Executive Summary

The Cystoscopy Department at St. Michael's Hospital extensively utilizes continuous bladder irrigation (CBI) in endoscopic surgeries to expand the surgeons' operative field and to clear bleeding from the surgical site. During these surgeries, nursing staff are responsible for monitoring the irrigation bags and for manually changing them out to maintain continuous irrigation flow. However, irrigation bags often run dry without nurses noticing, resulting in longer surgery times and safety concerns. The system for changing out the bags is also uncomfortable for nurses to use: Shorter nurses often complain about being unable to reach the bags, and the repetitive loads exerted on nurses' shoulders in trying to lift these bags have resulted in numerous injuries.

IrriGREAT, our proposed design, aims to remedy the issue of maintaining continuous irrigation flow during urology surgeries while addressing the ergonomics and accessibility of the irrigation system. Our device consists of 3 main components: (1) a redesigned IV pole to assist nurses in loading irrigation bags, (2) an automatic pinch valve that switches between loaded irrigation bags without the need for manual nurse intervention, and (3) an LED visual indication system to enable nurses to more easily discern relative irrigation levels. The estimated cost for IrriGREAT is $480, below the maximum budget of $500.

The functionality of our design was verified with both a high-fidelity physical prototype as well as theoretical calculations and considerations. However, due to time constraints, validation testing has yet to be performed on the fully integrated design. Validation tests such as mock operating room simulations and user surveys are outlined along with next steps for the design if work on this project is continued in the future, either by the design team or by the Cystoscopy Department at St. Michael's Hospital.

Acknowledgements

First and foremost, the design team would like to thank Dr. Monica Farcas, Mr. Brian Carrillo, and Ms. Sophia Duong for their help and guidance over the course of the semester. The team would like to thank you all for providing us with the opportunity to work on this project along with the willingness to take time to answer any questions we had.

Secondly, the team would like to thank Professor Chris Bouwmeester, Ms. Karly Franz, and Ms. Arushri Swarup for their support and guidance during the semester. Specifically, we would like to acknowledge the tremendous amount of effort they provided the team through the design process. Additionally, we truly appreciate their willingness to always take some time to answer any questions we had and provide us with the resources to advance our project.

The team would also like to thank Mr. George Matyas for his help in the design studio. His willingness to make time to answer any questions the team had was invaluable. Additionally, his involvement in the 3D printing portion of the project was indispensable.

Lastly, the team would like to thank the other groups in the class. The questions and suggestions during our bi-weekly presentations provided valuable insight that allowed us to better our project.

Table of Contents

1. Introduction

1.1 Background

Continuous bladder irrigation (CBI) is a procedure most commonly used during and after urologic surgeries, especially in those involving an endoscopic approach [1]. During CBI, the bladder is continuously irrigated with a sterile solution for many purposes. Specifically, during a procedure, the irrigation fluid expands the operative field, clears debris, prevents bleeding and dissipates heat from the other medical devices used [2]. Similarly, CBI that is performed post-operatively prevents any clot formations that may occur in the bladder [3] as the patient recovers. Proper irrigation in both environments is a necessity, as it helps facilitate a safe and efficient performance of the procedure [2].

During surgical procedures, the irrigation flow rate is controlled by the surgeon and is determined based on an optimal field of vision, while the nursing staff control the flow rate post-surgery in the ward, based on the drainage colour [3]. While continuous fluid irrigation can either be operated on an active or passive system, passive systems are more commonly used due to affordability, simplicity and decreased risk of stone migration in comparison to active systems [4] [5]. However, while passive systems (or gravity-fed) are preferred, challenges using this system include increasing flow pressure when desired to improve the field of view [6].

Currently, the gravity fed irrigation system employed in the Cystoscopy Department at St. Michael's Hospital relies on the nursing staff to constantly monitor, and replace the empty bags containing irrigation fluid (in addition to numerous other tasks) in order to maintain continuous flow in surgeries [7]. However, oftentimes empty bags are left unnoticed, increasing surgery times and safety risks which make the system unreliable and time-consuming [8]. Similarly, because the gravity-fed system requires the irrigation fluid to be located at a certain height, most nurses often times experience repetitive injury and fatigue in an attempt to switch out the empty bags, making the current solution a safety risk [7].

Improving the current solution employed by St. Michael's Hospital has the potential to increase efficiency in workflow during surgeries, and reduce safety risks in both environments. Creating a solution that is more reliable and self-sustained will minimize the risk of errors (such as empty bags being forgotten), decrease surgery times (due to manual labour of switching out bags), and improve the ergonomics and ease of use for nurses experiencing repetitive injuries in both the ward and surgical environments. Current solutions lack the level of automation required to create a self-sustained, reliable system that is affordable. Therefore, this project aims to solve the need to address disruption in irrigation flow during urologic surgeries to improve the efficiency, reliability, and safety of surgical procedures.

1.2 Project Requirements

The overall objective of this project is to prototype a device that reduces the number of incidents of disrupted irrigation flow in urology surgeries at St. Michael's Hospital. This overall objective can be broken down into 2 sub-objectives: (1) improving the usability of the irrigation system for the nurses who are responsible for monitoring and interacting with the system, and (2) partially automating the irrigation process to make the system more reliable and self-sustaining. The following table outlines the detailed project requirements and their associated validation and verification tests.

Table 1: Project requirements and associated tests.

Objectives	Metrics	Functional Requirements & Constraints	Verification & Validation
Maintain continuous flow	Average rate of incidents of disrupted flow during urology surgeries (measured via survey)	Target: 0 Must not exceed rate with current system	Survey (see Section 3.3 and Appendix F)
	Range of flow rates accommodated by irrigation system, as measured by range of heights of irrigant bag in gravity-driven systems	Must accommodate current range of heights (between 5 feet to 8 feet [9]) or the equivalent flow rates	Device design (see Section 3.1.1)
Improve reliability of irrigation system	Average rate at which nurses physically interact with the irrigation system	Target: Less than or equal to the current solution rate	Human factors testing & survey (see Section 3.3 and Appendix F)

Improve ease of monitoring irrigant levels	Average time between when an irrigant bag is < 25% full and when a nurse notices	Must not exceed 4 minutes, the average time for 25% of the bag to empty [7]	Human factors testing (see Section 3.3 and Appendix F)
	Average time taken during a surgery monitoring and interacting with bags (measured via survey)	Target: Less than or equal to the current solution time	Survey (see Section 3.3 and Appendix F)
Improve the ergonomics and accessibility of the irrigation system	Height (cm) of bag from ground when changing	Bag must be reachable by a 151.4 cm individual, the average Filipino female height [10] (representing a significant portion of the nursing staff [7])	Device design (see Section 3.1.1)
	Load (kg) lifted by nurses when changing out one irrigant bag	Must not exceed 5 kg, the recommended weight limit for lifting in the current situation [11]	Load calculation (see Section 3.1.2)
Be feasible for client to implement	Surface area (cm^2) of ground that device takes up	At most twice the floor space taken up by the current solution, which is estimated to take up 1641.7 cm^2 [9]	Area calculation (see Section 3.1.1)
	Cost of device in CAD	Must not exceed $500, the project budget	Cost calculation (see Appendix G)
	Should be compatible with existing 3L irrigant bags		Device design (see Section 3.1.1)
	Must not stop or disrupt flow when any loaded bag contains at least 100 mL of irrigation		Flow testing (see Section 3.2.2)

2. Final Design

2.1 System Level Overview

The system level overview for IrriGREAT, the final design, can be separated into mechanical and electronic subsystems with their associated modules, which include all of the discussed design components. A system-level block diagram and the latest physical prototype fabricated is shown in Figure 2.1.1 below while Blender renderings of the proposed design can be found in Appendix A. The purpose of the overall mechanical subsystem is to make the process of loading irrigation bags more ergonomic for nurses. On the other hand, the purpose of the overall electronic subsystem is to partially automate the irrigation system by switching between loaded irrigation bags and to monitor and indicate irrigation levels in each bag. Further details pertaining to each module are discussed below.

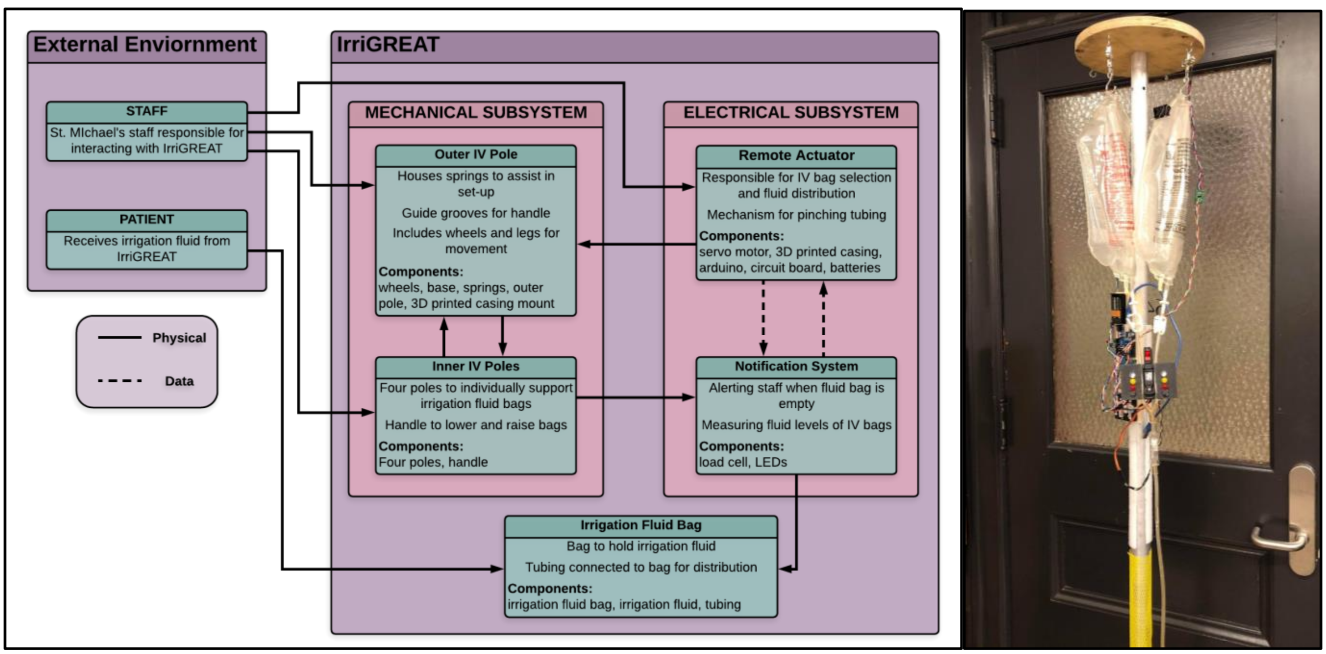

Figure 2.1.1: (Left) System-level block diagram and (right) latest physical prototype of IrriGREAT.

2.2 Module Level Overview

2.2.1 Mechanical Subsystem - Outer IV Pole

Physically interacts with: inner IV pole, staff module, remote actuator

The outer IV pole is compartmentalized into four equal sections to contain four smaller poles with hooks to which solution bags attach to. Beneath each inner pole sits a compression spring which assist in the loading and unloading of the bags. Grooves have been manufactured on the outer pole to serve as a guide to help staff when lifting and lowering the inner pole (see Appendix A, Fig. A.2). The IV pole is mounted onto a 6-legged spider base due to its low center of gravity, which provides overall stability to the system (see Appendix A, Fig. A.2). Like many other hospital equipment (e.g., the current IV pole), the outer pole will be made of stainless steel for its corrosion resistance, fire and heat resistance, high strength, and lower electrical conductivity. This module is directly connected to the staff who are responsible for setting up and monitoring (this includes both the irrigant fluid bags and remote actuator) is contained on the IV pole.

2.2.2 Mechanical Subsystem - Inner IV Pole

Physically interacts with: outer IV pole, notification system, staff

The four inner poles housed within the outer pole each individually support an irrigant fluid bag (see Appendix A, Fig. A.2). Each pole has a handle to promote ease of movement and eliminates the current the need for nurses to raise their hands above their shoulders to lift and load the bag. The handle restricts any hand movement to be within the power zone, as defined by the Occupational Safety and Health Administration (OSHA) [12]. For its material, like the outer pole, the inner poles will be made of stainless steel. The inner IV poles are physically connected to load cells which detect the amount of fluid left in each bag. This module is thus connected to the notification system module and the staff who interact with the inner pole when replacing the irrigant bags.

2.2.3 Electronic Subsystem - Remote Actuator

Physically interacts with: outer IV pole, staff. Data interaction: notification system

The remote actuator is responsible for maintaining continuous flow between two bags by physically pinching the tubing connected to one bag, allowing irrigant fluid in the second bag to flow freely. The remote actuator is a high-torque (17 kg*cm) servo motor that is controlled using Arduino Uno and powered by a separate power supply of 4 AA batteries (6V), while the pinch valve consists of a bespoke 3D printed housing and flange attachment for the servo motor arm. The pinch valve is designed to only pinch off at most one bag such that in the event of device failure, irrigation flow through at least one bag would remain.

The 3D printed pinch valve casing serves as the housing for various electrical components, while also providing mechanical support (see Figure 2.2.3.1a below for a design schematic of the housing). The housing consists of two cylindrical channels down its length that secure the tubing via friction. A central clearing allows for the attachment of the remote actuator to the housing. Furthermore, the housing incorporates a “rotational clearing” that allows the remote actuator to rotate freely and pinch the tubing. Moreover, the space allocated for the “rotational clearing” also serves as a conduit for the tubing to deform while being pinched (thus reducing the force required). Additionally, anchor points for the electrical components and notification system were incorporated into the back side of the housing. To achieve the pinching of the tubing, a bespoke flange was also created. The flange fits over a standard servo arm and consists of two protrusions on each side (see Figure 2.2.3.1b below for a design schematic of the flange) that allows for force to be exerted on a smaller surface area. Thus, the torque provided by the servo can be efficiently transmitted to the tubing through the small area, resulting in a greater depression into the tubing (and better pinching). For further images and information regarding the evolution of the housing and flange design, see Appendix E: CAD Models and 3D Prints.

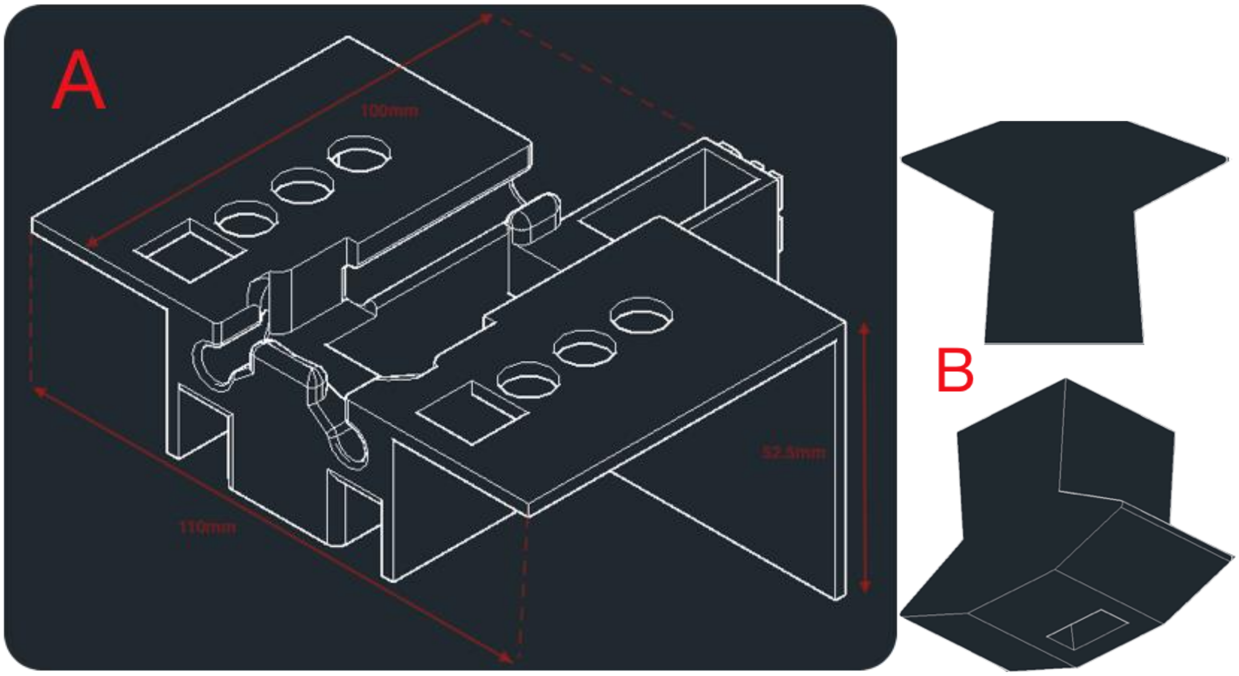

Figure 2.2.3.1: (a) Design Schematic of Pinch Valve Housing. (b) Design Schematic of Flange

The notification system module discussed in the following section transmits information on the status of the irrigant bags to this module to control the operation of the remote actuator. Staff members physically interact with this module by pressing tare push buttons located on the casing to reset the direction of the servo motor arm. There is also a switch located at the top of the casing to turn the overall device on or off. A prototype of the assembled and wired remote actuator can be seen in Figure 2.2.3.2 below.

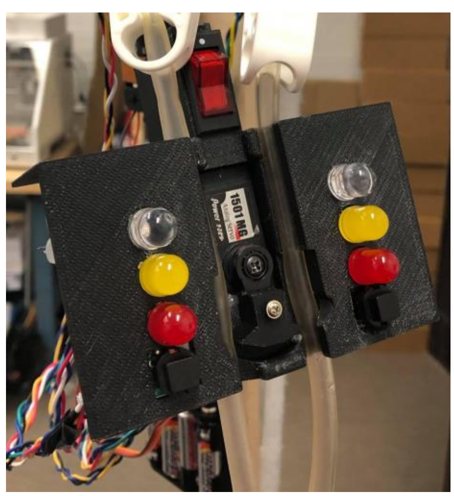

Figure 2.2.3.2: Prototype of the remote actuator and pinch valve.

2.2.4 Electronic Subsystem - Notification System

Physically interacts with: inner IV pole, irrigation fluid bag. Data interaction: remote actuator

The objective of the notification system module is to indicate the fluid levels left in each irrigant bag. Irrigation bags are hung from hooks attached to load cells, which detect the weight of the bags as they empty. The load cells are interfaced with an HX711 amplifier board to convert the analog signal to a digital one. To account for different starting weights of the irrigation system (e.g., if a pressure cuff is attached to the irrigation bag), nurses press the tare push button on the casing to indicate when they have loaded a full bag, and this weight is recorded. The reduction in weight of the irrigation bag over time is recorded, as it is representative of the amount of irrigation fluid lost and can range anywhere from 0 kg (when full) to 3 kg (when empty). To account for potential noise from pulling of the IV tubing, only small, incremental changes are saved, while large, high-frequency changes are ignored.

