Operation Feedback

Biomedical Engineering Design 200/300

University of Wisconsin-Madison

Department of Biomedical Engineering

Preliminary Design Report

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Abstract

Current models used to train veterinary students on IV placement often do not provide relevant feedback or use fake blood to do so. This is often messy and difficult to work with. If the blood is not used, the students have no way of knowing when they have reached the lumen and are left unsure if the procedure has been completed. There is additionally no feedback on the amount of damage they might be causing the surrounding tissue. If the lumen is missed or overshot, this can cause additional discomfort to the animal and often the students do not realize this until they are performing the procedure for the first time. This product will mimic the feel of placing an IV or catheter into the front limb of a dog while alerting the student as to when they are in the lumen. To accomplish this the needle used to practice the procedure will use two electrodes to detect a change in impedance resulting from the imitation vein being filled with conductive gel. This will be detected by a microcontroller and a green light will signal the completion of the procedure. As time allows additional sensors can be implemented to detect the amount of pressure applied within the vein or to determine where the student went wrong.

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Introduction

Motivation

The lack of applicable training devices for placing a catheter into a canine vein calls for a device that can provide students with feedback on their performance. The American Veterinary Medical Association (AVMA) states that universities or colleges should "provide appropriate training for students and faculty." [1] The client believes the existing models do not provide enough performance feedback to students, so to comply with the AVMA requirements the client requested a more applicable training device. By providing more feedback the students would be able to hone their IV placement on the practice model and cause less discomfort to animals early in their careers.

Existing Models

Figure 1: Canine Leg Vascular Access Simulator.

A Canine Leg Vascular Access Simulator can provide students with a model that resembles a dogs leg, but the model requires fake blood making the cleanup difficult. The vein must be filled and sealed each time the procedure is practiced. Additionally, the model does not have any fur on it, and the silicone quickly becomes sticky. One advantage to this design is the base is attached to two magnets which secure the device to the metal tables found in veterinary schools. This eliminates the need for a second student to be holding the apparatus while the other practices the procedure [2].

Figure 2: Synthetic dog leg from Life/Form®.

There is a model of a fur covered dog leg from Life/Form®. This model uses fake blood and an artificial vein to reassure students when they are in the lumen of the vein. The fake blood is in a bag suspended above the limb. Gravity is then used to fill the vein with the blood to be subsequently used in the intravascular catheter. Since the model is covered in fur, it provides students of an accurate representation of what the dog might feel like. The fur around the area of the procedure can be removed to model different scenarios. A main consequence of the simplicity of this model is the students will not get any alert as to when they have damaged tissue surrounding the vein [3].

Figure 3: Client Training Model.

The client created her own model consisting of plastic tubing with a 0.5 cm rubber tube on the top. This is all covered by imitation fur and skin to hide the vein from students. This device provides no feedback except for the feel. The student can feel when they have hit the vein but cannot distinguish between being in the lumen, the side, or going completely through the vein.

Problem Statement

The current models that veterinary students use to practice IV and catheter placement require fake blood to provide feedback as to whether or not the student is in the lumen of the vein. This is a messy process and is unfavorable for the students and professors. They also often require another student to stabilize the device while the other practices. These models can also be expensive which makes it unideal to use for training since classrooms would require numerous models to effectively train the students.

Background

Background Research

Veterinarians frequently give cephalic vein injections in dogs to either obtain blood samples or to place IV catheters for the administration of drugs and fluid therapy. Typically, this procedure will require two staff members, where one is restraining the animal and the other is administering the injection. This model assumes the animal is being properly restrained and thus will be entirely static. Proper preparation and sterilization techniques are essential for maintaining the health of the patient during the procedure, one key step during preparation is shaving of the anterior antebrachium [9]. Catheters used in this procedure are relatively large being 21G or wider and are inserted at an angle between 15 and 30 degrees. Additionally, a normal blood draw will take between 2-5 ml of blood [9].