Three different LEDs (green, yellow, and red) are used as visual indicators of how much fluid is left, which can be seen in Figure 2.2.3.2. When 1.5 kg of fluid is left (this is equivalent to 1.5 L or approximately 50% of the bag), the green LED turns off and a yellow LED turns on. Similarly, when 0.1 kg of fluid is left, the yellow LED turns off and a flashing red LED is turned on to attract attention to the system. The notification system module sends information on the weight of the bag to the remote actuator module and is physically connected to the inner IV pole and irrigant fluid bags module via the load cells. The Arduino code to control this process is outlined in Appendix C, and the circuit schematic for the entire electronic subsystem is shown in Appendix D.

2.2.5 Irrigation Fluid Bag

Physically interacts with: patient, notification system

Patients receive the irrigation fluid contained in the 3L bags during surgery and therefore, are physically connected to the irrigation fluid bag module. The notification system module is physically connected to the irrigation fluid bags via load cells.

2.2.6 External Environment

Physically interacts with: remote actuator, outer IV pole, inner IV pole, irrigation fluid bags

The external environment system consists of two modules: staff and patient. The patient directly receives the irrigation fluid and is therefore physically connected to the irrigant fluid bag. The staff directly interact with not only the bags, but also the outer and inner IV poles, and the remote actuator mounted on the outer pole.

3. Assessment of Final Design

Assessment of IrriGREAT's individual mechanical and electronic subsystems compared to the project requirements is outlined in the sections below. Due to time constraints and a device redesign partway through the project schedule, a high-fidelity prototype with both integrated subsystems and validation testing of the overall design were unable to be completed. However, preliminary verification of the mechanical subsystem and functionality testing of the electronic system are outlined in the sections below. Validation and human factors testing of the final design at the system level is also discussed, which can be later pursued if work continues on this device.

3.1 Mechanical Subsystem: Spring-Based IV Pole

3.1.1 Evaluation Against Project Requirements

Table 1 in Section 1.2 outlines the objectives for the project, and although most objectives are similar to when the proposal was written, there is no longer the constraint of having no electronic components as part of the design. The table below outlines the specific objectives which the mechanical subsystem meets, and provides a reason as to why the proposed design achieves this.

Table 2: Project requirements related to the prototype addressing the mechanical subsystem.

Objectives	Functional Requirements & Constraints	Requirement Met?	Reason
Maintain continuous flow	Target: 0 incidents of disrupted flow Must not exceed rate with current system	**Yes**	Since the proposed design has four individual hooks, each bag is independent of the others and therefore can never interfere with the flow of the other bags.
	Must accommodate current range of flow rates (defined through heights - between 5 feet to 8 feet [9])) or the equivalent flow rates	**Yes**	The proposed design reaches a minimum height of 5.5 feet, which is shorter than the current IV poles, and reaches a maximum height of 8 feet, which is the maximum height currently used at St. Michael's Hospital.
Improve the ergonomics and accessibility of the irrigation system	Bag must be reachable by a 151.4 cm individual, the average Filipino female height [10] (representing a significant portion of the nursing staff [7])	**Yes**	The minimum height the proposed design reaches is 5.5 feet, which is accessible by an individual who is 151.4cm. Future iterations of the prototype can extend the grooves such that the IV pole is lowered even more, if necessary.
	Must not exceed 5 kg, the recommended weight limit for lifting in the current situation [11]	**Yes**	The amount of force calculated to lift the bag is approximately 20 N of force, which is the equivalent to approximately 2 kg. The nurse would at most load one bag at a time
Be feasible for client to implement	At most twice the floor space taken up by the current solution, which is estimated to take up 1641.7 cm^2 [9]	**Yes**	Although the diameter of the proposed IV pole is approximately twice as much as the current IV pole used, the height is the same and the space taken up is not increased due to the elimination of the exterior handle that was implemented on the current IV pole
	Must not exceed $500, the project budget	**Yes**	The estimated cost for the mechanical subsystem is $320.23. The combined cost for IrriGREAT is $479.54, which is less than $500. (see Appendix G: Estimated Cost for IrriGREAT)
	Should be compatible with existing 3L irrigant bags	**Yes**	Hooks have been installed and tested on the current IV prototype to verify compatibility

3.1.2 Calculations

Both the current and proposed design were verified through calculations which identified the amount of force needed to lift the IV pole, and compress the pole without the weight of the bags (either with one bag in the proposed design or two bags in the prototype). Both these calculations were compared against the current situation experienced at St. Michaels as can be seen in Table 3 below. Additional details about these calculations can be found in Appendix B: Calculations for Mechanical Subsystem.

Table 3: Calculation comparison between current IV pole, latest prototype built, and proposed design.

	Force required to lift bag [N]	Force required to compress IV pole [N]
@ St. Michael's currently	30	30
Current prototype	64	69
Proposed design [1]	29	29
Proposed design [2]	20	20

1: Proposed design with handle located 0.06m from the top of the groove
2: Proposed design with handle located 0.29m from the top of the groove

3.1.3 Verification and Validation Tests

Force Applied

While experimental tests of the force required to lift and lower the bags has been done on the current prototype, only theoretical analysis and calculation have been done to validate the force needed for the proposed designs (see Table 3 above). This means that the proposed design must be fabricated and experimental tests for the force to lift and lower the bags must be performed to validate the design. This experimental test will also be used to validate the height of the bags once they are lowered and raised such that they match the displacements achieved with the current prototype.

Stability

It is also important to confirm the stability of the physical design. There will be a torque applied to the poles when the handle is being used to lift and lower the irrigant fluid bags, and this torque must not cause the design to topple over or to deform; this will be confirmed experimentally when the proposed design is manufactured. The design should also be able to withstand at least two IV irrigant fluid bags and must not toppled over, in case a situation arises where a nurse feels the need to place two bags on one hook.

Structural Integrity

The outer IV pole will contain grooves for each of the individual inner IV poles which hold one irrigant fluid bag, each. The grooves manufactured on the outer IV pole are not only meant to lower and raise the inner IV poles to a maximum and minimum height, but they also provide slots in between the maximum and minimum heights to allow for different flow rates, based on the height due to gravity's impact. The dimensions of the these slots on the outer IV pole at these specific heights must be carefully designed so the structural integrity at the specific cross sections does not diminish. Namely, the thickness of the grooves for these slots needs to be calculated such that enough material is still left at those specific cross sections. Generally, stress experienced by the IV pole should not exceed half the yield stress of the IV pole material.

Sterilizability

According to Infection Prevention and Control in Public Health Ontario, IV poles are classified as a low-level disinfection, non critical equipment/device. While cleaning methods are dependent on the manufacturer's instructions, typical methods used for sterilization include: 3% hydrogen peroxide, 60-95% alcohol and sodium hypochlorite [13]. The proposed IV pole can be disassembled into the following components: four aluminum rods, springs pertaining to each pole, handles for each pole, a 5 foot aluminum rod, and a base. Once the IV pole is disassembled, each component can be individually cleaned, if needed. IV poles are typically cleaned in case of accidents, and are not cleaned after each surgery.

Safety

General safety standards for IV poles can be found in the following ISO standards: ISO 8536-4 (2010), ISO 8536-5 (2004), ISO 8536-13 (2016). These documents provide additional tests needed to be performed in order for the proposed design to approved by Health Canada, and includes tests needed to be performed for the proposed design's risk assessment.

3.2 Electronic Subsystem: Automated Bag Switch Over

The purpose of the electronic subsystem is to automate the process of switching between multiple loaded irrigation bags and to allow nurses to more easily discern when irrigation bags need to be replaced with an LED indication system. The project objectives that this subsystem addresses as well as how they are met are outlined in Table 4 below. The following subsections outline testing and considerations that assess and verify the functionality of the subsystem; however, validation testing in the context of the OR has yet to be performed and is discussed in Section 3.3.

Table 4: Project requirements related to the prototype addressing the electronic subsystem.

Objectives	Functional Requirements & Constraints	Requirement Met?	Reason
Maintain continuous flow	Target: 0 incidents of disrupted flow Must not exceed rate with current system	**Yes**	The pinch valve and automatic switchover mechanism was tested to not cause any additional disturbances in flow (see Section 3.2.2).
Improve reliability of irrigation system	Target: reduced rate at which physically interact with the irrigation system compared to the current system	**Yes**	The automatic switchover mechanism effectively halves the number of times that nurses must physically interact with the irrigation system, as they would no longer have to manually clamp and unclamp bags as one runs dry.
Improve ease of monitoring irrigant levels	Average time between when an irrigant bag is < 25% full and when a nurse notices	**TBD**	The performance of the device in addressing this requirement can only be determined with validation testing (e.g., mock OR simulation) of the overall system.
	Average time taken during a surgery monitoring and interacting with bags (measured via survey)	**TBD**	The performance of the device in addressing this requirement can only be determined with validation testing (e.g., mock OR simulation) of the overall system.
Be feasible for client to implement	Cost of device in CAD must not exceed $500	**Yes**	The estimated cost for the electronic subsystem is $159.31. The combined device cost is $479.54, which is less than $500. (see Appendix G: Estimated Cost for IrriGREAT)

3.2.1 Load Cell Resolution

The resolution of both of the acquired load cells was tested by measuring the weight of various objects and comparing it to the corresponding weight measured by a scale with a resolution of 0.01 g. After calibration, the load cells' resolution was experimentally found to be ±10 g, consistent with the advertised resolution. However, the acquired load cells were discovered to suffer from creep over time with a constant load of 3 kg from the irrigation bag. Namely, upon loading a single unspiked irrigation bag, the load cell reading decreased by 200 grams over a period of 2 minutes and continued to fluctuate around 2.8 kg for the remainder of the test. Thus, the practical resolution of the sensor is on the order of

100-200 grams, unless the creep behavior of the sensor is characterized through further testing and compensated for accordingly.

3.2.2 Pinch Valve Flow Stoppage

The ability of the pinch valve to fully pinch off the IV tubing was tested by inserting the tubing into the pinch valve, attaching a filled irrigation bag to the system, and observing whether the servo motor and flange are able to completely stop flow. Iterations of flanges were tested alongside a high-torque servo motor (17 kg*cm) to determine an ideal flange shape. Overall, the pinch valve with the final flange shape was found to drastically reduce flow, with only residual drops remaining downstream of the pinch valve. To highlight the testing, a video regarding the functionality of the pinch mechanism can be seen here [14]. Additionally, the servo and flange attachment did not visibly damage the IV tubing during the course of testing. In fact, there was no damage visible even though a total of two tubing systems were used throughout the entire testing process. The repeated exposure of the tubing systems to the pinch mechanism identified the durability. Moreover, the use of new tubing (due to sterility) for each surgery will further limit the risk of damage inflicted by the pinch mechanism over time. To increase the longevity of the pinch mechanism, a servo motor of higher torque could be considered. Operating under the maximum torque output could reduce any stress to the motor. However, this would introduce a higher power consumption and potential damage to the IV tubing. Conversely, a gear system could be incorporated with the current spec servo. The gearing could magnify the force transmitted to the tubing while maintaining the current power consumption.

3.2.3 Battery Life

The high-torque servo motor operates on a separate 4 AA battery supply (6V) from the Arduino due to its high power demand. While the relevant datasheet states that the motor has a stall current of 2.5 A when operated at 6V, the measured current delivered to the servo while pinching the IV tubing was determined to initially spike at 1.25 A and quickly drop down to 0.55 A [15]. Assuming a battery capacity of 2500 mAh, the 4 AA batteries are able to supply approximately 4.5 hours of pinching until a battery change is required, exceeding the maximum time for a single operation (up to 3 hours). To improve the device's battery life, a second 4 AA battery supply could be placed in parallel to the existing supply to effectively double the capacity.

3.2.4 Integrated Electronics Subsystem Testing

The overall functionality of the integrated electronic subsystem was tested by loading 2 irrigation bags onto the IV pole prototype, turning on the device, and allowing for irrigation flow through the IV tubing. A time-lapse video of one such test can be found in [16]. Overall, the LEDs switch on and off according to the relative irrigant levels in each bag, and the pinch valve successfully switches between bags without disruption in flow. However, the irrigant level at which the LED light turns red and the pinch valve switches to the opposite bag varied by up to 100 mL between load cells and from test to test. This error could be due to a combination of sensor creep, noise, and inherent differences between individual sensors. Consequently, the threshold for switching is set to 0.1 kg to ensure that irrigation flow is never prematurely disrupted by the switchover.

3.3 Final Design Assessment

Final verification and validation tests will be performed for the final, integrated proposed design. Due to the time constraints of the project, the tests outlined in the proposal were not able to be performed on time (see Appendix F: Verification and Validation Tests for a table outlining these tests). However, the main validation tests which must be performed in order to deliver a successful product are listed in Table 5 below.

Table 5: Validation testing on overall design.

Objective*	**Test**	**Test Description**	**Justification**
High-level Objective: Assess the functionality of device in OR simulation			
Maintain continuous flow	Time taken for users to replace empty bags	The moderator will begin recording time once the user	The new system must improve ease of use and

		begins to lower the IV pole of the empty bag and the task will be considered complete once a new, full bag is loaded and the IV pole is raised to the desired height	because the nurses already have indicated their limited time spent with this system, the time to replace bags must not be greater than the current system
Maintain continuous flow	Recording of how many times the irrigation flow was stopped throughout the surgery simulation	The moderator will record the number of times the irrigation flow has stopped, or how many times there has been a disruption of continuous flow (ie. introduction of bubbles) throughout the surgery duration	The new system must not introduce any disruptions in continuous flow, otherwise it will be considered unreliable by the client and will not be used
Improve ease of monitoring irrigant levels	Time taken for the nursing staff to notice a change in LED color	Users will be asked to verbally state once they noticed a change in LED color, and the moderator will record the time elapsed since the color has actually changed and when the user had noticed this change	The notification system design will be considered successful if attention is drawn when the 1) LEDs change color 2) flashing red occurs for low irrigant levels. The time between the user noticing and the LED actually changing color should be minimized
Improve the ergonomics of the irrigation system	Amount of time taken to setup IV pole and bags prior to surgery start time	Moderator will record the amount of time taken for the users to set up the entire system (this includes setting up at least two bags at the desired height) prior to surgery	Due to the limited amount of time nurses are able to spend interacting with the irrigation system, the setup time should be minimized and must not take longer than the current set up
Improve the ergonomics of the irrigation system	Total amount of time users spend interacting with system during surgery time	Moderator will record start and stop times each time the user is required to interact with the system during the duration of the surgery	The new system must not increase the amount of time users are required to interact with the system, due to the many other tasks the nursing staff are responsible for
High-level Objective: Assess repetitive strain from users			
Improve the ease of use and accessibility of the irrigation system	Testing ease of use by comparing new and old arm motions required to operate system	Users perform: 1) the old arm motion (arms over the shoulder) required to load the bags and 2) the current arm motion (within the power zone) to load the bags and state their preference	The new system requires users to exert a force within the power zone boundaries, as defined by OSHA to improve ergonomics and ease of use. The new system must be easier to use than currently
Improve the ease of use and accessibility of the irrigation system	Long term survey (after ~1 month of use)	Users will be asked to assess the ease of using the new system, compared to the old system following one month	One month after implementation provides opportunity for repetitive strain injury to arise, if the

		after implementation	new system has not been successfully designed to restrict this from occurring

*: Objectives taken from Project Requirements stated in Section 1.2.

4. Summary and Conclusions

When comparing IrriGREAT to the original project goals and requirements, it can be argued that the goals and requirements were met. Through the testing process, the efficacy of the proposed design was compared with the current solution. Moreover, it was found that the proposed solution performed better than the current standard. The introduction of an automated bag switchover system that helped improve maintain continuous flow while also increasing the reliability of the irrigation system (by removing human error). Furthermore, the integrated notification system allowed for easier monitoring of irrigant levels due to the presence of visual indicators. By redesigning the IV pole to incorporate a spring-loaded mechanism, the design facilitates the changing of bags, thus improving the accessibility and ergonomics of the system for the nurses. Lastly, the minimalist design and compatibility with current equipment in the operating room allows the proposed design to be more readily implementable within the hospital.

The current design serves as a high-fidelity prototype and shows functionality as a replacement for the current irrigation system employed in hospitals. However, there are some limitations of the current design that require further refinement. The current design incorporates an early version of the spring-loaded mechanism. Further redesigns and modifications have been conducted and verified through mathematical simulations. Nevertheless, these changes were not feasible during the timescale of the project. Thus, this is an area that requires focus in subsequent versions. Additionally, the automatic flow control presented in the current design is also an early version. The wire connections between various components are exposed and fragile, thus introducing the risk of damage during use. Furthermore, the exposed nature of the electronics can lend itself for water damage in the event that a bag ruptures. As a result, this is also an area for further improvement.

Due to the apparent limitations of the current design, the next phase of the project will aim to solve these issues. Specifically, a new version of the spring-loaded IV pole will be fabricated according to the specifications derived from the mathematical simulations. Subsequent usability and functionality testing will be conducted to further modify the system. Likewise, modifications to the electrical components will be undertaken to improve the functionality. Namely, the system will be designed to become wireless, such that the control system is independent of the physical pole. This will allow the system to be more portable within the tight constraints of the operating room. Furthermore, channels will be added to the IV pole to house the electrical connections, thus limiting exposure to external factors. Lastly, a refined pinch valve housing will be fabricated to completely cover and protect the actuator and notification system. Following these modifications, user testing will be conducted to further gather performance data of the proposed design.

In conclusion, we claim that implementation of our IrriGREAT design can improve the current irrigation system employed in cystoscopic surgical procedures at St. Michael's Hospital. By incorporating IrriGREAT into the operating room, we aim to reduce the issues observed in the currently employed gravity fed irrigation system. Specifically, we aim to reduce the potential strain injuries incurred by nurses due to the system. Likewise, we plan to reduce the workload required for operating the current system and reduce the propensity for human error to negatively impact surgical outcomes. The overall IrriGREAT device not only addresses all of these issues but is also feasible to implement, as it is estimated to cost only $480. Thus, the IrriGREAT fulfills the project requirements while opening up more possibilities for improving the irrigation system in hospitals. The team hope to continue forth with this project and aims to produce a functional device that can be implemented in the Cystoscopy Department at St. Michael's Hospital.

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Appendix A: Model Representation of Redesigned IV Pole

Figure A.1: Side view (a), top-right view (b), and top view (c) of Blender model of proposed redesigned IV pole.