Common complications are important for veterinary students to understand before beginning to place an intravenous catheter in live animals. The most common complication seen in canines and other animals during injections is tissue or nerve damage [8]. Inexperienced veterinarians, specifically vet students, often times will miss the lumen of the vessel either by puncturing through the vein or missing off to the side entirely. A puncture through the vein is common when administering catheters, as this technique requires a subsequent step in which unintentional force can be easily applied [6]. There are more serious side effects like blood clots and infections, but these are much more rare. These complications can be avoided if the student, or veterinarian, places the needle steadily into the lumen of the vein [8]. Intravenous catheters are placed to administer drugs at a much higher rate than an oral or rectal delivery system. Emergency situations are normally when an intravenous injection is much more common than pill or liquid delivery [8].

Client Information

Kristen Cooley is a professor at the University of Wisconsin-Madison School of Veterinary Medicine. She sees this device as a way to provide more feedback on how well a student is completing the IV placement so that when they perform the procedure on an actual animal they are not experiencing additional discomfort.

Design Specifications

The model should last biweekly use for two years, assuming some parts (such as the tubing and gel) are replaced more frequently. The exact amount of time will be determined through further testing. The intended use would be in a classroom setting, so the design must be portable and easy to set up. It should be under 15 pounds in weight and able to be powered by a laptop or wall outlet. The device should cost under $350 to make it affordable to purchase several of the model per classroom.

Preliminary Designs

Design One

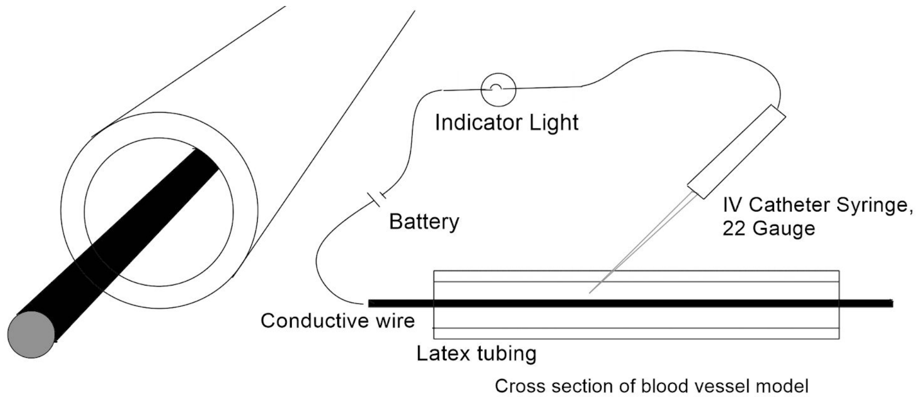

Figure 4: Design One, Wire Circuit

The latex tubing shown in figure four models the blood vessel of the dog. Running concentric to the tube is a conductive wire in circuit with an IV Catheter Syringe. Upon proper insertion of the catheter into the tube, the needle will make contact with the conductive wire in the center of the lumen. This closes the circuit and indicates to the student that they have inserted the needle correctly.