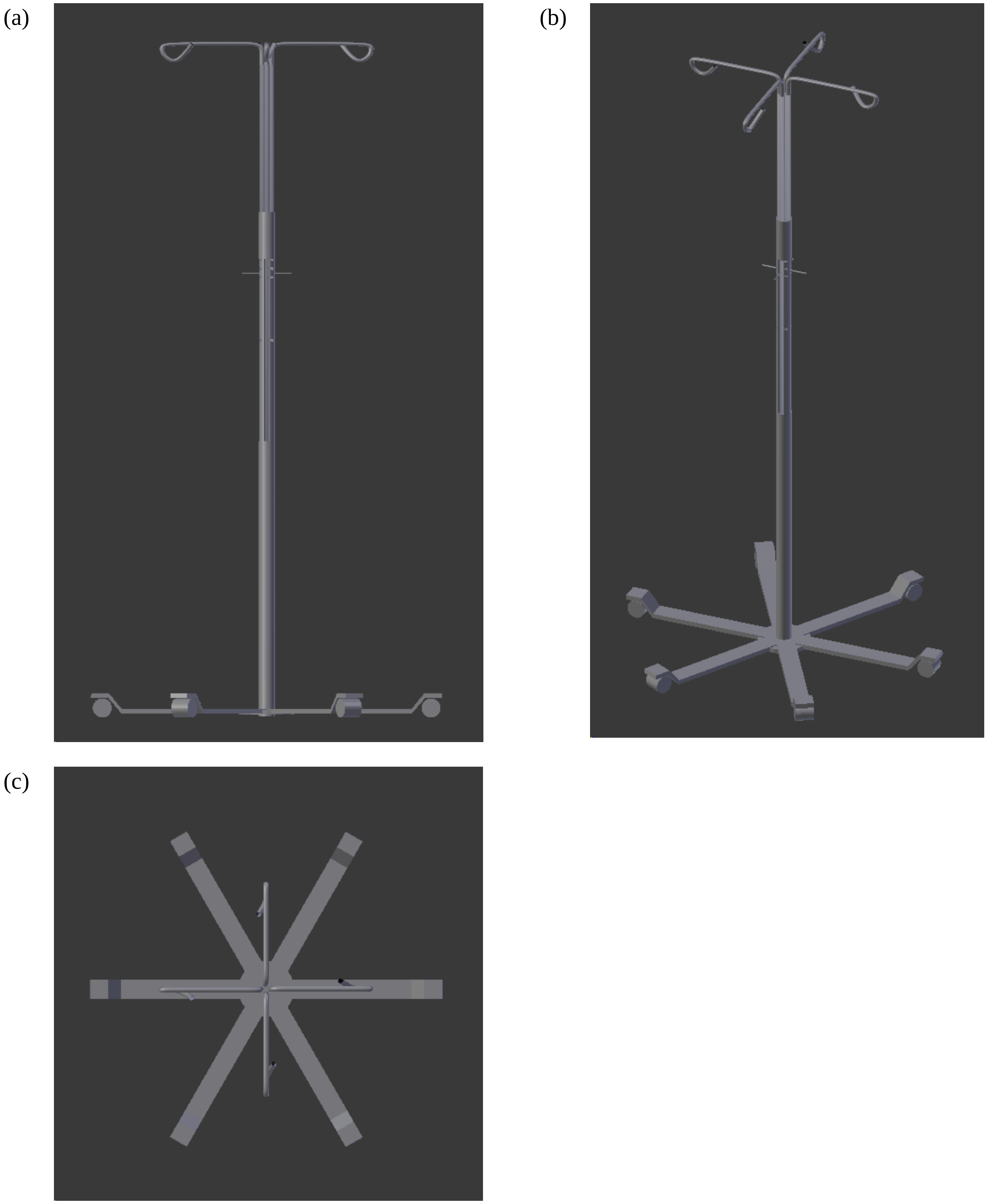
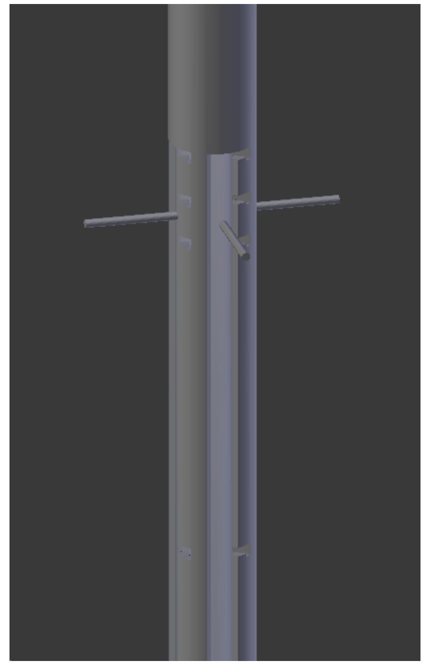


Figure A.2: Close up renderings of the discrete inner poles (a), grooves on the outer pole (b), and spider base (c).

(a)

(b)



(c)

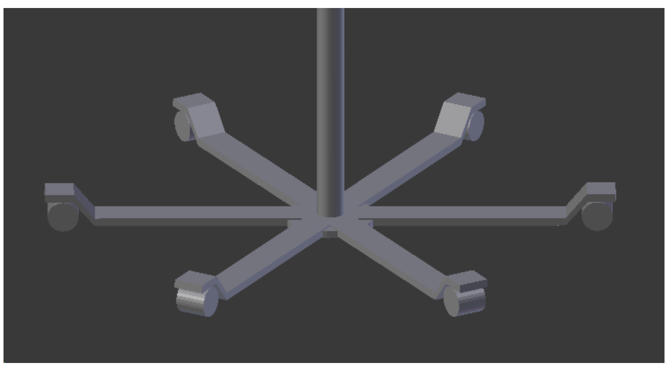
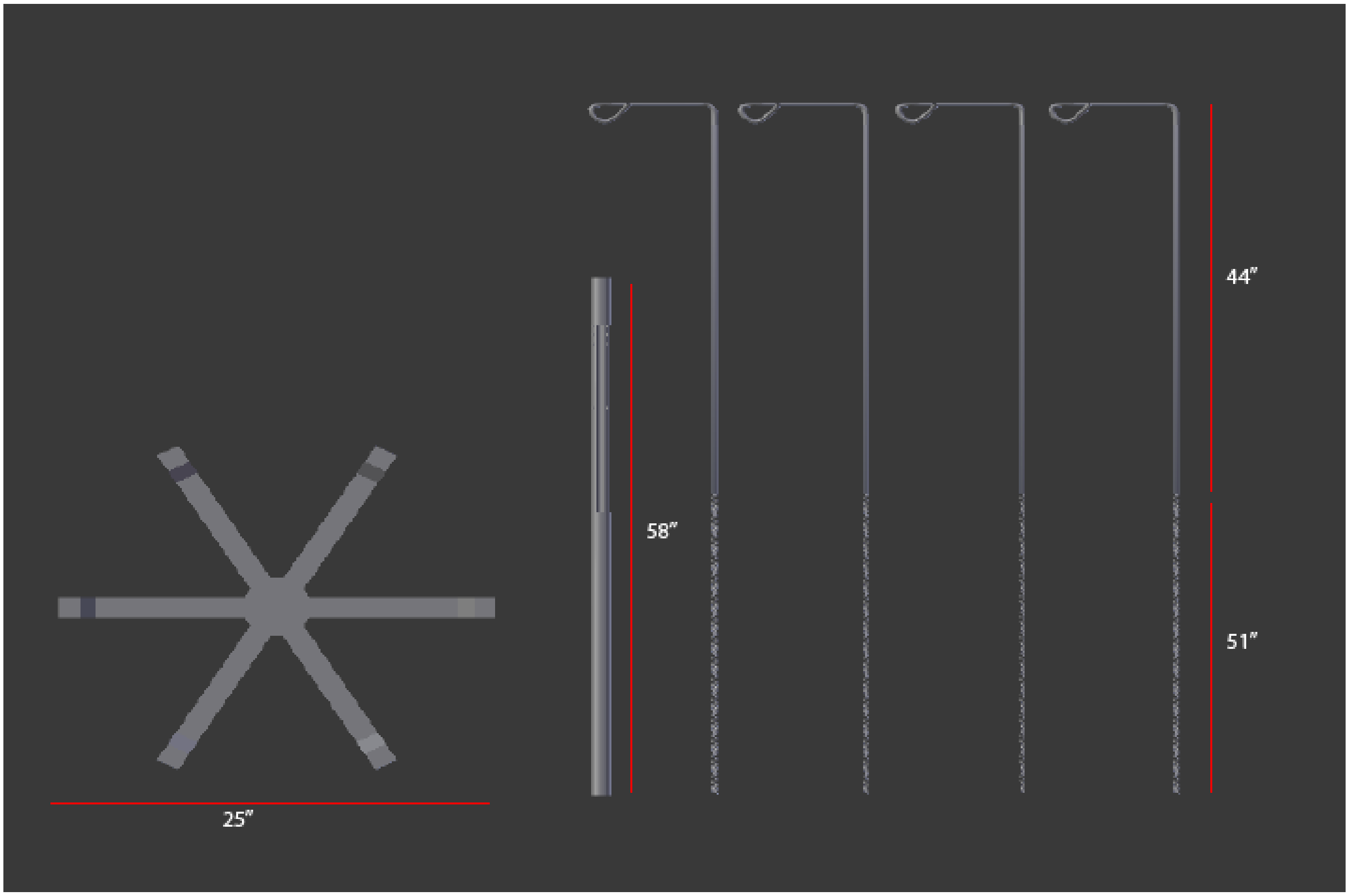


Figure A.3: Expanded view of proposed design with dimensions.

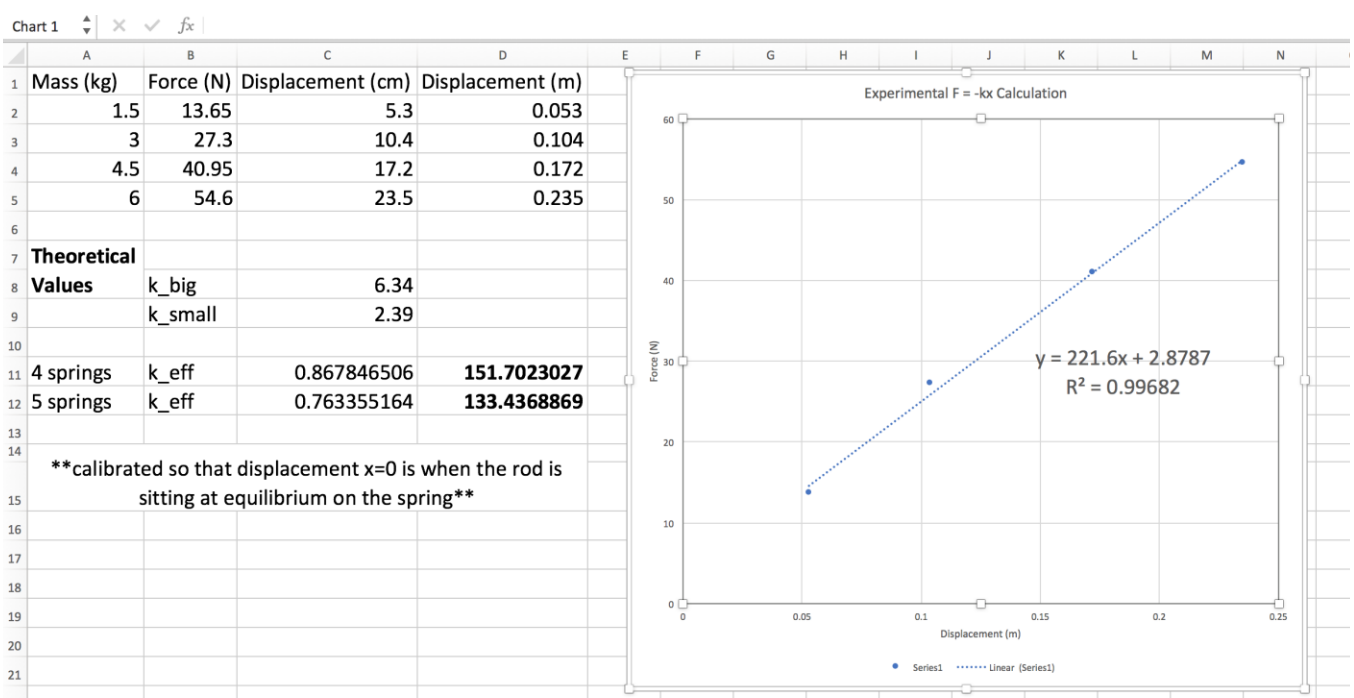


Appendix B: Calculations for Mechanical Subsystem

B.1 Calculations for Latest Prototype Built

Calculating K values

The figure below shows the results for calculated spring constants which were used on the final prototype that was built. Different displacements were recorded with varying weights and a graph was generated plotting the displacement vs force experienced, and the spring constant was calculated by finding the slope on the graph. External factors such as the temperature of the room when these experiments were conducted may have affected the final results, due to the material expanding in warmer temperatures. The experimental k value was then used to calculate the amount of force needed to compress the inner IV pole and lift the IV pole with bags loaded. Comparison between final and experimental values can be seen in Table 1.



Mass (kg)	Force (N)	Displacement (cm)	Displacement (m)
1.5	13.65	5.3	0.053
3	27.3	10.4	0.104
4.5	40.95	17.2	0.172
6	54.6	23.5	0.235
Theoretical			
Values	k_big	6.34	
	k_small	2.39	
4 springs	k_eff	0.867846506	**151.7023027**
5 springs	k_eff	0.763355164	**133.4368869**

calibrated so that displacement x=0 is when the rod is sitting at equilibrium on the spring

Figure 1: Experimental k values for the springs used in the final prototype that was built were calculated.

Table 1: Experimental and theoretical k value comparison for the latest prototype that was built

Experimental	221 N/m
Theoretical: 4 springs	151 N/m

Theoretical: 5 springs	133 N/m

The most recent prototype built originally had five springs housed inside the hollow, outer IV pole, and the theoretical spring constant is 133 N/m. However, after performing some validation tests to evaluate the functionality of the prototype, there was greater ease of use when only four springs were used instead of five. This is so because the displacement the handle needs to travel is greater with more springs, and as a result there is a greater spring force acting against your motion as you compress the springs downwards, and a greater force needs to be applied.

Calculating Force

Force required to raise two IV bags a total distance of 40 cm:

At equilibrium (with two IV bags):

- Distance moved when two bags placed on IV pole = 0.23 m
    - Force exerted by spring = $221\ N/m * 0.23\ m$= 53.04 N
- Force exerted by the pole and bags = $9.81\ m/s^2 * (6\ kg\ +\ 1.9\ kg)$= 77.5 N

  Note: At equilibrium, forces should balance but in this case it does not. This may be due to frictional forces

Let F_g= force exerted by pole and bag, F_a= applied force, and F_s= force of spring

Using the following force diagram,

$$\Sigma\ forces\ =\ 0$$

$$-F_g + F_a + F_s =\ 0$$

If displacement at equilibrium is 0.06 m,

$$77.5\ N + F_a + 221\ N/m * 0.06\ m =\ 0$$

$$F_a =\ 64\ N$$

Therefore, the user is required to exert an estimated 64 N of force when lifting two bags on the latest prototype which was built.

Force required to compress two IV bags a total distance of 40 cm:

$$F = 1.9\ kg * 9.8\ m/s^2 - 221\ N/m * 0.4\ m$$

$$F = 69\ N$$

The force required to compress the current prototype, fully is approximately 69N without any bags loaded

B.2 Calculations for Proposed IV Pole

Identifying the diameters of the inner IV pole

The proposed IV pole will have four inner IV poles which are housed in an outer IV pole. The outer IV pole will be compartmentalized into four, equal sections with the same area (see Fig. 2 below).

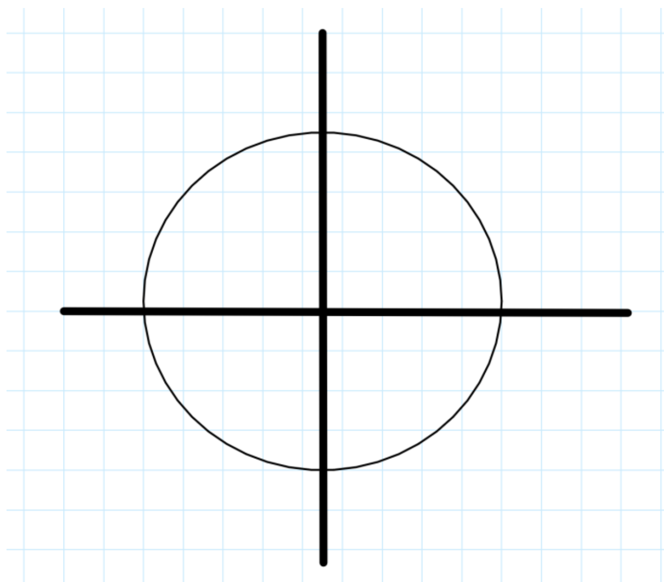


Figure 2: Outer IV pole with compartmentalized sections

Let:

- Inner diameter of the outer, hollow IV pole = 1.5”
- Wall thickness of the walls = ⅛” = 0.125”
- To determine the area of each section, equally: (see Fig. 2 for schematic of circle, and Fig. 3 for circle optimization)

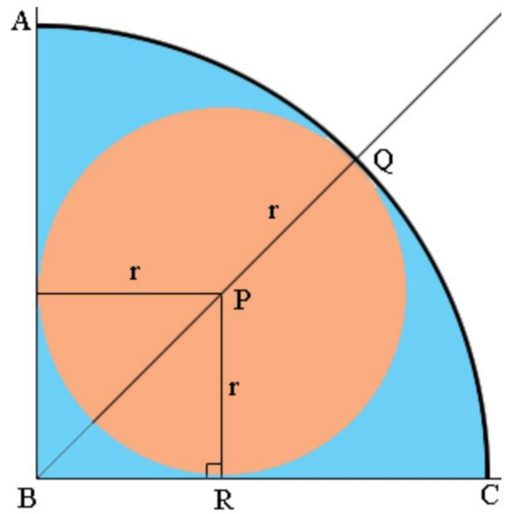


Figure 3: how to optimize circular area within a quarter of a circle

- Radius of circle which can fit inside a quarter circle = **0.417”**

Identifying the force required to lift one bag with the proposed design

Using the following spring,

OD	ID	Wire Dia.	Wire Wd.	Wire Thick.	Compressed Lg. @ Max. Load	Max. Load, lbs.	Rate, lbs./in.	Material	End Type	Pkg. Qty.		Pkg.
2.5" Lg.												
0.406"	0.28"	__	0.063"	0.063"	1.41"	19.95	38	Spring-Tempered Steel	Closed and Ground	1	9620K11	$2.74

Figure 4: McMaster Carr spring which meets the criteria for having the optimized radius

Properties of the spring are as follows:

Length	2.5’’
Rate	38 lbs/inches
K_{eq}	367.3 N/m

Total length of springs needed = 44” (based on current prototype constraints), meaning that

44” / 2.5” = 18 springs needed in total

As the new system only interacts with one inner pole, the weight of the pole is taken to be:

$$\frac{1}{4} * 1.9\ kg = 0.475\ kg$$

The new equilibrium of spring can be found by,

$$x_{eq} = \frac{F_{pole\ +\ bag}}{K}$$

$$x_{eq} = \frac{0.475\ kg * 9.81\ m/s^2}{367\ N/m}$$

$$x_{eq} = 0.0126\ m$$

Max applied force required can be calculated using,

$$-F_g + F_a + F_s = 0$$

$$-(3.475\ kg * 9.81\ m/s^2) + F_a + (367\ N/m * 0.01\ m) = 0$$

$$F_a = 30\ N$$

Therefore, with the proposed design, the user only needs to apply 30 N of force when lifting one 3 kg bag. However, additional details, such as how much force is required to push the each bag down, is also required.

Identifying the force required to compress one inner pole of the proposed design

$$F = (0.39\ m * 367\ N/m) - (0.475\ kg * 9.81\ m/s^2)$$

$$F = 138\ N$$

The total force required to compress the springs with no bags loaded is approximately 138 N. The force needed to compress and raise the bags needs to be further optimized.