Design Two

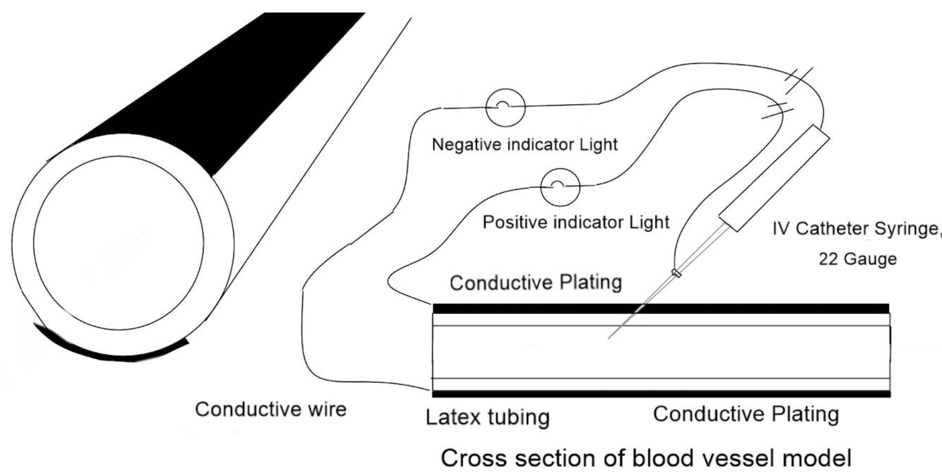

Figure 5: Design Two, Double Feedback

Similar latex tubing is used in Design Two, as shown in figure five. Conductive plating is placed on the upper and lower surfaces of the tube. A conductive band is also mounted to the middle of the needle connected in a circuit with the positive indicator light. When a student inserts the needle at the appropriate insertion angle (between 15-30 degrees) the band will make contact with the conductive plating on the superior surface of the tube, which signals successful insertion to the student via the positive indicator light. In the circumstance that a student inserts the needle beyond an angle of 30 degrees, the needle will make contact with the lower conductive plating, completing the circuit for negative feedback before the conductive band will reach the upper conductive plating.

Design Three

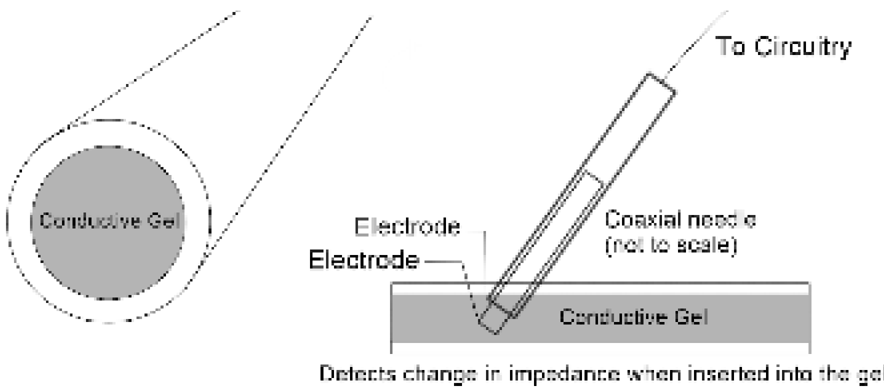

Figure 6: Design Three, Conductive Gel.

Design three involves a coaxial needle capable of detecting impedance when inserted into a conductive gel. There are two electrodes on the needle, separated by an insulator. When the needle is inserted into the conductive gel, a circuit is completed between the electrodes, and impedance of the gel can be measured. The model is a positive and negative response system. If the impedance is close to the predetermined value indicative of insertion in the conductive gel, a green light will go off to indicate a positive response. If the coaxial needle misses the vein or goes through the vein, the measured impedance not be within the allowed range, and a red light will indicate a negative response.

Preliminary Design Evaluation

Design Evaluation

Preliminary Design Matrix

Criteria	Wire Through	Thin Band	Conductive Gel
Cost (10)	9 (0.9)	8 (0.8)	5 (0.5)
Accuracy (20)	5 (1)	9 (1.8)	10 (2)
User friendly (30)	4 (1.2)	7 (2.1)	9 (2.7)
Durability (20)	10 (2)	6 (1.2)	8 (1.6)
Complexity (20)	8 (1.6)	5 (1)	7 (1.4)
Weighted Score	6.7	6.9	8.2

Figure 7: Preliminary Design Matrix

Cost: A low score represents an expensive design, while a high score represents a more affordable design. This rating is based on the estimated materials cost. Cost only accounts for 10% of the weighted score since the client does not have a specified budget and none of these designs are predicted to cost upwards of $350.