Optimized K Value

```
Fa_dw = 160;

counter = 1;

while(abs(Fa_up-Fa_dw) > 0.1 && counter < 1000)
    dx1 = Fg1/k;

    Fa_up = g*(m1+m2) - k*dx1;
    Fa_dw = k*dx - g*m1;

    err = Fa_up-Fa_dw;

    if(err > 0)
        k = k + 2;
    elseif(err < 0)
        k = k - 2;
    else
        return;
    end
    counter = counter + 1;
end
```

counter	1000
dx	0.4500
dx1	0.0613
err	-0.1103
Fa_dw	29.5403
Fa_up	29.4300
Fg1	4.6598
g	9.8100
k	74
m1	0.4750
m2	3

Figure 5: Matlab code to identify a k value such that the force applied is equal in both cases

The calculated spring constant is 74 N/m. The amount of force needed to both compress and lift the bags is approximately 29 N.

Table 2: Summary of force required to lift and compress IV pole on current prototype and proposed design

	Force needed to lift the bag (N)	Force needed to compress fully (N)*
Current prototype	64	69
Proposed design	29	29

**: 'fully' defined as displacing the inner pole the maximum distance of 40 cm*

While the proposed design requires half the force than the current prototype built, it is approximately the same amount of force that is currently being used to lift a bag by a nurse. Therefore, the only advantage to this prototype is that the arm motion is within the power zone (as defined by OSHA) and no longer required the nurse to lift their arms above their shoulders.

Fig. 6 and Table 3 below demonstrate the optimized force required when the handle location relative to the inner pole can be relocated to a different location than currently. The required force to load and compress the IV pole would be 20 N.

```
counter = 1;

while(Fa_z - Fa_z_prv < 0 && l < 0.29)

    counter = 1;
    k = 200;
    Fa_up = 30;
    Fa_dw = 160;
    while(abs(Fa_up-Fa_dw) > 0.05 && counter < 100000)
        dx1 = Fg1/k;

        Fa_up = g*(m1+m2) - k*dx1 - k*l;
        Fa_dw = k*dx - g*m1 + k*l;

        err = Fa_up-Fa_dw;

        if(err > 0)
            k = k + 0.01;
        elseif(err < 0)
            k = k - 0.01;
        else
            return;
        end
        counter = counter + 1;
    end
Fa_z_prv = Fa_z;
Fa_z = Fa_dw + Fa_up;

l = l + 0.01;

end
```

ans	-0.4500
counter	16622
dx	0.4500
dx1	0.1379
err	-0.0483
Fa_dw	20.0143
Fa_up	19.9660
Fa_z	39.9803
Fa_z_prv	40.2863
Fg1	4.6598
g	9.8100
k	33.7900
l	0.2900
m1	0.4750
m2	3

Figure 6: Extended Matlab code to vary the location of the handle on the IV pole to require a smaller force that must be exerted to lift and compress the inner poles

Table 3: Summary of force required to lift and compress IV pole on current prototype and proposed design

	Force needed to lift the bag (N)	Force needed to compress fully (N)**
Current prototype	64	69
Proposed design	20	20

***: 'fully' defined as: displacing the inner pole the maximum distance of 40 cm*

Calculating Stability

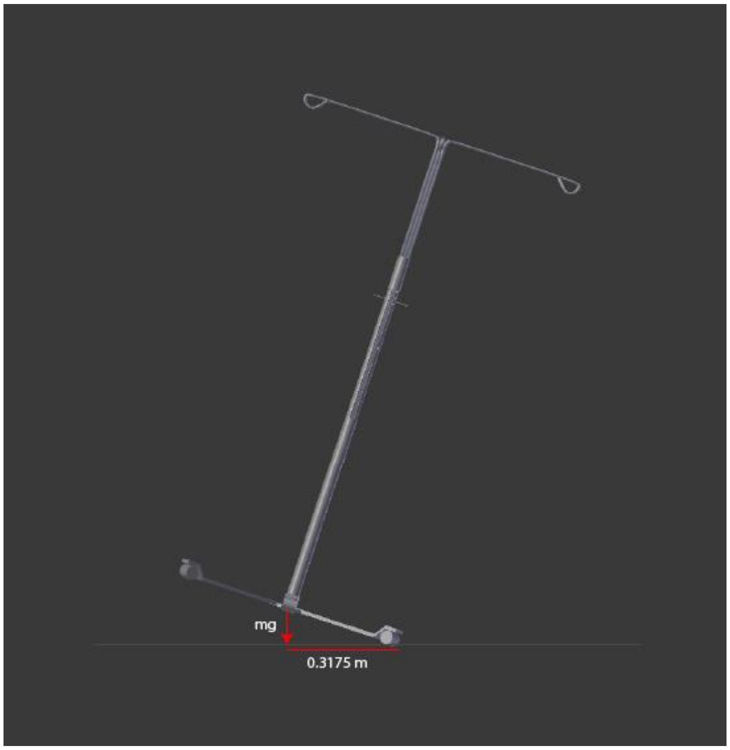


Figure 7: Rough schematic of restoring force as IV pole is tipping over.

Taking the overall mass of the proposed IV pole to be:

$$mass_{total} \; = \; mass_{inner\ poles} + mass_{outer\ pole} + mass_{base}$$

$$mass_{total} = 1.9\ kg \; + \; 3\ kg + 3.2\ kg = 8.1\ kg$$

An estimate of the restoring force of the pole when it is tipping over can be calculated by:

$$force_{restoring} = mass_{total} * 9.81\ m/s^2 * radius_{base}$$

$$force_{restoring} = 5.7\ kg * 9.81\ m/s^2 * 0.3175\ m$$

$$force_{restoring} = 18.4\ Nm$$

Current IV poles in the hospital have the following range of properties:

Base diameter	59 cm - 63.5 cm
Total weight	3.5 kg - 7.6 kg

Looking at one the models of IV pole boasting the highest weight, the restoring force is calculated to be:

$$force_{restoring} = 7.6\ kg * 9.81\ m/s^2 * 0.3\ m$$

$$force_{restoring} = 22.4\ Nm$$

The restoring force of the proposed IV pole is similar to that of that of IV poles seen in the market as such the features of the proposed design do not detract from the stability of the overall IV pole.

Appendix C: Arduino Code

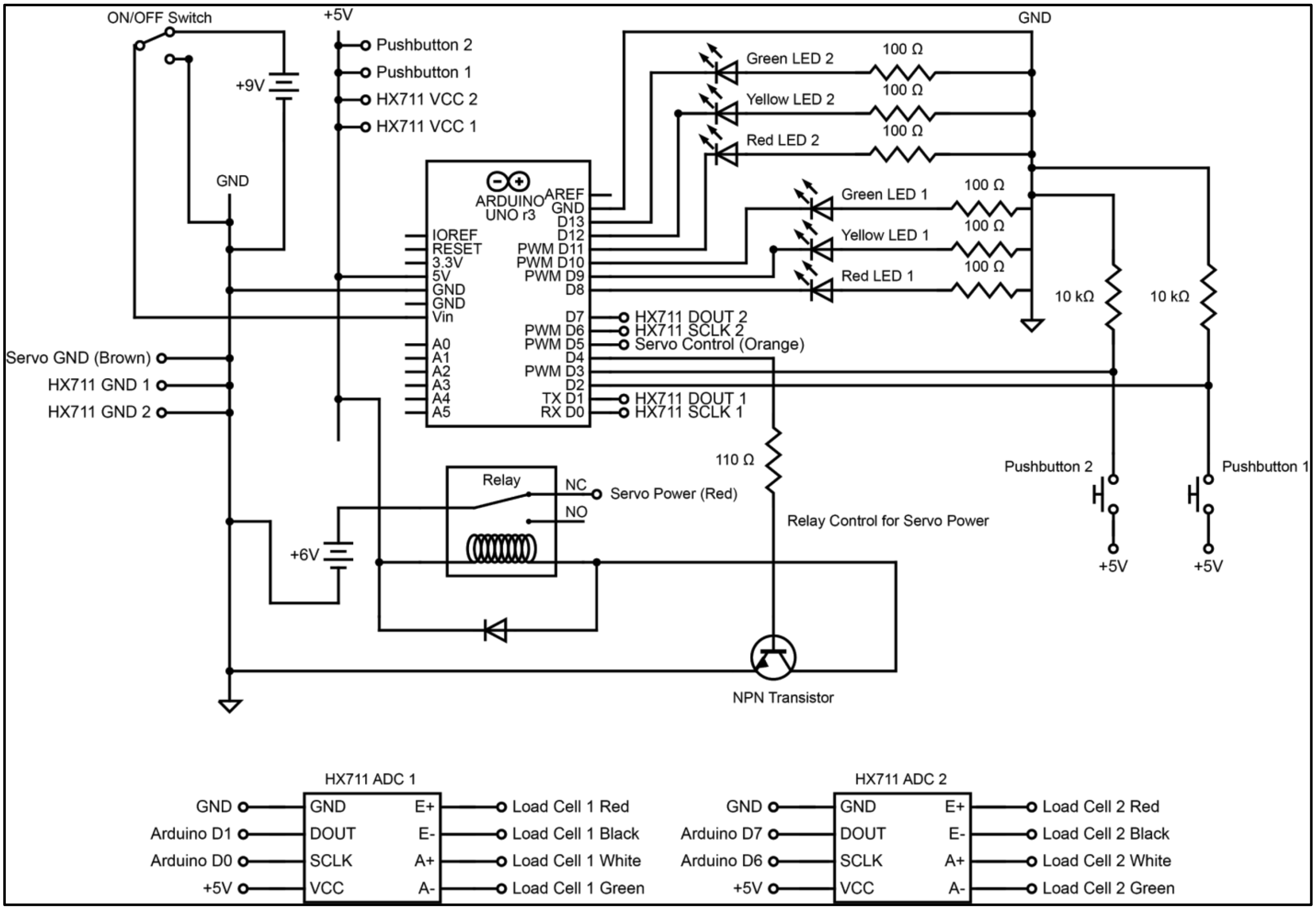
```
#include "HX711.h"
#include <Servo.h>
#include <math.h>

// threshold values
const int yellow_thresh = 1500;
const int switch_thresh = 3000;
const int max_change = 100;

// set up scales:
HX711 scale1(1, 0); // 0 = SCLK, 1 = DOUT
float calibration1 = -58; // need to adjust based on individual load cell
long offset1 = 59862;
float full_reading1;
float units_curr1;
float units_new1;

HX711 scale2(7, 6); // 6 = SCLK, 7 = DOUT
float calibration2 = -56;
long offset2 = 431717;
float full_reading2;
float units_curr2;
float units_new2;

// set up servo:
Servo myservo;  // create servo object to control a servo
int pos = 0;    // variable to store the servo position
int angle2 = 0;
int angle1 = 180;
int middle_angle = 85;

// set pin numbers:
const int buttonPin1 = 2;     // tare pushbutton pins
const int buttonPin2 = 3;
const int ledPin_r1 =  8;     // LED pins
const int ledPin_y1 =  9;
const int ledPin_g1 =  10;
const int ledPin_r2 =  11;
const int ledPin_y2 =  12;
const int ledPin_g2 =  13;
const int relay = 4;          // relay control to turn on/off servo motor power
supply when device turns on/off

// other variables:
int bag_ready1 = 0;
float weight_lost1;
int bag_ready2 = 0;
float weight_lost2;
float temp;
int bag_active = 0;

void setup() {
  // initialize the LED pins and relay as an output:
  pinMode(ledPin_r1, OUTPUT);
  pinMode(ledPin_y1, OUTPUT);
  pinMode(ledPin_g1, OUTPUT);
  pinMode(ledPin_r2, OUTPUT);
```

```
  pinMode(ledPin_y2, OUTPUT);
  pinMode(ledPin_g2, OUTPUT);
  pinMode(relay, OUTPUT);

  digitalWrite(ledPin_g1, LOW);
  digitalWrite(ledPin_y1, LOW);
  digitalWrite(ledPin_r1, HIGH);
  digitalWrite(ledPin_g2, LOW);
  digitalWrite(ledPin_y2, LOW);
  digitalWrite(ledPin_r2, HIGH);
  digitalWrite(relay, HIGH);

  // initialize the pushbutton pins as an input interrupt signal:
  pinMode(buttonPin1, INPUT_PULLUP);
  attachInterrupt(digitalPinToInterrupt(buttonPin1), buttonpress1, RISING);
  pinMode(buttonPin2, INPUT_PULLUP);
  attachInterrupt(digitalPinToInterrupt(buttonPin2), buttonpress2, RISING);

  // Set up scales
  scale1.set_scale(calibration1);
  scale1.set_offset(offset1);
  units_curr1 = scale1.get_units(10);
  if (units_curr1 < 0)
  {
    units_curr1 = 0.00;
  }
  scale2.set_scale(calibration2);
  scale2.set_offset(offset2);
  units_curr2 = scale1.get_units(10);
  if (units_curr2 < 0)
  {
    units_curr1 = 0.00;
  }

  // Initialize servo to middle
  myservo.attach(5);  // attaches the servo on pin 5 to the servo object
  myservo.write(middle_angle);
  delay(15);

  bag_ready1 = 0;
  bag_ready2 = 0;
  bag_active = 0;
}

void loop() {
  // read weight sensors
  units_new1 = scale1.get_units(10);
  if (units_new1 < 0)
  {
    units_new1 = 0.00;
  }
  units_new2 = scale2.get_units(10);
  if (units_new2 < 0)
  {
    units_new2 = 0.00;
  }

  if (bag_active == 1) {

    temp = units_curr1 - units_new1;
    if (temp < max_change && temp > 0) {
```

```
      // only increment weight_lost1 variable for small changes
      weight_lost1 = weight_lost1 + temp;
    }

    if (weight_lost1 > switch_thresh) {
      digitalWrite(ledPin_g1, LOW);
      digitalWrite(ledPin_y1, LOW);
      digitalWrite(ledPin_r1, HIGH);

      // deactivate bag 1
      bag_ready1 = 0;

      if (bag_ready2) {
        // actuate servo to switch to other bag
        myservo.write(angle2);
        delay(15);
        bag_active = 2;
      }

      else {
        // nurse hasn't reloaded other bag yet; open both channels
        myservo.write(middle_angle);
        delay(15);
        bag_active = 0;
      }
    }
    else if (weight_lost1 > yellow_thresh) {
      digitalWrite(ledPin_g1, LOW);
      digitalWrite(ledPin_y1, HIGH);
      digitalWrite(ledPin_r1, LOW);
    }
    else {
      digitalWrite(ledPin_g1, HIGH);
      digitalWrite(ledPin_y1, LOW);
      digitalWrite(ledPin_r1, LOW);
    }
  }

  else if (bag_active == 2) {
    temp = units_curr2 - units_new2;
    if (temp < max_change && temp > 0) {
      // only increment weight_lost2 variable for small changes
      weight_lost2 = weight_lost2 + temp;
    }

    if (weight_lost2 > switch_thresh) {
      digitalWrite(ledPin_g2, LOW);
      digitalWrite(ledPin_y2, LOW);
      digitalWrite(ledPin_r2, HIGH);

      // deactivate bag 2
      bag_ready2 = 0;

      if (bag_ready1) {
        // actuate servo to switch to other bag
        myservo.write(angle1);
        delay(15);
        bag_active = 1;
      }

      else {
```

```
        // nurse hasn't reloaded other bag yet; open both channels
        myservo.write(middle_angle);
        delay(15);
        bag_active = 0;
      }
    }
    else if (weight_lost2 > yellow_thresh) {
      digitalWrite(ledPin_g2, LOW);
      digitalWrite(ledPin_y2, HIGH);
      digitalWrite(ledPin_r2, LOW);
    }
    else {
      digitalWrite(ledPin_g2, HIGH);
      digitalWrite(ledPin_y2, LOW);
      digitalWrite(ledPin_r2, LOW);
    }
  }

  units_curr1 = units_new1;
  units_curr2 = units_new2;
}

void buttonpress1() {
  full_reading1 = scale1.get_units(10); //Get a baseline reading
  if (full_reading1 < 0)
  {
    full_reading1 = 0.00;
  }

  bag_ready1 = 1;
  weight_lost1 = 0;
  digitalWrite(ledPin_g1, HIGH);
  digitalWrite(ledPin_y1, LOW);
  digitalWrite(ledPin_r1, LOW);

  if (bag_active == 0) {
    myservo.write(angle1);
    delay(15);
    bag_active = 1;
  }
}

void buttonpress2() {
  full_reading2 = scale2.get_units(10); //Get a baseline reading
  if (full_reading2 < 0)
  {
    full_reading2 = 0.00;
  }

  bag_ready2 = 1;
  weight_lost2 = 0;
  digitalWrite(ledPin_g2, HIGH);
  digitalWrite(ledPin_y2, LOW);
  digitalWrite(ledPin_r2, LOW);

  if (bag_active == 0) {
    myservo.write(angle2);
    delay(15);
    bag_active = 2;
  }
}
```

Appendix D: Circuit Schematics



Appendix E: CAD Models and 3D Prints

E.1 CAD Models

The following images depict the CAD models of the pinch valve housing and flange from various angles. The images on the left show the edges and lines of the model while the images on the right show a realistic rendering of the model.