Accuracy: Lower scores imply the model not replicating a realistic process of implementing a catheter into a dogs vein. On the other hand, a high score indicates the model being very realistic. This is a more important factor to consider since the product should mimic the feel of a real animal as closely as possible.

User friendly: User friendly is the most important category since the students must be able to repeatedly use the design with minimal set-up. This also factors in the reliability of the procedural feedback. The device should be able to consistently alert the user on their completion or shortcomings during the procedure.

Durability: This rating describes the estimated amount of time that the design will properly operate. The designs are anticipated to have some replacements to maintain accuracy and feel but the maintenance should be minimal and easy to complete which makes it an important factor.

Complexity: Describes the difficulty of the fabrication process. In order to have a product for the client, this device must be created within the scope of a semester which gives it a significant weighting. Those designs with a higher score are anticipated to be easier to create.

Weighted Score: The number next to each category describe how highly we value the criteria. The total weight adds up to 100, and each category has a maximum of ten unweighted points. Each number is equal to the percent value associated with the category. As shown above, the green highlighted boxes show which model score highest for the individual criteria. To continue, the weighted number next to each criterion will be multiplied, as a percentage, with the value derived by the group. For example the conductive gel was given a score of five for cost which is weighted at 10%, five multiplied by 0.1 equates to one half. These values are then summed to give the total weighted score.

Proposed Final Design

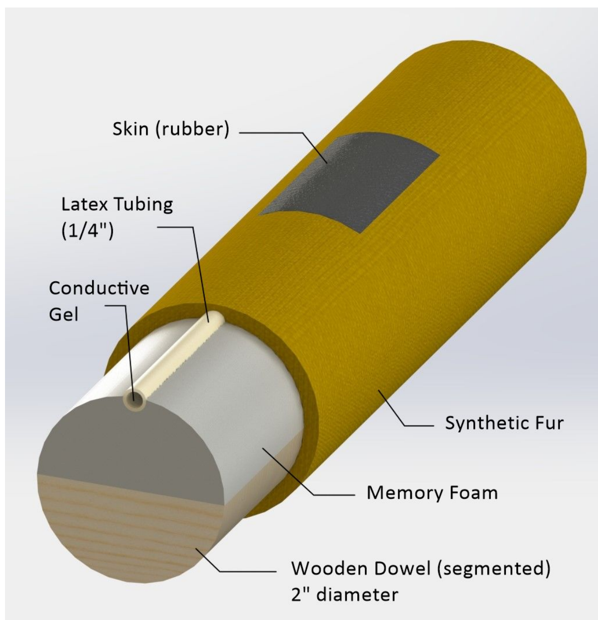

Figure 8: Final design incorporated into the model dog limb.

Design three, the Conductive Gel, will be pursued as the intended final product. This model has the highest upside when it comes to accuracy and user feel which are two of the most important design considerations. This model will be the most accurate because if the user is anywhere inside the lumen the coaxial needle will read an impedance level indicative of positive feedback, while the alternative would result in negative feedback. “User friendly” is essentially criteria for how realistically our model can simulate the leg and vein of a dog. The Conductive Gel method will not have any obvious hindrances such as the wire being threaded through the middle of the lumen or conductive plating being placed above and below the vessel. Using a conductive gel will get result in as close to real feel as possible while still being able to complete an electrical circuit. Additionally, this design will have very few parts and a relatively simple circuit design, increasing its longevity and durability.