Figure E.1.1: Housing Top View

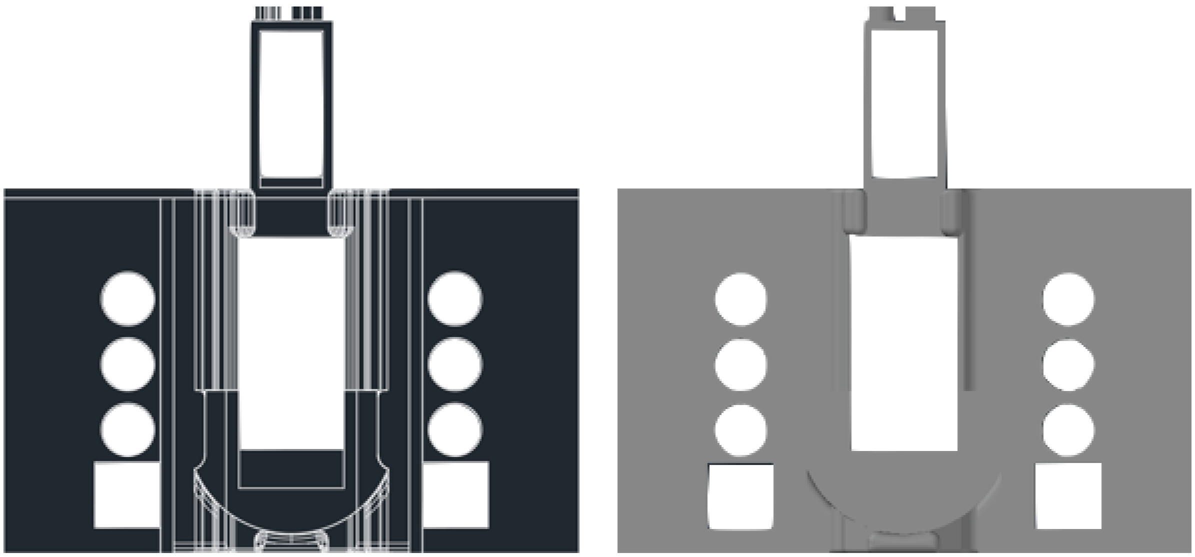


Figure E.1.2: Housing Front View

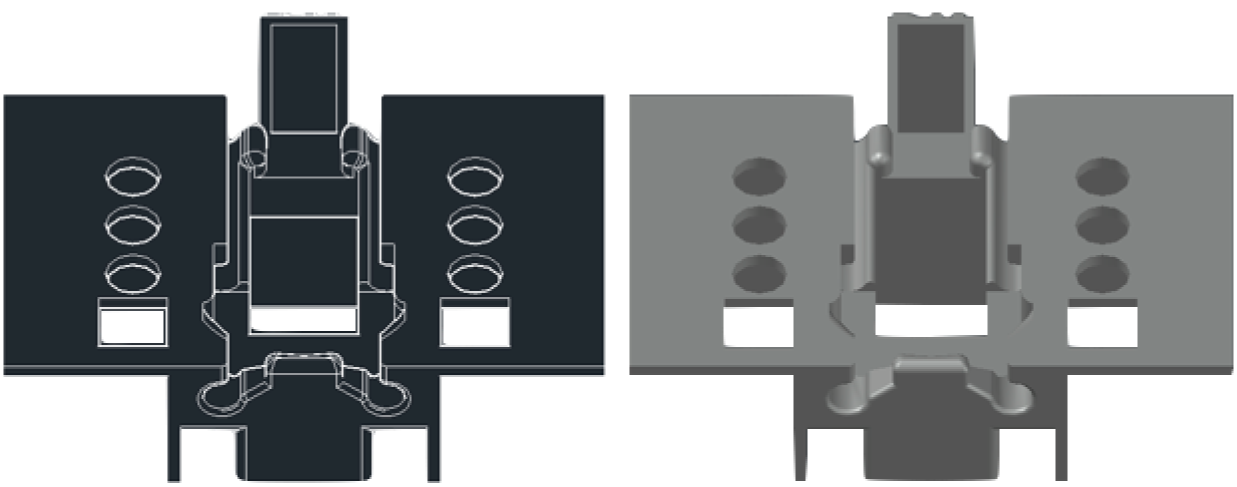


Figure E.1.3: Housing Front-Right Top Corner View

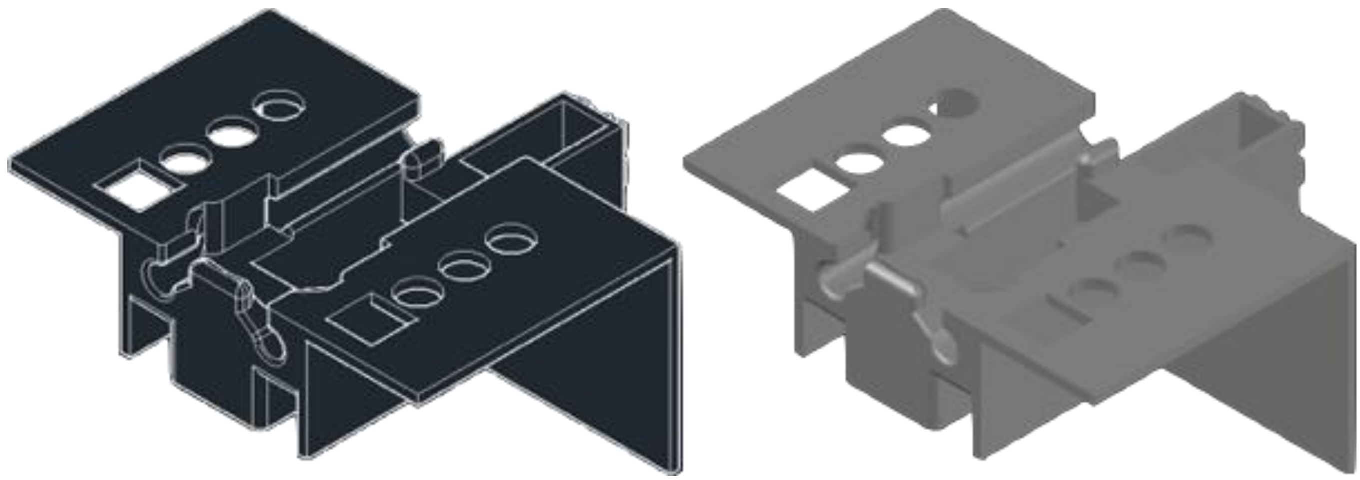


Figure E.1.4: Housing Front-Right Bottom Corner View

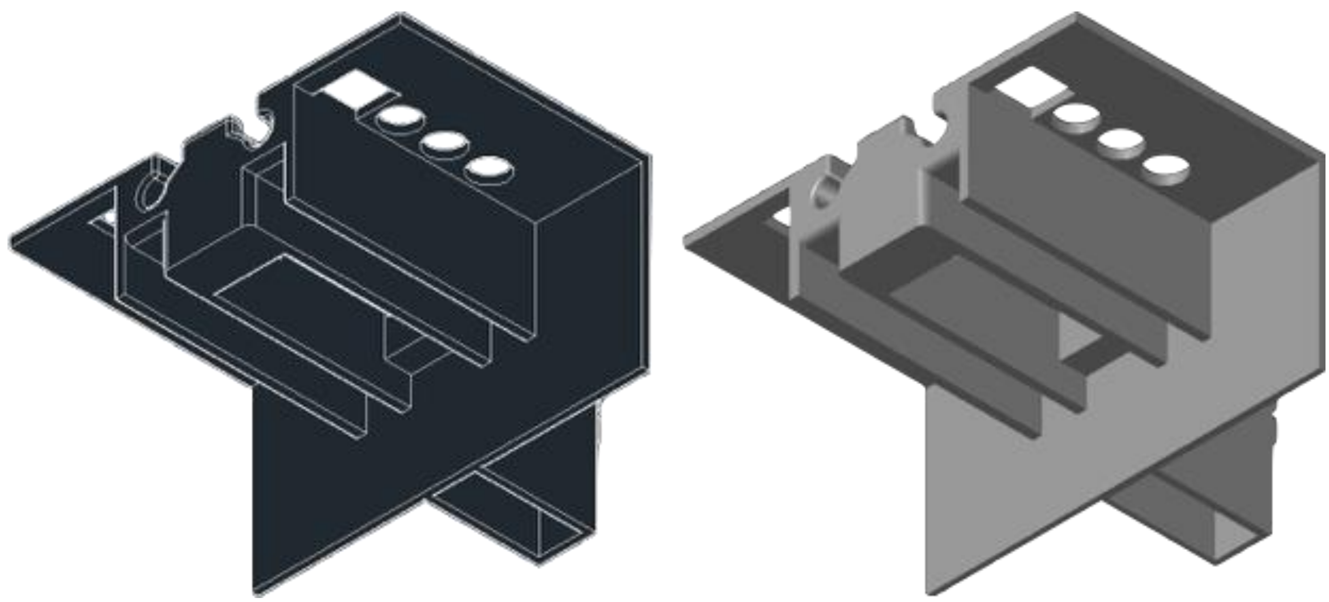
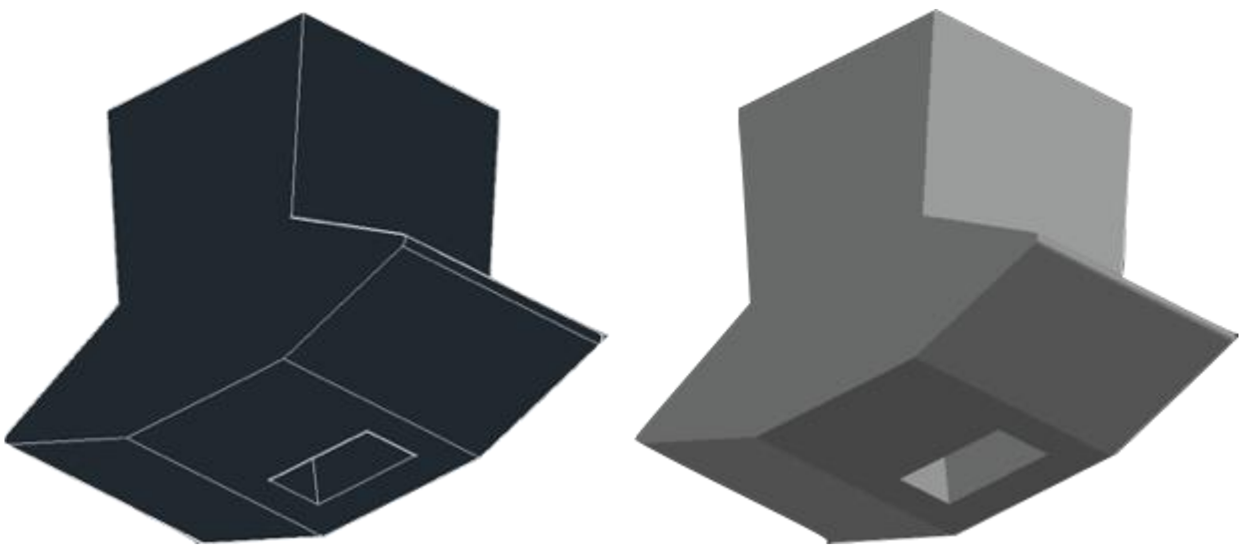


Figure E.1.5: Flange Top View

Figure E.1.6: Flange Front-Right Corner View



E.2 3D Prints

The following images depict the 3D printed models of the pinch valve housing the flange. The images depict the evolution of the design through subsequent iterations and modifications.

Figure E.2.1: Pinch Housing Evolution

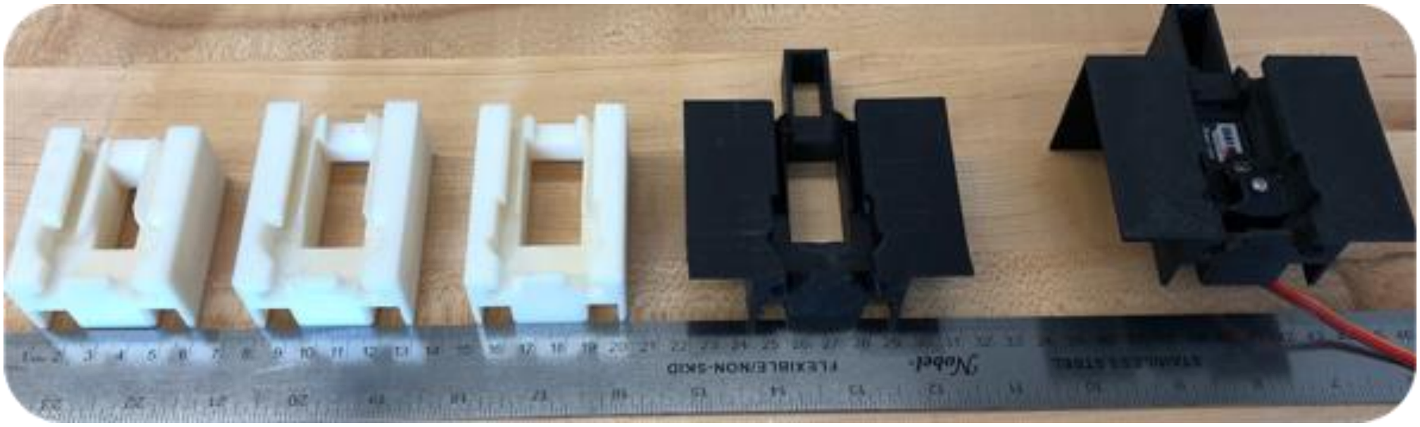


Figure E.2.2: Pinch Housing Evolution (Version 1-3)

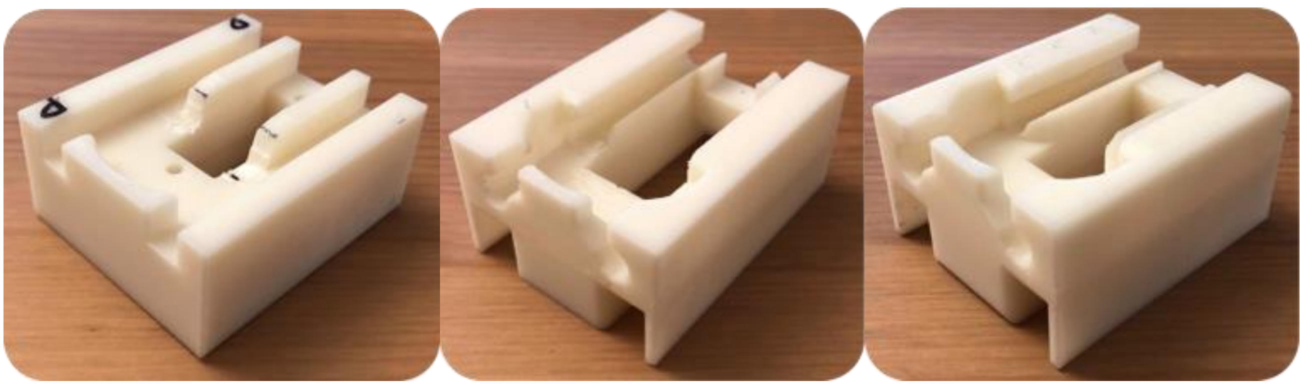


Figure E.2.3: Pinch Housing Evolution (Version 4-5)

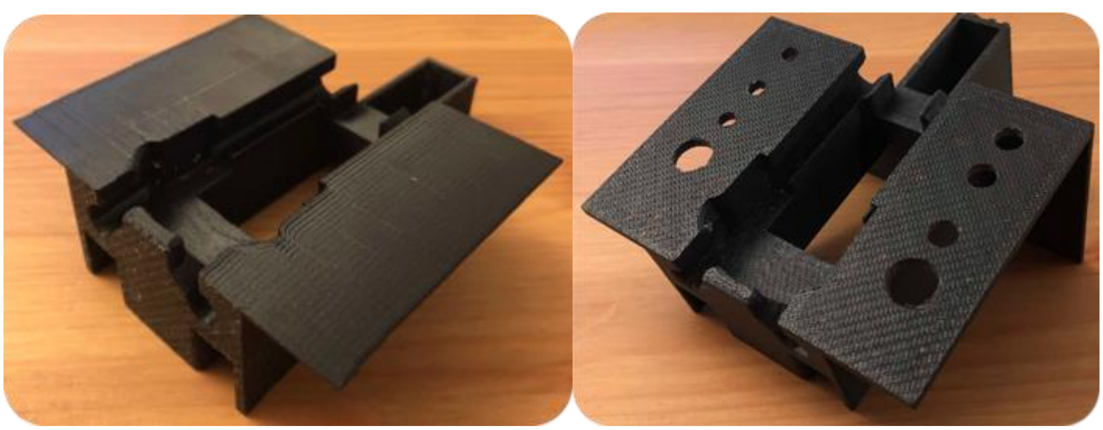


Figure E.2.4: Pinch Housing Final Version

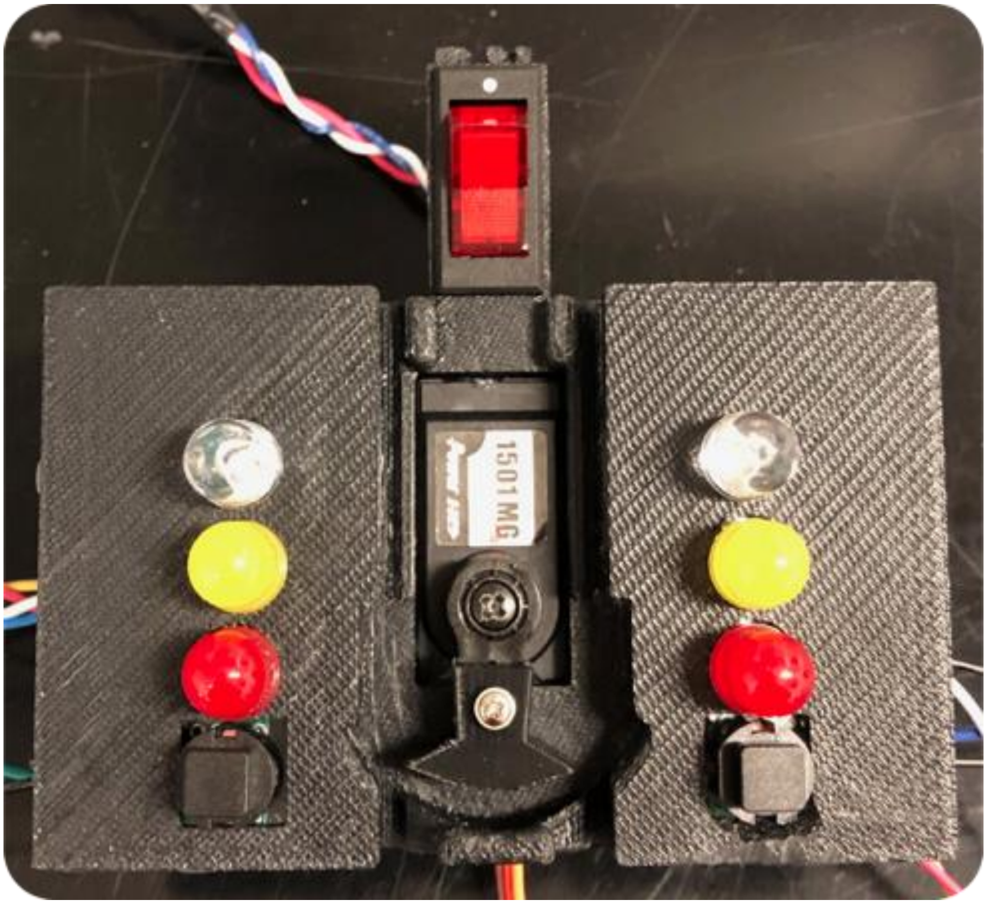


Figure E.2.5: Pinch Flange Evolution

Appendix F: Verification and Validation Tests

Given the nature of the project, the need for thorough and rigorous testing of the design is essential. The table below outlines the verification and validation tests which must be eventually done and testing on our proposed design. Due to the significant user element of the project, the final testing of the product will revolve around human factors. However, the preliminary testing will be composed of isolated testing of the product to validate the functionality. The following table outlines the various testing scenarios and the anticipated procedures and materials. In addition to the tests, a post-simulation survey will be given to participants. Sample questions for this survey can be seen in Appendix F.1. Given the time constraints of the project, verification and validation tests were not able to be performed.