Development Process

Materials

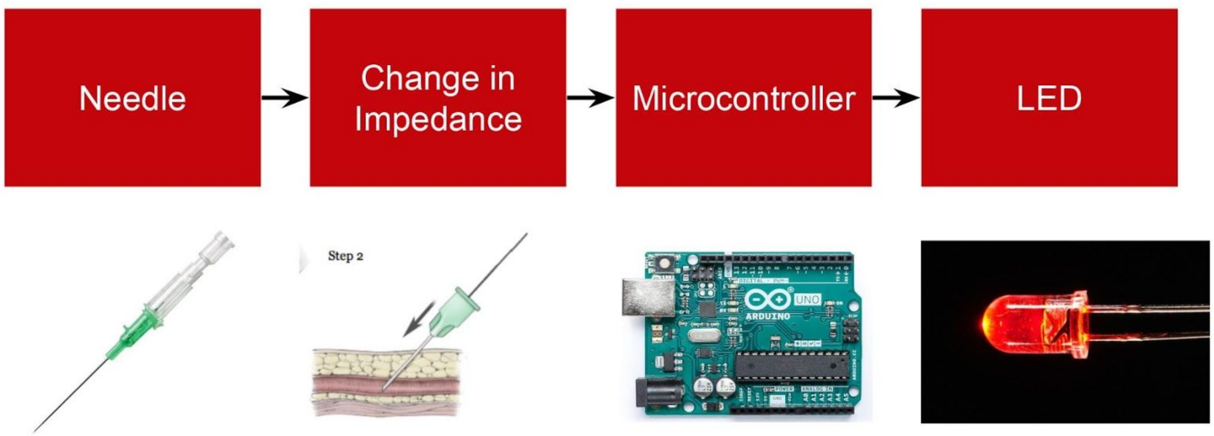

Figure 9: The different components and materials needed to complete the prototype.

A coaxial needle or equivalent will be needed to construct the device. This will either be obtained through purchasing the device or creating one using the catheter needles provided. The needle will be connected to an Arduino microcontroller. Two LEDs and wires will also be utilized in this device.

Material	Source	Cost
Arduino Microcontroller	Arduino.com	$22.00
22 Gauge Catheter	Client	$0.00
Imitation Fur (20x30cm)	Hobby Lobby [10]	$16.99
Imitation Skin (Chamois Cloth)	Amazon [11]	$12.95
0.5 cm Diameter Rubber	Amazon [12]	$6.07

Tubing		
3 cm Diameter Wooden Dowel	Team Lab	$0.00
Wires and LEDs	Personal Supplies	$0.00
Coaxial Needle or Equivalent	Unknown	~$100.00
Memory Foam	Amazon [13]	$17.96
Conductive Gel	Parker Labs [14]	$7.50
Total:		$183.47

Figure 10: Estimated cost and where the proposed materials are going to be purchased.

Fake fur and material that is similar to the look and feel of skin will also be bought to wrap around the vein and provide a more realistic feel to the device. The wooden dowel will provide support and the memory foam will provide a buffer for if the students miss the vein.

Methods

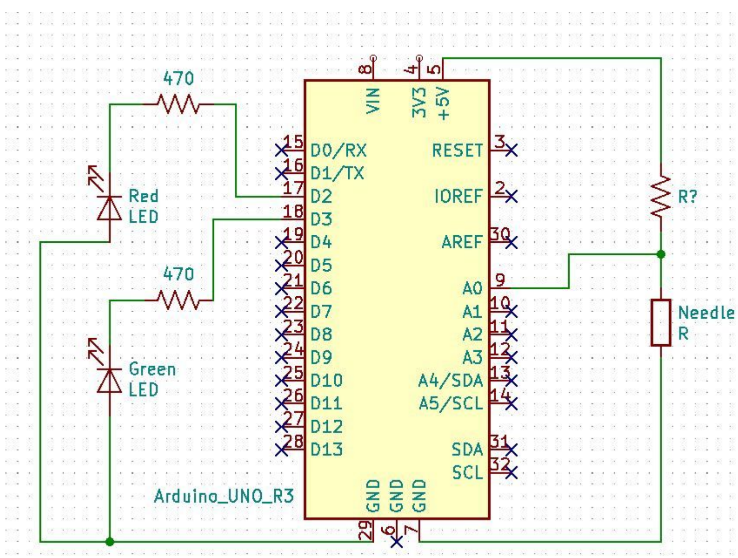

Figure 11: Preliminary circuitry design consisting of a voltage divider where the second resistor is the coaxial needle.

The assembly of the device will consist of a voltage divider connected to the five volt pin on the Arduino. The needle will act as a variable resistor depending on where it is located in our model. This will result in a variable voltage drop across the first resistor which will be measured by an analog pin. Once the impedance of the conductive gel is determined, the value of the unknown resistor will be selected to be close to that value. The voltage measured by the Arduino will then be approximately 2.5 volts.

The microcontroller will be connected to and powered by a computer which will make it easily movable around the classroom. Additionally, a red and green LED will be connected in series with a 470 ohm resistor and each with their own digital pin as seen in the figure above. The red LED will be on until the student reaches the lumen of the vein when the green light will turn on instead.

The vein will be replicated by a rubber tube filled with conductive gel that is sealed on either side. This will prevent the vein from leaking gel into the rest of the device. It will be held in place by two straps which will allow for it to be replaced after repeated use. The leg itself will have a base of a 3 cm diameter wooden dowel which will be cut in half down the middle. The top half of the leg will be constructed from memory foam to prevent damage from occurring to the needle if the vein is missed and to give a more realistic feel. The entire device will be covered by a fake fur with a small “shaved” patch where the IV will be inserted. This will be removable in order to allow for the vein to be replaced and the layer itself if needed.

Testing

In order to determine the impedance of the gel, the needle will be placed in the gel and a voltmeter will be used to measure the resistance across the two wires attached to the needle. This process will be repeated five times and the average resistance will be calculated. This will then be used as the impedance value of the gel and needle combination.

Four different testing scenarios will be performed in order to determine the accuracy of the device. The first scenario will be just holding the needle in open air. If the device is working properly the red light will remain on. The second will be the needle goes directly into the lumen. Before the needle is inserted the light should be red and the green light should not go on until the needle has been fully inserted into the lumen. Third, the needle will go into the lumen and then out the other side of the imitation vein. This test will be a success if the light goes from red, to green, to red again. Finally, the vein will be missed all together and the light should remain red.

Each of these tests will be repeated ten times. In order for our device to be considered a success, these tests should be able to be completed with at least 95% accuracy.

It is anticipated that the gel and the vein will need to be replaced periodically to maintain functionality. The first issue is the repeated punctures are eventually going to cause deterioration and leakage. To determine the lifespan of each vein a three centimeter stretch of tubing will be filled with gel and the number of punctures will be counted until leakage occurs. This test will be repeated five times and the results averaged.

The gel will eventually harden as well after being exposed to air. This will affect the functionality of the device and the impedance. After the vein has been punctured ten times, it will be left to sit and monitored once a day to determine the amount of time it takes for the impedance to change by more than 10% or for it to completely dry. This will be done with five different veins.

Conclusions

The coaxial needle combined with the conductive gel will effectively fill the gap in the market for mess free IV and catheter placement training. It will require minimal maintenance and will be easily portable which will make it ideal for training situations and movement around the classroom.

The focus of this project will initially be obtaining or creating a coaxial needle or an equivalent needle. Ideally, it will be similar in size to a 22 gauge needle at the request of the client. From there the impedance can be determined and tests performed.

Since there is much more to inserting an IV than just ensuring the needle is in the lumen, other features may be added to the device. Excessive movement and searching for the vein once in the leg can cause damage to the surrounding tissue and bring discomfort to the animal. Several different pressure sensors would be placed around the vein with one on either side and one on the bottom. This change in pressure would be detected by the Arduino and communicated to the user. The microcontroller could also run a display that gives the student more specific feedback. It could convey information such as how long it took for the user to complete the procedure and specific information on where they went wrong. Some sample display messages may include, "Missed the vein right," or "Punctured through the far side of vein."

The display could also show a score out of 100 in order to provide measurable feedback to the students. It would factor in information such as time taken to complete the procedure, pressure applied, and movement allowing students to see how they are progressing over time. Another suggestion from the client was to create various "levels" of this design. This model could be replicated with veins of different sizes, starting with a larger tubes and progressively becoming smaller to increase difficulty.