Test Overview	Test Procedure	Objective	Materials
Isolated Device Functionality Testing	The various components of the design will be tested in isolation and also as a whole. The functionality of these parts will be ascertained in a controlled environment to locate and rectify and bugs in the system. The isolated component test verify the proper functionality of the: ● IV pole attachment mechanism ● Spring counter weight and notification system ● Pulley movement during use ● Bag loading and removal mechanism The whole device test will investigate the: ● Setup of device to IV pole ● Proper functionality of the notification system during irrigation ● Functionality of the bag detachment mechanism ● Ease of bag replacement with the new system These tests will be done to validate the design prior to a OR simulation.	These tests aim to locate any system bugs in an isolated system in order to optimize the design. Since these tests are not done within a operating room simulation, workflow aspects will not be the primary objective. In addition to basic functionality of the device, these tests will aim to recreate fringe cases and understand how the system responds. This will provide the team the ability to improve the functionality of the design to cope with the unlikely event of such fringe cases.	● IV pole ● Saline Bags ● Irrigation tubing ● Proposed solution ● Water ● Bucket (patient substitute)
Operating Room Simulation	Participants will simulate the workflow of nurses within an OR. A makeshift simulation OR will be created, including the irrigation system, sterile table,	The test aims to critique the design functionality with respect to the metrics for the following objectives:	● Design Studio ● IV pole ● Saline Bags ● Irrigation tubing

	operation paperwork, and other relevant activities. Participants will be required to simulate the activity of nurses by conducting the necessary task provided. During the simulation, the irrigation bag will be running. Participants will be required to change the bags at appropriate times. The simulation will be completed for both the current irrigation system and our proposed design. The following quantitative measures will be obtained during the simulations: ● Bag replacement time ● Number of stoppages of irrigation flow ● Time required to notice status of the irrigation bag's volume ● Number of times participants look at bag The following qualitative measures will be obtained during the simulations: ● Efficiency of system ● Stress levels of participants ● Ease of use of system	● The ergonomics and accessibility of the system ● The ease of monitoring irrigant levels ● Continuity of irrigant flow	● Proposed solution ● Water ● Bucket (patient substitute) ● Participants (~ 10) ● Nurse OR activities ● Stopwatch ● Pitch counter
Repetitive Strain	The test will consist of two parts. The first test will involve the surveying of participants in the OR simulation test. A post simulation survey will be given to them to gauge any strains imposed upon their bodies during the replacement of bags for the current system and the proposed system. The second test will involve nurses using the proposed design in the hospital and providing feedback through a survey.	These tests aim to gauge the potential physical strains caused to nurses by the proposed design.	● IV pole ● Saline Bags ● Irrigation tubing ● Proposed solution ● Water ● Participants ● User Survey
Ergonomic Testing	The ergonomic testing will be based on comparison of the proposed design to ergonomic standards.	These tests aim to gauge the ergonomic aspect of the design.	● Proposed solution ● Tape Measure ● Weight scale

F.1 Sample Survey Questions

The following are some example question that will be included in a survey given to participants after they complete the operating room (OR) simulation, where they will assume the role of a nurse in the OR. The survey will be segmented into three main components: workflow, physical strain, and proposed design. The following outline a selection of potential questions.

Workflow

- Was the notification system discernible amidst the other various sounds and visuals?
- Did you need to consciously check on the system between tasks or was it sufficient to depend on noticing a visual change from the periphery?
- On a scale of 1-7, how preoccupied were you with monitoring the irrigation system versus focusing on other tasks? (1 = didn't think at all about checking irrigation, 7 = couldn't focus on other tasks because of preoccupation with irrigation monitoring)
- On a scale of 1-7, how much time did the automatic switching between bags save you during an operation? (1 = much more time spent maintaining irrigation; 4 = no change in time spent on maintaining irrigation; 7 = much less time spent maintaining irrigation)

Personal Strain/Injury/Fatigue

- Did you experience any excessive muscle strain during the simulation? If so, what areas specifically.
- Did any required movements during the replacing of irrigation bags cause discomfort? If so, what were the specific movements? How severe was the discomfort?

Proposed Design

- Were there aspects of the design that made the replacing of the bags EASIER? If so, what specifically?
- Were there aspects of the design that made the replacing of the bags HARDER? If so, what specifically?

Appendix G: Estimated Cost for IrriGREAT

Although the accumulated cost to build the current prototype is outlined in Appendix I: Financial Plan, the details below outline specific components that will be purchased to create the proposed design. The total cost estimation for the mechanical design is approximately $320.23, while the electronic design costs approximately $159.31, resulting in a total of **$479.54** for the entire device.

Table 1: Mechanical subsystem cost.

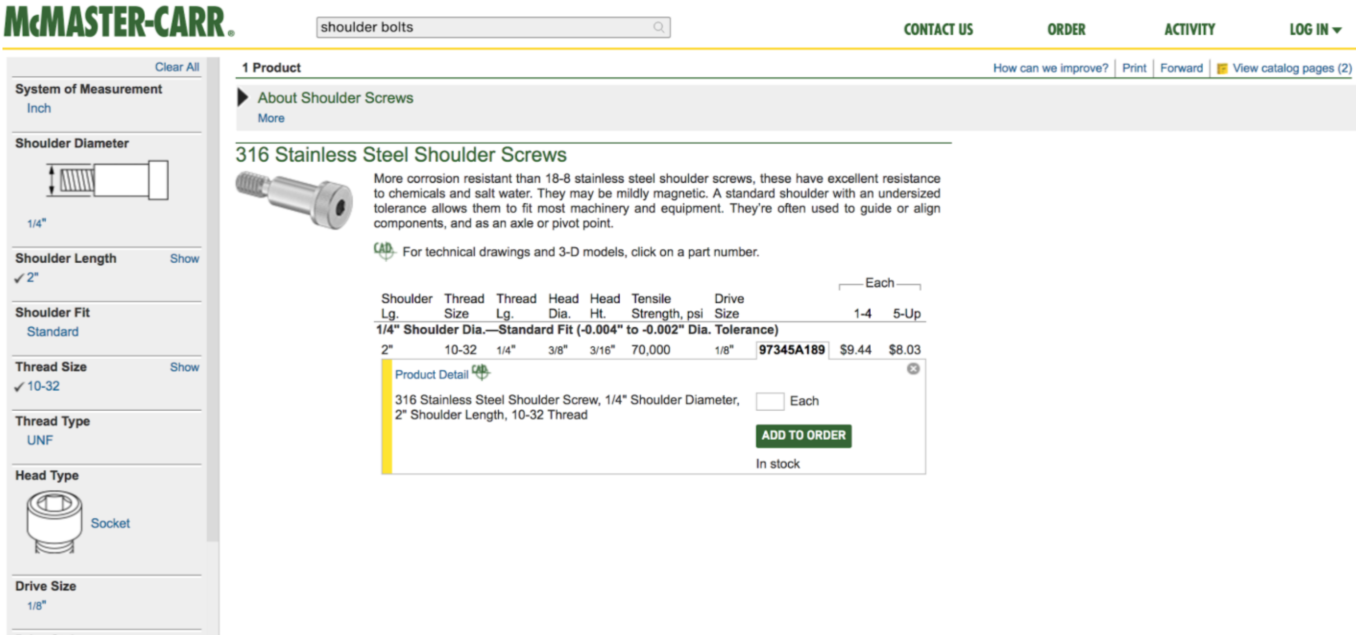
Component	**Purchased at:**	**Reason for purchase**	**Quantity**	**Reference**	**Price ($)**
Shoulder bolt	McMaster-CARR	Shoulder screws used for handle	4	A	37.76
Machine screws	McMaster-CARR	To connect the base and the IV pole	8	B	1.82
Caster wheels	Home Depot	To create ease of use when moving the IV pole	3	C	14.82
Steel screw eye	Home Depot	To withstand the weight of the bags	4	D	0.40
Compression spring	McMaster-CARR	To help alleviate the force required to compress and lift the bags	16	E	37.05
Aluminum rod	Metals Depot	To create inner and outer IV poles	1	F	179.68
Steel Disc	McMaster-CARR	For the base of the IV pole and the top where hooks will be installed. (Using ¼" thickness and 6" diameter)	1	G	19.48 (top base) 29.22 (bottom base)
				MECHANICAL TOTAL	**$320.23**

Table 2: Electronic subsystem cost.

Component	**Purchased at:**	**Reason for purchase**	**Quantity**	**Reference**	**Price ($)**
Arduino Uno	Electronics Surplus	Microcontroller for electronic subsystem	1	H	$25.95
High Torque Servo Motor (17 kg*cm)	Creatron	Pinch valve actuator	1	I	$29.95
HX711 ADC boards	Creatron	Interface with load cells	2	J	$17.00
Load Cells	Amazon	Measure weight of bags	2	K	$25.98
5-pack LEDs	Creatron	Visual notification/indication system	3	L	$5.25
Pushbutton	Creatron	Taring buttons	2	M	$1.90
3-pin rocker switch	Creatron	ON/OFF switch for entire device	1	N	$1.50
5 cm x 7 cm protoboards	Creatron	Soldering circuits	2	O	$6.50
9V battery	Creatron	Power Arduino and peripherals	1	P	$1.50
4x AA batteries	Creatron	Power servo	1	Q	$1.50
9V battery holder	Creatron	Contain batteries	1	R	$2.75
4x AA battery holder	Creatron	Contain batteries	1	S	$1.95
100 ohm resistors	Creatron	LED circuit	6	T	$1.50
10k ohm resistors	Creatron	Pushbutton circuit	2	T	$0.50
110 ohm resistor	Creatron	Relay circuit	1	T	$0.25
Diode	Creatron	Relay circuit	1	U	$0.42
NPN transistor	Creatron	Relay circuit	1	V	$0.30
5V 2A DC Relay	Creatron	Turn servo power supply on and off when device is powered on or off	1	W	$2.30
Printer Material (in^3)	Javelin	3D printed casing/flange	3.94	X	$26.64
Printer Support Material (in^3)	Javelin	3D printed casing/flange	0.86	Y	$5.67

ELECTRONIC TOTAL	**$159.31**

A: Steel shoulder set screws used as handles for the four inner IV poles


McMASTER-CARR. shoulder bolts CONTACT US ORDER ACTIVITY LOG IN

Clear All

System of Measurement: Inch

Shoulder Diameter: 1/4"

Shoulder Length: ✓ 2" (Show)

Shoulder Fit: Standard

Thread Size: ✓ 10-32 (Show)

Thread Type: UNF

Head Type: Socket

Drive Size: 1/8"

1 Product — How can we improve? | Print | Forward | View catalog pages (2)

About Shoulder Screws
More

316 Stainless Steel Shoulder Screws

More corrosion resistant than 18-8 stainless steel shoulder screws, these have excellent resistance to chemicals and salt water. They may be mildly magnetic. A standard shoulder with an undersized tolerance allows them to fit most machinery and equipment. They're often used to guide or align components, and as an axle or pivot point.

For technical drawings and 3-D models, click on a part number.

Shoulder Lg.	Thread Size	Thread Lg.	Head Dia.	Head Ht.	Tensile Strength, psi	Drive Size		Each 1-4	Each 5-Up
1/4" Shoulder Dia.—Standard Fit (-0.004" to -0.002" Dia. Tolerance)									
2"	10-32	1/4"	3/8"	3/16"	70,000	1/8"	97345A189	$9.44	$8.03

Product Detail

316 Stainless Steel Shoulder Screw, 1/4" Shoulder Diameter, 2" Shoulder Length, 10-32 Thread

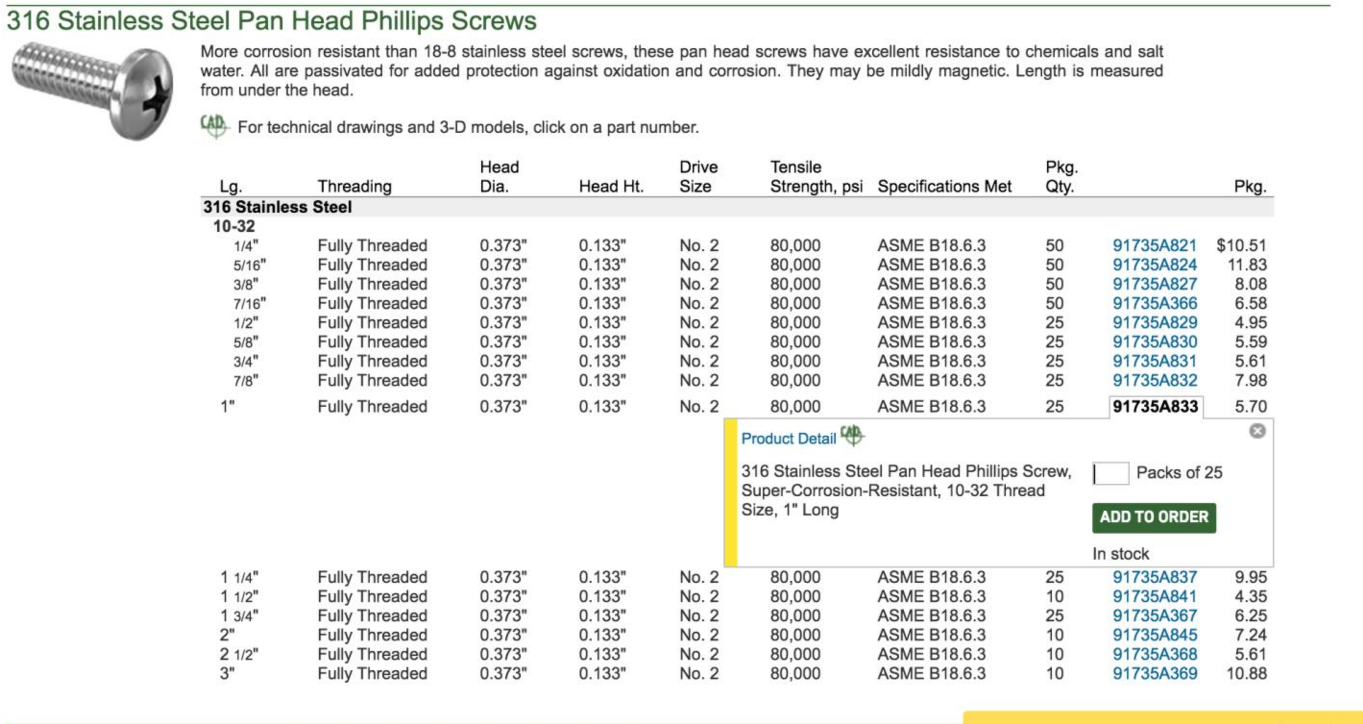
Each

ADD TO ORDER

In stock

Source: https://www.mcmaster.com/shoulder-bolts

B: Machine screws used to connect the metal base and IV pole


316 Stainless Steel Pan Head Phillips Screws

More corrosion resistant than 18-8 stainless steel screws, these pan head screws have excellent resistance to chemicals and salt water. All are passivated for added protection against oxidation and corrosion. They may be mildly magnetic. Length is measured from under the head.

For technical drawings and 3-D models, click on a part number.

Lg.	Threading	Head Dia.	Head Ht.	Drive Size	Tensile Strength, psi	Specifications Met	Pkg. Qty.		Pkg.
316 Stainless Steel									
10-32									
1/4"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	50	91735A821	$10.51
5/16"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	50	91735A824	11.83
3/8"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	50	91735A827	8.08
7/16"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	50	91735A366	6.58
1/2"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	25	91735A829	4.95
5/8"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	25	91735A830	5.59
3/4"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	25	91735A831	5.61
7/8"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	25	91735A832	7.98
1"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	25	91735A833	5.70
1 1/4"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	25	91735A837	9.95
1 1/2"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	10	91735A841	4.35
1 3/4"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	25	91735A367	6.25
2"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	10	91735A845	7.24
2 1/2"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	10	91735A368	5.61
3"	Fully Threaded	0.373"	0.133"	No. 2	80,000	ASME B18.6.3	10	91735A369	10.88

Product Detail

316 Stainless Steel Pan Head Phillips Screw, Super-Corrosion-Resistant, 10-32 Thread Size, 1" Long

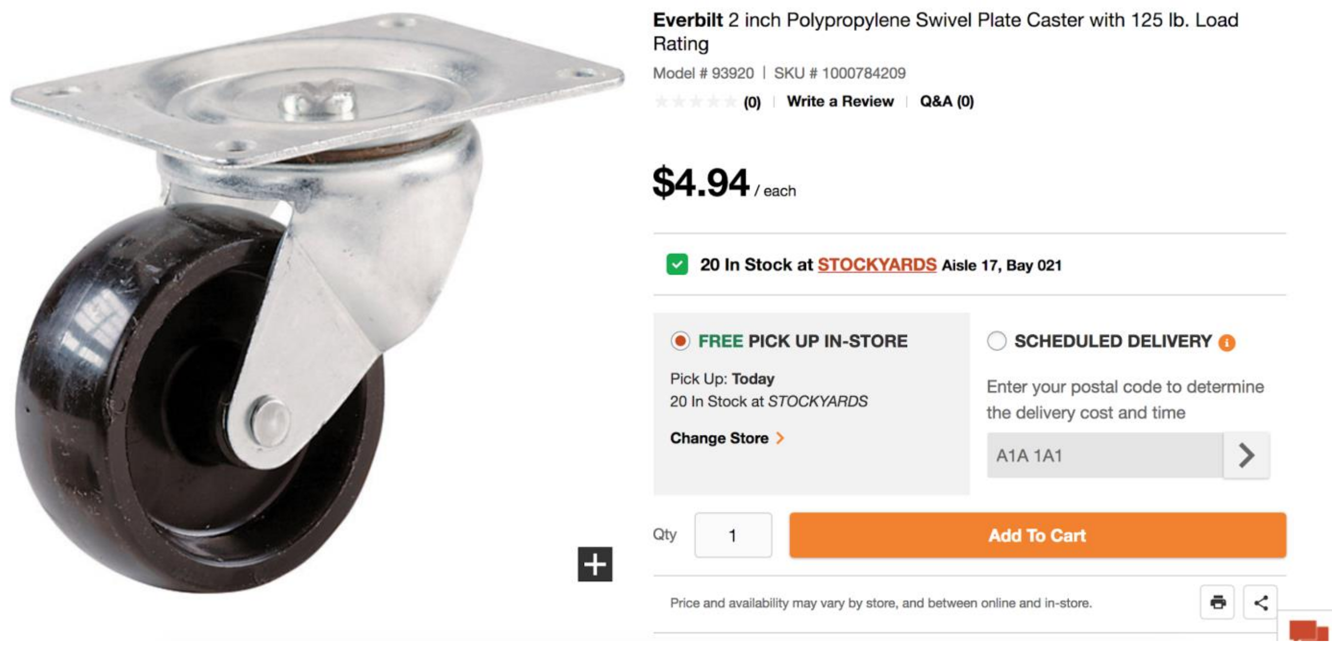
Packs of 25

ADD TO ORDER

In stock

Source: https://www.mcmaster.com/machine-screws

C: Caster wheels which will be used on the final prototype

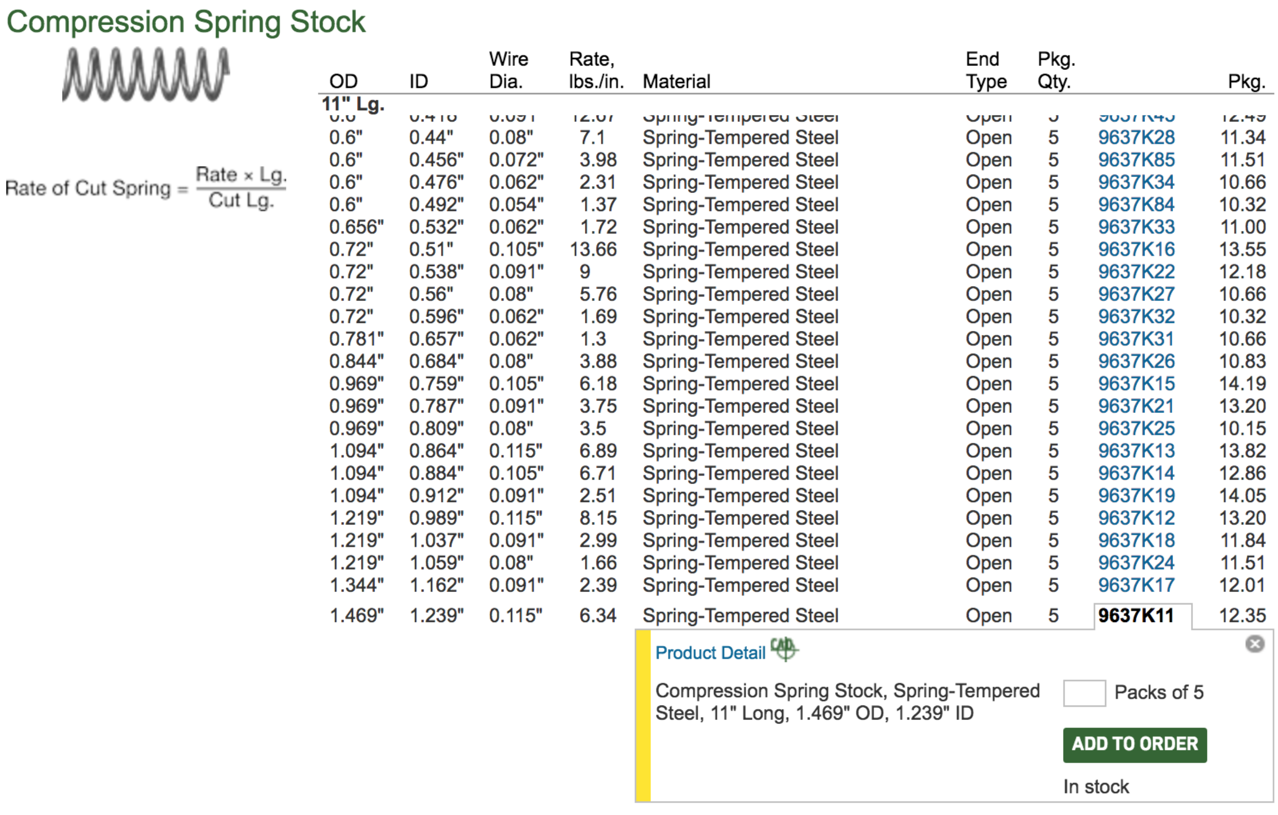


Source: https://www.homedepot.ca/en/home/p.2-inch-polypropylene-swivel-plate-caster-with-125-lb-load-rating.1000784209.html

D: Hooks which will be used to connect the bags onto the individual smaller IV poles

Source: https://www.homedepot.ca/en/home/p.12-inch--zinc-small-screw-eye-12pk.1000772898.html

E: Compression springs that will be used based on optimal, calculated value in calculations above



OD	ID	Wire Dia.	Rate, lbs./in.	Material	End Type	Pkg. Qty.		Pkg.
11" Lg.								
0.6"	0.418"	0.091"	12.07	Spring-Tempered Steel	Open	5	9637K45	12.49
0.6"	0.44"	0.08"	7.1	Spring-Tempered Steel	Open	5	9637K28	11.34
0.6"	0.456"	0.072"	3.98	Spring-Tempered Steel	Open	5	9637K85	11.51
0.6"	0.476"	0.062"	2.31	Spring-Tempered Steel	Open	5	9637K34	10.66
0.6"	0.492"	0.054"	1.37	Spring-Tempered Steel	Open	5	9637K84	10.32
0.656"	0.532"	0.062"	1.72	Spring-Tempered Steel	Open	5	9637K33	11.00
0.72"	0.51"	0.105"	13.66	Spring-Tempered Steel	Open	5	9637K16	13.55
0.72"	0.538"	0.091"	9	Spring-Tempered Steel	Open	5	9637K22	12.18
0.72"	0.56"	0.08"	5.76	Spring-Tempered Steel	Open	5	9637K27	10.66
0.72"	0.596"	0.062"	1.69	Spring-Tempered Steel	Open	5	9637K32	10.32
0.781"	0.657"	0.062"	1.3	Spring-Tempered Steel	Open	5	9637K31	10.66
0.844"	0.684"	0.08"	3.88	Spring-Tempered Steel	Open	5	9637K26	10.83
0.969"	0.759"	0.105"	6.18	Spring-Tempered Steel	Open	5	9637K15	14.19
0.969"	0.787"	0.091"	3.75	Spring-Tempered Steel	Open	5	9637K21	13.20
0.969"	0.809"	0.08"	3.5	Spring-Tempered Steel	Open	5	9637K25	10.15
1.094"	0.864"	0.115"	6.89	Spring-Tempered Steel	Open	5	9637K13	13.82
1.094"	0.884"	0.105"	6.71	Spring-Tempered Steel	Open	5	9637K14	12.86
1.094"	0.912"	0.091"	2.51	Spring-Tempered Steel	Open	5	9637K19	14.05
1.219"	0.989"	0.115"	8.15	Spring-Tempered Steel	Open	5	9637K12	13.20
1.219"	1.037"	0.091"	2.99	Spring-Tempered Steel	Open	5	9637K18	11.84
1.219"	1.059"	0.08"	1.66	Spring-Tempered Steel	Open	5	9637K24	11.51
1.344"	1.162"	0.091"	2.39	Spring-Tempered Steel	Open	5	9637K17	12.01
1.469"	1.239"	0.115"	6.34	Spring-Tempered Steel	Open	5	9637K11	12.35

Product Detail

Compression Spring Stock, Spring-Tempered Steel, 11" Long, 1.469" OD, 1.239" ID

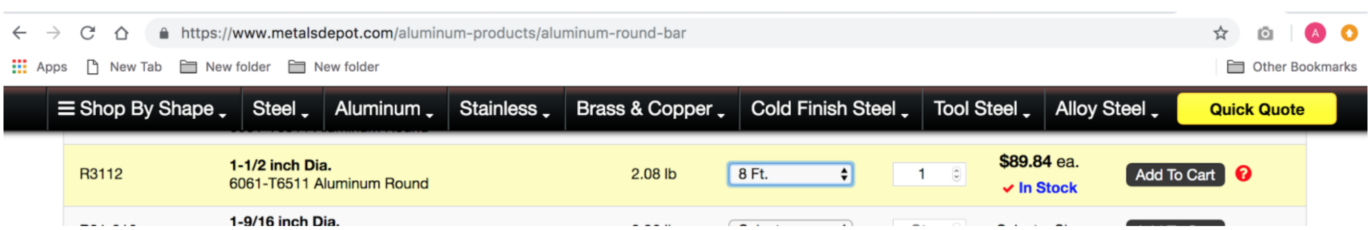
Packs of 5

ADD TO ORDER

In stock

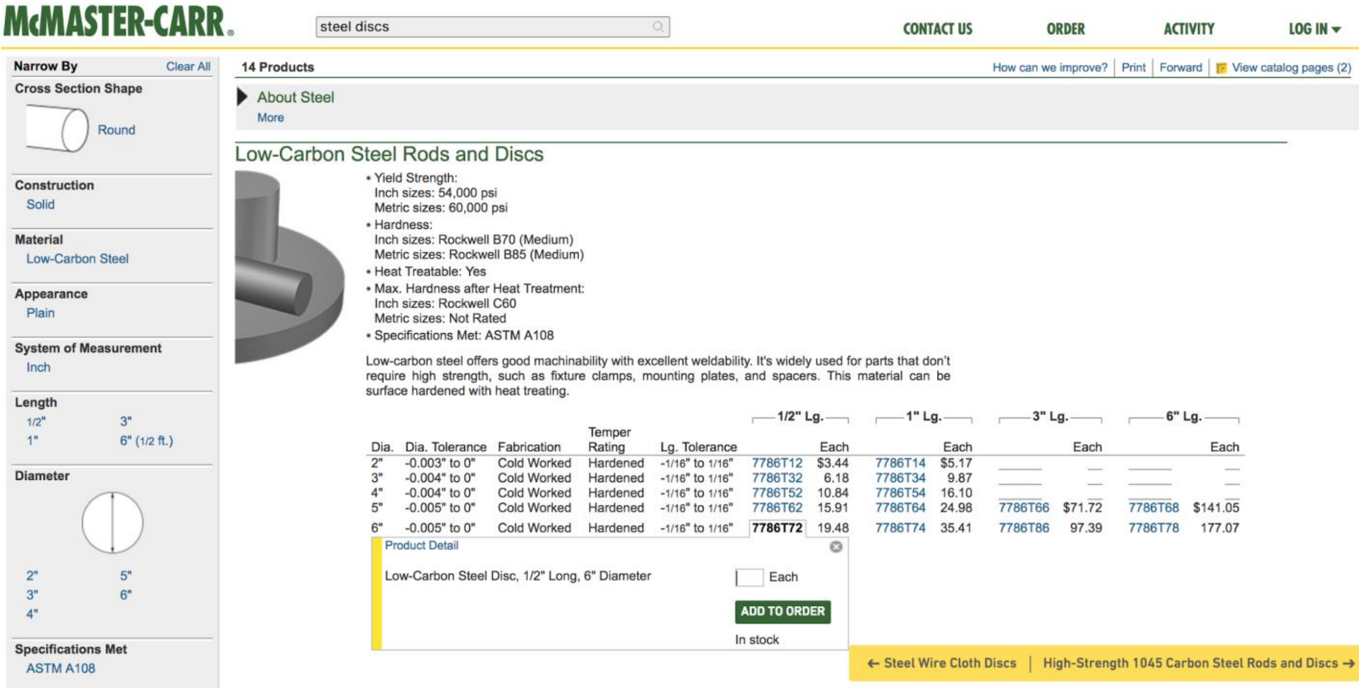
Source: https://www.mcmaster.com/catalog/124/1322

F: Aluminum rods used to create the outer, bigger pole and four inner, smaller poles



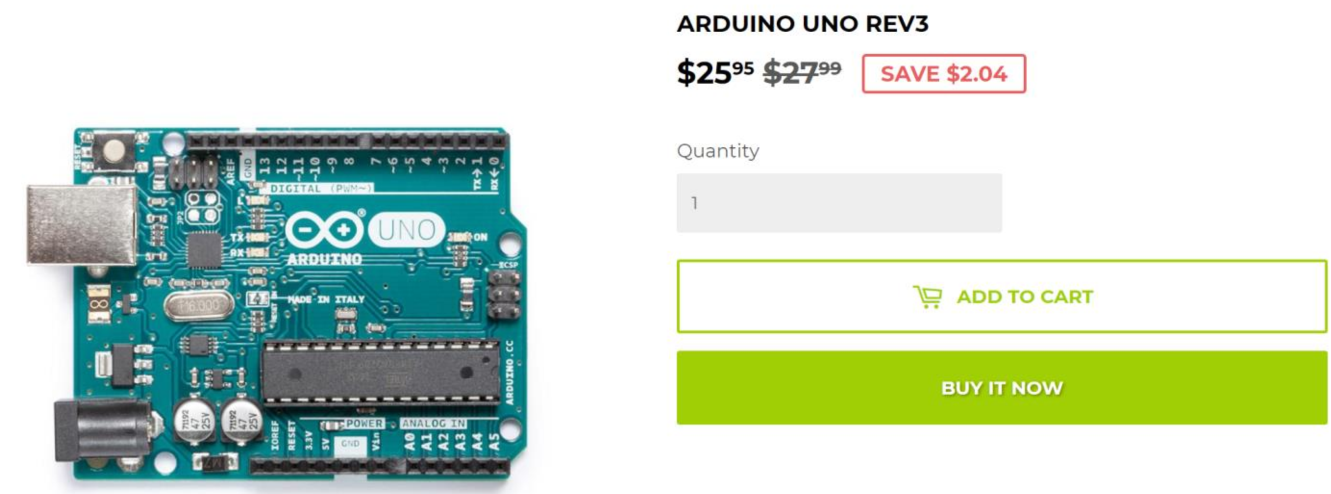
Source: https://www.metalsdepot.com/aluminum-products/aluminum-round-bar

G: Steel discs used to create the base and top of the IV pole. The following calculations were performed to determine the total amount of material needed to purchase. For ¼" thickness and 6" diameter = \$19.48/2 = \$9.74. Therefore, for a 12" base the total = \$19.48 and the bottom base = \$29.22. The total amount needed = \$48.70.



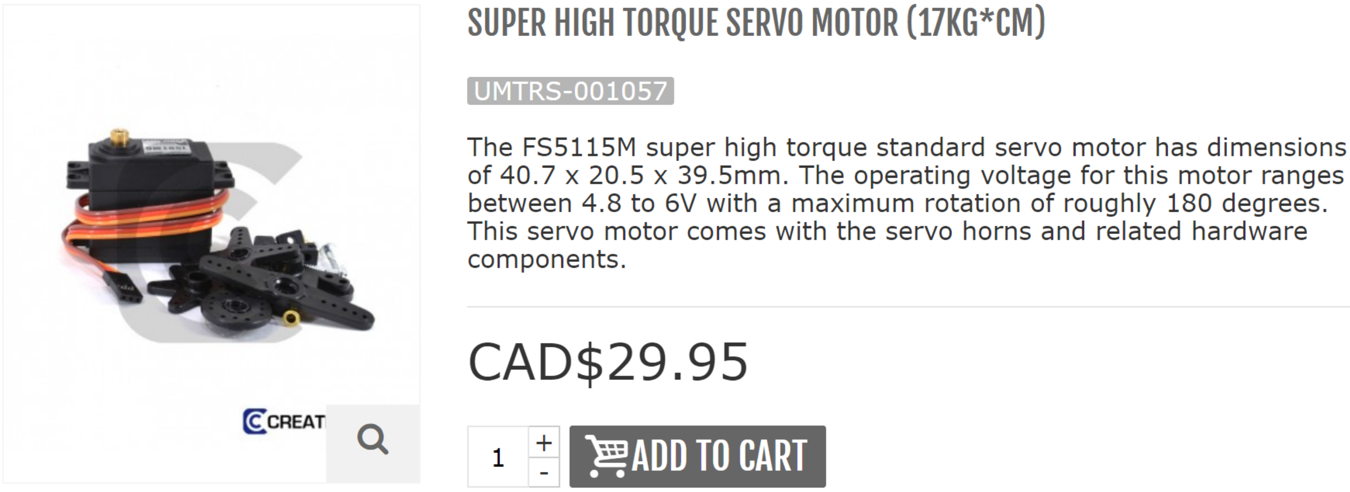
Source: https://www.mcmaster.com/steel-discs

H: Arduino Uno



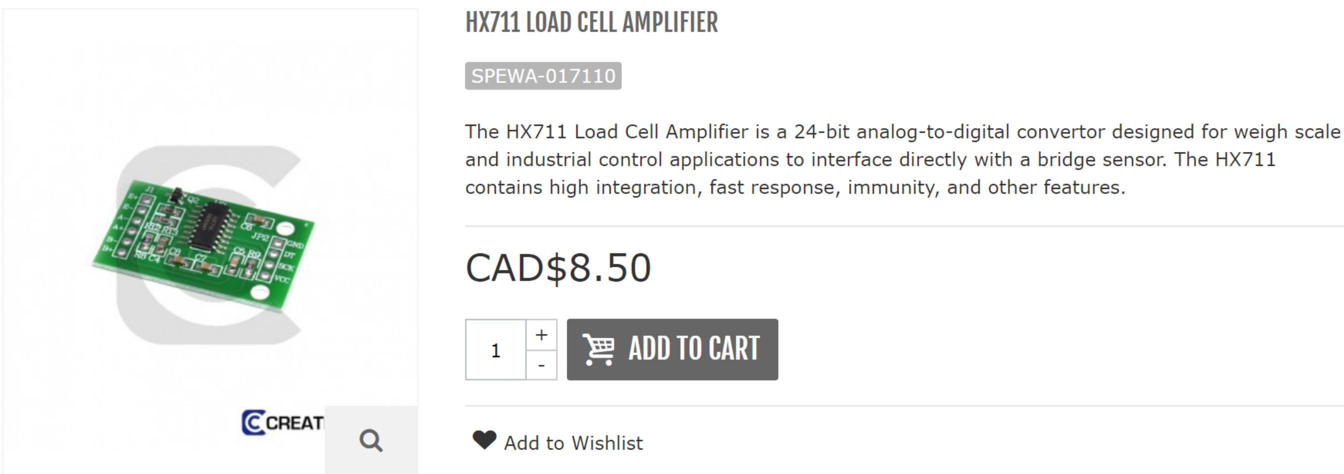
Source: https://electronicsurplus.ca/products/arduino-uno-rev3

I: Servo motor



Source: https://www.creatroninc.com/product/super-high-torque-servo-motor-17kgcm/

J: HX711 Load Cell Amplifier



Source: https://www.creatroninc.com/product/hx711-load-cell-amplifier/

K: Load cell (harvested from a hanging luggage scale)

WiseField 88lb/40kg Hanging Scale Luggage Digital Backlight Fishing Pocket Weight, Dark Blue
by WiseField
4 customer reviews

Available from these sellers.

5 new from CDN$ 12.99

- Equipped with high precision sensor:Accurate to 0.01lb/0.005kg, Capacity: 88lb/40kg,and with widely used unit: kg/lb/oz/jin
- Compact design with fast and accurate measurement; Auto-Off Function
- LCD Screen Display with Backlight: Blue Color Backlight make you can read screen value clearly at night
- ABS engineering plastic; Stainless steel hook for durable to use with tare function
- Battery: 2 x AAA Battery. (For Safety Reason of Shipping, Battery Not Included)

Report incorrect product information.

Source: https://www.amazon.ca/gp/product/B01IXZGYLM/

L: LEDs

10MM LED - RED (5 PACK)

LEDGR-105020

This pack contains 5 general purpose LEDs. Each LED is rated for 1.8V 10mA.