Citations

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Appendix

PDS

1. Physical and Operational Characteristics
    a. Performance requirements: The device should be able to be used repeatedly with minimal degradation. Since it is a training device, it should be able to last at least five years without needing to have any parts replaced. It will most likely be used several times a month depending on when the procedure is being practiced.
    b. Safety: The device will involve an electrical circuit and therefore all wiring must be properly insulated. The voltage supplied will be 5 volts in order to ensure proper function from the Arduino while avoiding overheating [1]. This device will contain a sharp tipped needle that presents its own safety hazards. This will be labeled and expressed clearly as a potential safety hazard.
    c. Accuracy and Reliability: The device should be able to determine that it is in the lumen of the vein 95% of the time.
    d. Life in Service: The device will be able to withstand bi-weekly use for two years. Expected use will consist of repeated vessel punctures for roughly 15 minutes. Replacement of the vessel and conductive gel is expected once every two months.
    e. Shelf Life: Copper wiring would be a cheap and effective wire, as the life-span could be anywhere from 50-100 years.(4) With typical wear and tear this could drop down to 20-25, but this time frame still does not create a problem. The plastic tubing that replicates the vain would need to be replaced after about 350 injections, to be careful. The environment should not affect the model while in storage. Depending on the battery size, but if we use a nickel cadmium battery the shelf life, that is without use, should be around 18 months. If we were to use a typical lithium double A battery, the shelf life would be upwards of 5 years.
    f. Operating Environment: Device will be operated at room temperature in a classroom environment. May be exposed to potential damage from gel leakage and needle puncturing

g. Ergonomics: Uses should be restricted to supervised classrooms only. The needle should never be inserted towards the user.
h. Size: The maximum size of the leg and total model will not be any larger than a 2 foot by 1.5 foot
i. Weight: The device should be portable. The model should be under 15 pounds. There are no problems with a model that is too light.
j. Materials: Materials are intended to mimic the real feel of a dogs leg while being able to withstand repeated puncture.

Material	**Source**	**Cost**
Arduino Microcontroller	Arduino.com	$22.00
22 Gauge Catheter	Client	$0.00
Imitation Fur (20x30cm)	Hobby Lobby [10]	$16.99
Imitation Skin (Chamois Cloth)	Amazon [11]	$12.95
0.5 cm Diameter Rubber Tubing	Amazon [12]	$6.07
3 cm Diameter Wooden Dowel	Team Lab	$0.00
Wires and LEDs	Personal Supplies	$0.00
Coaxial Needle or Equivalent	Unknown	~$100.00
Memory Foam	Amazon [13]	$17.96
Conductive Gel	Parker Labs [14]	$7.50

Total:		$183.47

k. Aesthetics, Appearance, and Finish: Resembles the leg of a dog. Potential fur-like finishing outside of blood vessel region.

2. Production Characteristics:
    a. Quantity: Only one prototype is required.
    b. Target Product Cost: The expected total product cost is $183.47 if all expected materials are purchased. In general the cost should stay below $350.
3. Miscellaneous
    a. Standards and Specifications: The imitation vein that is used should comply with the size provided with a 0.5 cm outer diameter.
    b. Customer: Dislikes the use of fluid as a positive indicator within the tube that models the blood vessel since it dyes the operators hands.
    c. Patient-related Concerns: The device should not need to be sterilized, as the needles will not be used on humans. The people using the device must be careful when using the needle, or when they put the needle away as to not poke themselves.
    d. Competition: There are a few models that use a fluid solution to replicate blood but only one that uses an electrical system we are proposing and that is by the game operation(2).

PDS Sources

[1] “Arduino Uno Rev3.” [Online]. Available: https://store.arduino.cc/usa/arduino-uno-rev3. [Accessed: 09-Oct-2019].

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