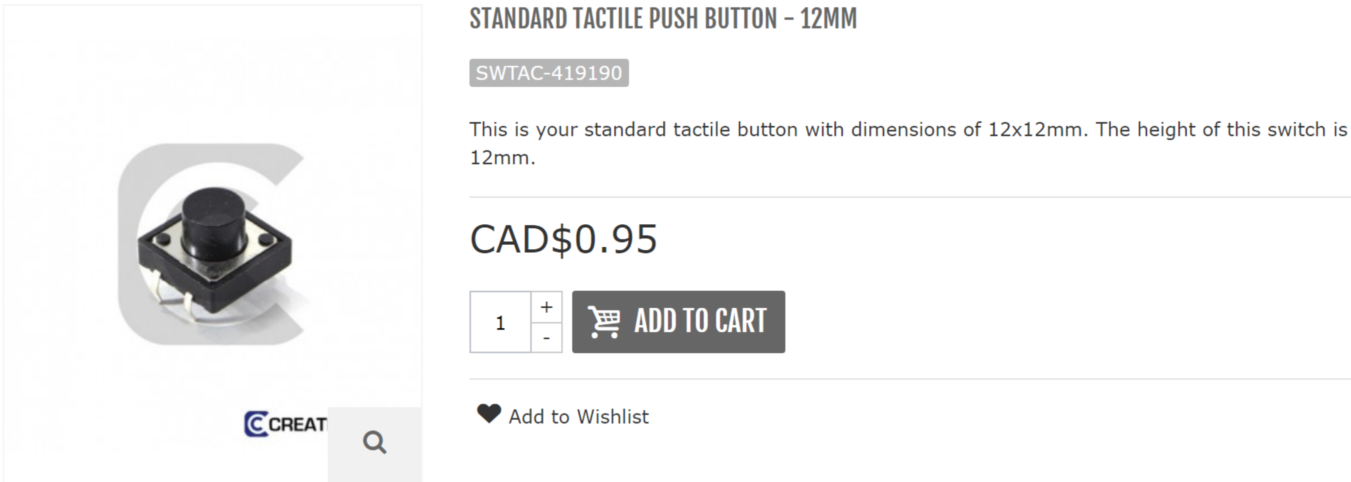
CAD$1.75

1 + - ADD TO CART

Add to Wishlist

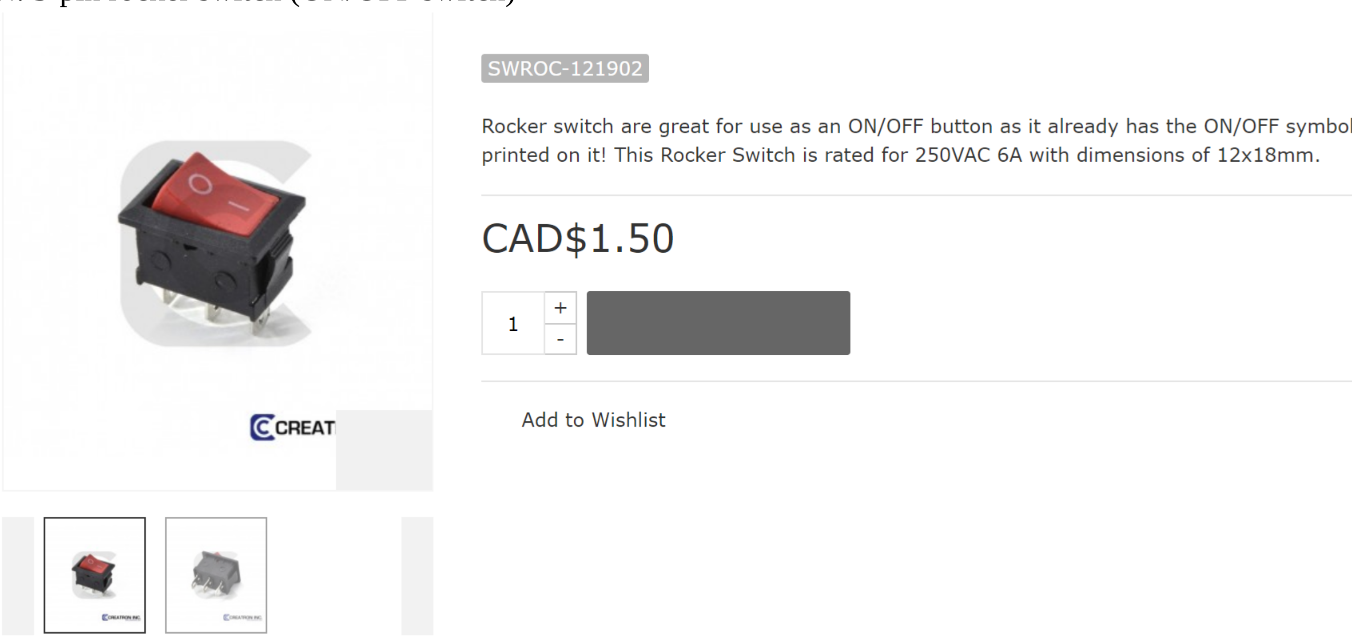
Source: https://www.creatroninc.com/product/10mm-led-red-5-pack/

M: Pushbutton



Source: https://www.creatroninc.com/product/standard-tactile-push-button-12mm/

N: 3-pin rocker switch (ON/OFF switch)

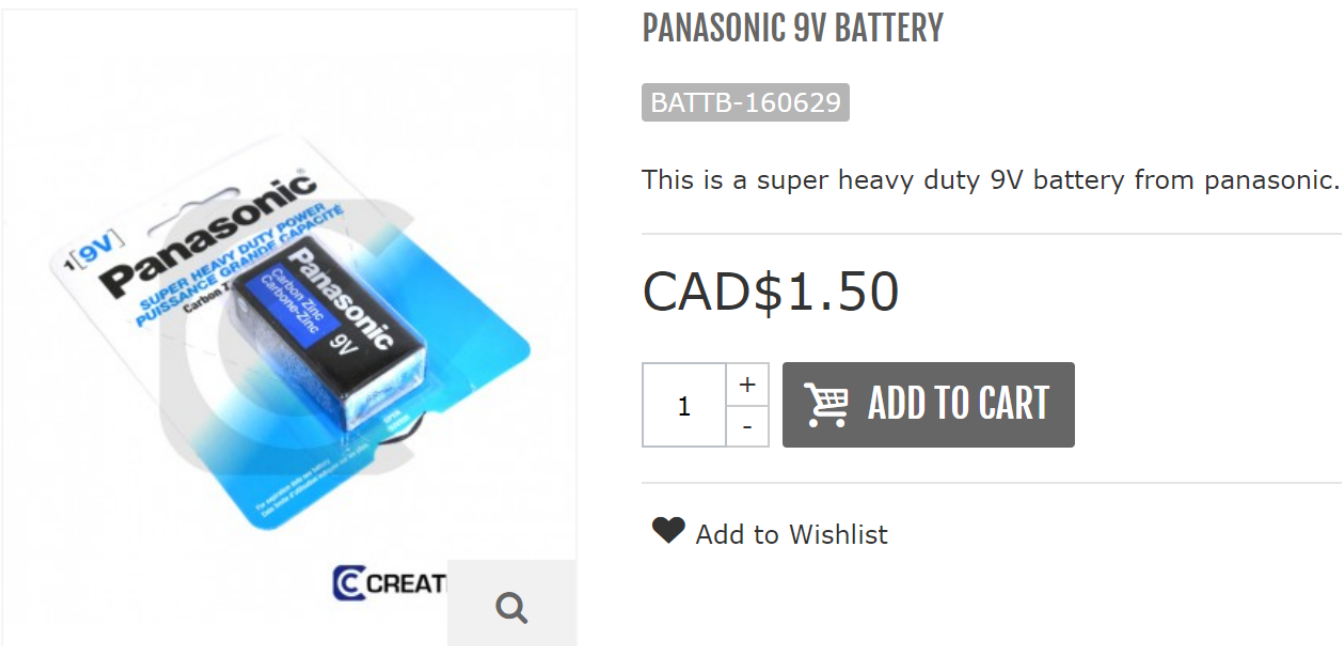


Source: https://www.creatroninc.com/product/spdt-rocker-switch/

O: Protoboards

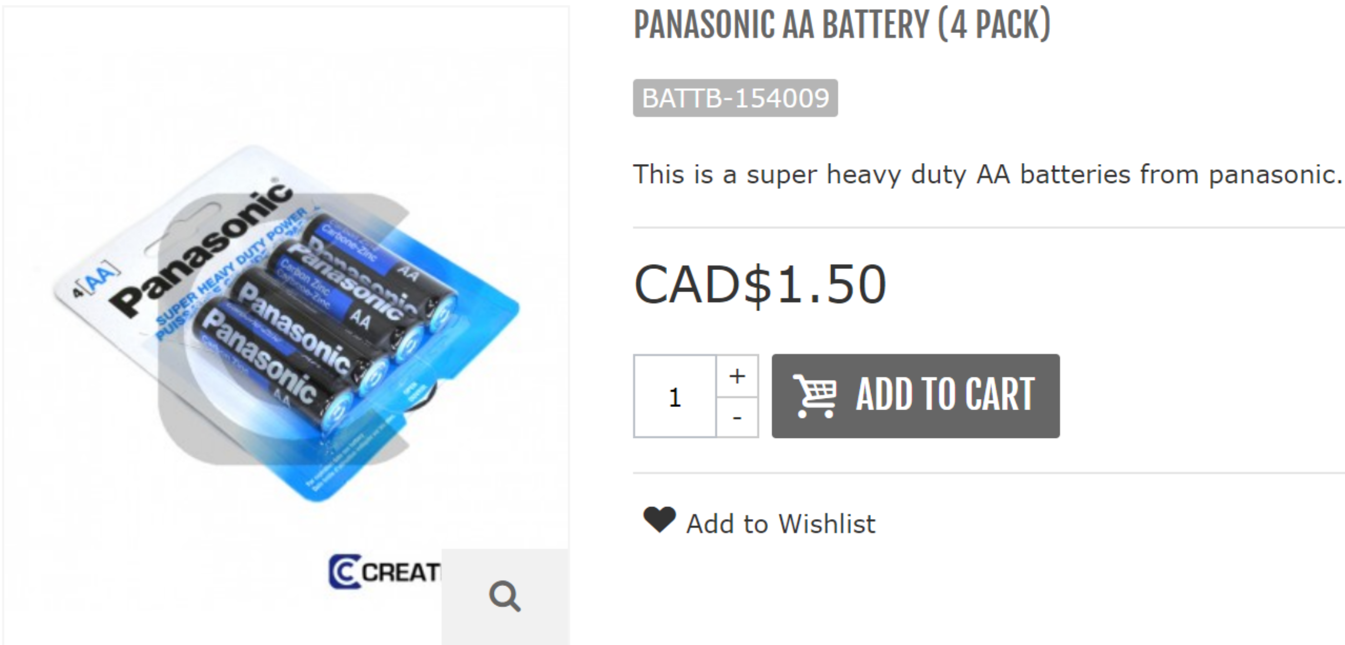
Source: https://www.creatroninc.com/product/5-x-7cm-double-side-prototyping-board/

P: 9V battery



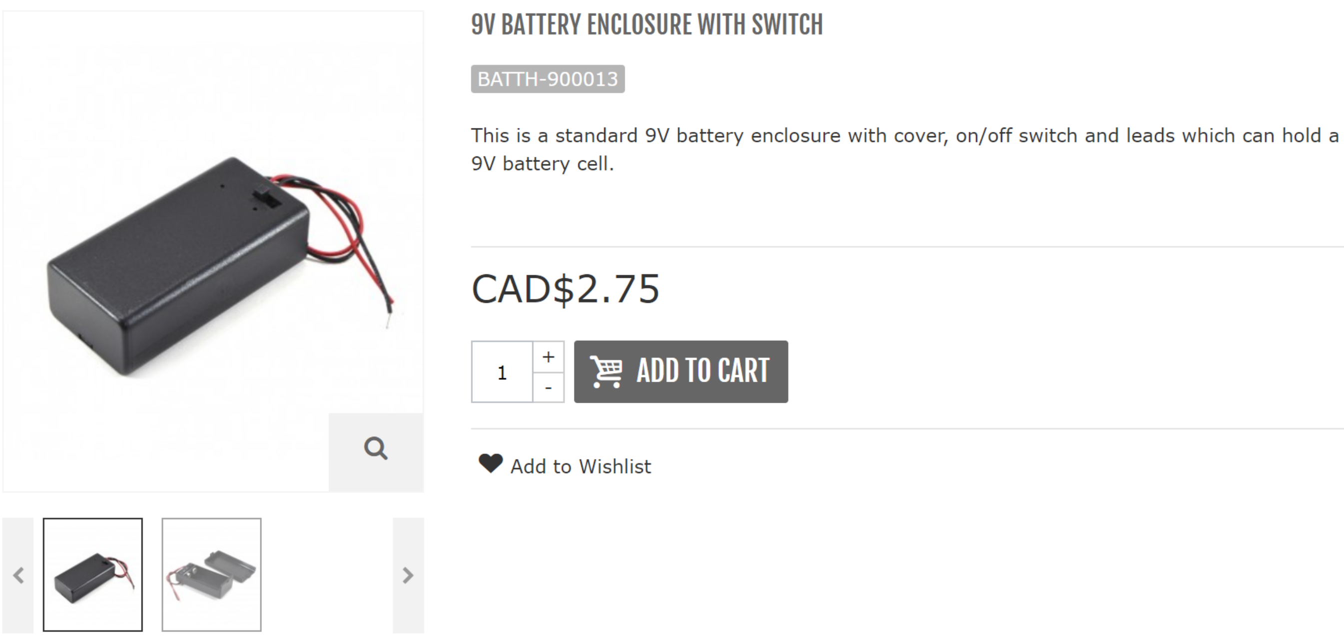
Source: https://www.creatroninc.com/product/panasonic-9v-battery/

Q: 4-pack AA batteries



Source: https://www.creatroninc.com/product/panasonic-aa-battery-4-pack/

R: 9V battery box/container



Source: https://www.creatroninc.com/product/9v-battery-enclosure-with-switch/

S: 4x AA battery box/container

AA X 4 CELL BATTERY ENCLOSURE WITH SWITCH

BATTH-411109

This is a standard AA battery enclosure with cover, on/off switch and leads which can hold 4xAA battery cell.

CAD$1.95

1 + - ADD TO CART

Add to Wishlist

Source: https://www.creatroninc.com/product/aa-x-4-cell-battery-enclosure-with-switch/

T: Resistors

1/4W 5% RESISTOR (10 PACK)

RESIS-500002

This pack comes with 10 individual resistors. Each resistor is rated for 1/4W at 5%.

Note: Please select a resistance value in the drop down menu.

CAD$0.25

Resistance Value 0ohm

1 + - ADD TO CART

Add to Wishlist

Source: https://www.creatroninc.com/product/14w-5-resistor-10-pack/

U: Diode

1N4001 – 50V 1A RECTIFIER DIODE (4 PACK)

DIREC-004001

The 1N4001 is a general purpose diode. It is rated for 50V 1A.

Documents:

- 1N4001 Datasheet

CAD$0.42

1 + - ADD TO CART

Add to Wishlist

Source: https://www.creatroninc.com/product/1n4001-50v-1a-rectifier-diode-4-pack/

V: NPN transistor

TRANQ-003904

Bipolar Junction Transistor is a solid-state device in which the current flows between the collector and the emitter are controlled by the current flow through the base.

CAD$0.30

1 + -

Add to Wishlist

Source: https://www.creatroninc.com/product/2n3904-npn-bjt-40v-02a/

W: 5V DC relay

5V 2A DPDT DC RELAY

RELAY-054078

A relay is a switch which can be controlled through a digital signal. This is a board mount DPDT DC mechanic relay. There are 2 separate channels, each channel has NO (Normal Open), COM (Common), NC (Normal Closed) terminals.

CAD$2.30

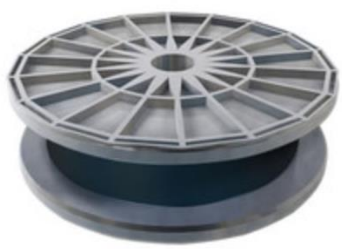
1 + - ADD TO CART

Add to Wishlist

Source: https://www.creatroninc.com/product/5v-2a-dpdt-dc-relay/

X: 3D printer filament

uPrint P430XL Model Spool - BLACK



Price CAD: $284.00

1 ADD TO CART

Replace your production-grade thermoplastic model material.

Item: P430XL Model Spool

Printer(s): uPrint SE, uPrint SE Plus

Plastic: ABS

Colour: Black

Voume: 42cu in / 688cc

About ABSPlus Material

ABSplus is the most affordable Stratasys 3D printing material, meaning designers and engineers can work iteratively, prototype often and test thoroughly. But it's so durable that your concept models and prototypes perform much like the final product.

Source: http://store.javelin-tech.com/Store-Catalog/uPrint-SE-Plus/uPrint-P430XL-Model-Spool-BLACK_2

Y: 3D printer support material

SR-30XL Soluble Support Spool (42 cu in/688 cc)

Price CAD: $277.00

1 ADD TO CART

Replace your production-grade thermoplastic support material.

Item: SR-30XL soluable support Spool

Printer(s): uPrint SE, uPrint SE Plus

Voume: 42cu in / 688cc

Source: http://store.javelin-tech.com/Store-Catalog/uPrint-SE-Plus/SR30XL-Soluble-Support-Spool_2

Appendix H: Work Plan

The accomplished work plan during the course of the semester is shown in the Gantt chart on the following page. It should be noted that the team switched designs halfway through the allocated schedule, restricting the amount of time remaining for more in-depth validation and verification testing.

Appendix I: Financial Plan (Accumulated Expenses)

The following table outlines a detailed list of all expenses accumulated thus far in the course of building prototypes.

Product	**Quantity**	**Total cost (Inc. tax)**	**Store**
Rope	1	$1.53	Home Hardware
Spring (medium)	1	$1.80	Home Hardware
Spring (small)	1	$1.80	Home Hardware
HX711 driver	2	$19.22	Creatron
Fishing scale	1	$33.89	Canadian Tire
Mini servo motor	2	$38.42	Creatron
Pulley	1	$6.20	Home Hardware
Wood/metal for machining	-	$14.84	Home Depot
Fishing scale	2	$20.00	Amazon
Ratchet pulley	1	$18.07	Home Hardware
Fishing scale	2	$24.00	Amazon
Velcro, ratchet buckle,	-	$46.85	Home Hardware
Super high torque servo motor	1	$33.84	Creatron
Galvanized wire	1	$3.38	Home Hardware
Pliers, wire cutters	-	$10.16	Home Hardware
Pulley	1	$6.20	Home Hardware
Wire	1	$1.36	Home Hardware
Heat Shrink	1	$1.13	Home Hardware
Wire	1	$2.26	Home Hardware
Square LEDs	-	$1.70	Home Hardware
3 x AA battery holder	1	$1.70	Home Hardware
Battery Connector with Wire	1	$0.51	Home Hardware
4 x AA battery holder	1	$2.26	Home Hardware
9V battery holder with wire	1	$5.64	Home Hardware
9V battery	1	$5.64	Home Hardware
4-pack AA batteries	1	$7.11	Home Hardware
Rocker Switch	1	$3.96	Home Hardware
Protoboards	4	$15.82	Home Hardware

Heat Shrink	1	$1.13	Home Hardware
Large LEDs	-	$5.09	Home Hardware
Relay	1	$3.96	Home Hardware
Wheels for current prototype	4	$25.03	Home Depot
Wires, heatshrink	-	$9.83	Home Hardware
Total		**$339.44**	

Item	**Purchased at:**	**Reason for purchase**	**Quantity**	**Price ($)**
Prototyping				
2x2x8 Framing Lumber	Home Depot	To build first IV prototype stand	2	6.48
Everbilt Screw Eye Pck 12 pack		To build first IV prototype stand	1	2.52
Simpson Strong-Tie Steel Angle		To build first IV prototype stand	4	5.84
Galvanized Wire	Home Hardware	To build first pulley prototype	1	3.38
Single Fixed Eye Pulley		To build first pulley prototype	1	6.20
Wire Cutters		To build first pulley prototype	1	10.16
Small spring		To build first pulley prototype	2	3.60
Pulley		To build first pulley prototype	3	18.83
Rope		To build first pulley prototype	1	1.53
Ratchet buckle		To test feasibility of mechanism	1	22.6
Velcro		For final prototype	1	14.69

Fishing scale	Canadian Tire	To build first pulley prototype	1	38.42
Fishing scale	Amazon	For final prototype	4	44.00
Ratchet pulley		To test feasibility of mechanism	1	16.00
HX711 driver board	Creatron Inc.	For final prototype	2	19.22
Mini servo motor		To build first pulley prototype	2	38.42
Super High Torque Servo		For final prototype	1	33.84
Caster wheels	Home Depot	To build final IV prototype	4	25.03

Appendix J: Report Attribution Table

Section	Team Member 1 - Rishi	Team Member 2 - Antonia	Team Member 3 - Nhien	Team Member 4 - Derrick
Executive Summary			A	
Introduction		X	A	
Final Design	X	A	X	A
Assessment of Final Design	X	A	X	X
Summary and Conclusions	A		X	X
Work Plan	A			
Financial Plan		X	X	A
Appendices	X	X	X	X