Canine Insulin Pump

Design Document

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ECE 445 Project Proposal – Spring 2020
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1 Introduction

1.1 Objective

While technology for managing diabetes in humans has improved significantly in the last few decades, the same is not true for most pets and animals including dogs. Owners of dogs that suffer from diabetes typically do not have options to purchase the same kind of insulin delivery and blood-glucose monitoring systems that are available for humans. Instead, owners must manually give their diabetic dogs insulin shots every time they have a meal, which is recommended to be twice a day [1]. That process requires measuring insulin into a syringe, injecting insulin into the dog, and disposing of used sharps. This is a wasteful process that is also very time intensive for the owner and potentially stressful for the dog. Additionally, unlike for a human, most dog owners do not measure blood glucose on a regular basis or at all and simply deliver a fixed amount of insulin when the dog has a meal. This ignores medical research showing that insulin requirements change over time [2].

Our solution is a system comprised of a wearable, miniaturized insulin pump for the dog that can connect to an owner's smartphone app via Bluetooth Low Energy (BLE). The app allows the owner to dispense insulin doses as necessary with a button press. The amount of insulin dispensed can also be adjusted from the app, saving the owner the difficulty of measuring out slightly more or less insulin into a syringe. The wearable pump will be battery powered and will be charged whenever the insulin reservoir is refilled. The app will track general pump status information, time of feedings, time and amount of insulin infusions, and optional discrete blood glucose measurements performed by the owner with separate tools. If these glucose measurements are provided, the insulin dose can be adjusted over time. The goal is to prove that such a device can be made in a small enough form factor and for a low enough cost that it would be beneficial as a real product. We believe the proposed system provides utility to both the dog, the owner, and the veterinary doctor. The dog will no longer have to deal with a lengthy and invasive injection, the owner gets an easy way to administer and track infusions, and the vet can get useful data on how well the feeding and insulin infusion schedule is being followed. The occasional blood glucose measurements can be used to adjust dosages [1].

1.2 Background

In the typical case of treating a diabetic dog, the veterinarian only can adjust dosages every time the dog goes to the vet which is typically every few months [1]. Insulin resistance in dogs varies with many factors so more frequent measurements can keep glycemic control on track since insulin resistance can vary among dogs and within one dog over time [2]. There are models that provide a method of estimating insulin dose based on infrequent discrete blood sugar measurements [3] and with this device and accompanying app, it becomes easier for the owner to track these measurements. This resource was strongly recommended to us by Jeremy DeJournett, a UIUC ECE alumni whose company is developing a human rated artificial pancreas [4].

In addition to personal use, many studies involving diabetes use canines instead of humans. Researchers usually use off the shelf disposable subcutaneous insulin catheters meant for humans on dogs [5]. An insulin pump scaled down and designed for dogs would be useful to researches, and the accompanying app would assist in data collection and tracking.

1.3 Visual Aid

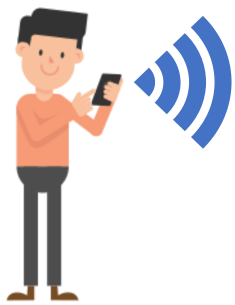

Figure 1 - System Overview

1.4 High Level Requirements

- The device must be able to deliver bolus infusions of 1-15 units of insulin (U100) twice a day for at least three days before refilling or charging.
- The device must communicate with an Android phone over Bluetooth Low Energy to receive infusion commands and send device status.
- The Android app must be able communicate with the device to send infusion commands and receive device status. The app must be able to log the data including time of infusion, time of meal, infusion amount, and optional glucose level monitoring.

2 Design

2.1 Block Diagram

The pump circuit board contains the necessary hardware and software to precisely drive a brushed DC gearmotor from a single cell lithium polymer battery. Encoder feedback is used to stop the motor when a full infusion has been delivered. Over a wireless Bluetooth Low Energy connection, the pump communicates with an Android phone that tracks all infusion management data. Date is stored in a Google Firebase backend in an encrypted form. The Android app can pull down previous data from this backend to display to the user. Unless otherwise specified, all power connections in the following figure are raw battery voltage.

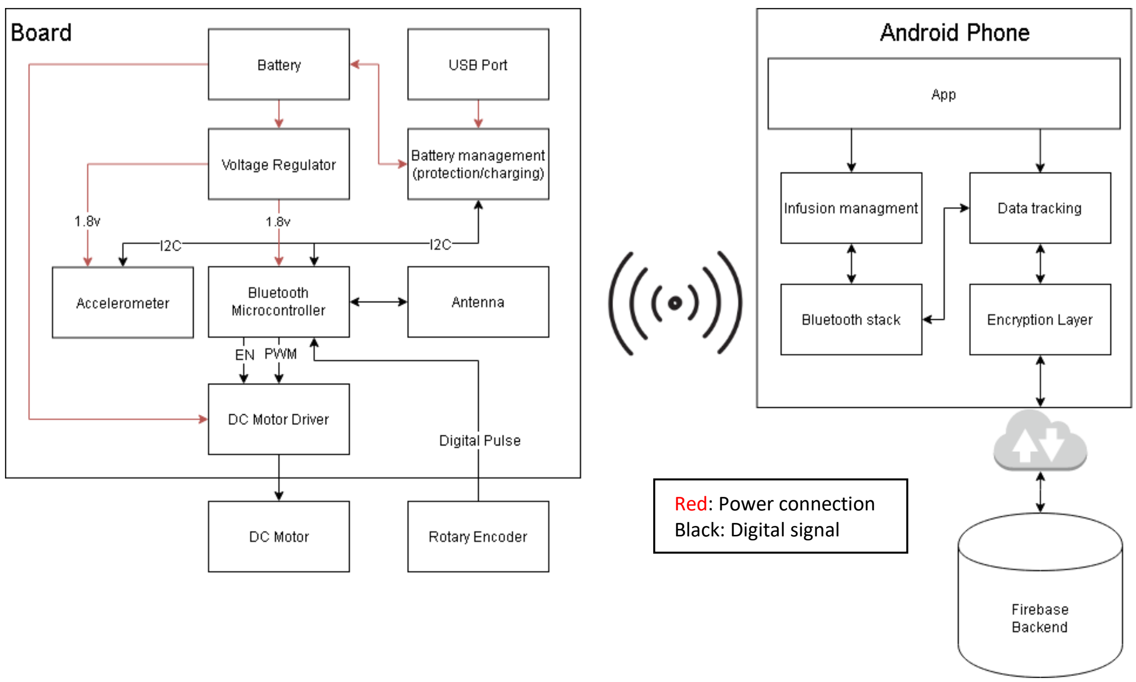

Figure 2 - Block Diagram

2.2 Physical Design

The physical design of the insulin pump must be small enough to fit on a dog's collar. The reservoir and pump consist of a small 1mL glass syringe. A custom syringe plunger will slide linearly as the motor spins an M4 threaded shaft. A 3d printed clamshell will hold the insulin syringe, motor, battery, and PCB. Mounting clips built into the clamshell will allow the pump to be attached to a dog collar. The end of the syringe will have a Luer-Lok [6] connector to attach to a small hose that leads to the subcutaneous catheter. The catheter and hose are beyond the scope of this project.

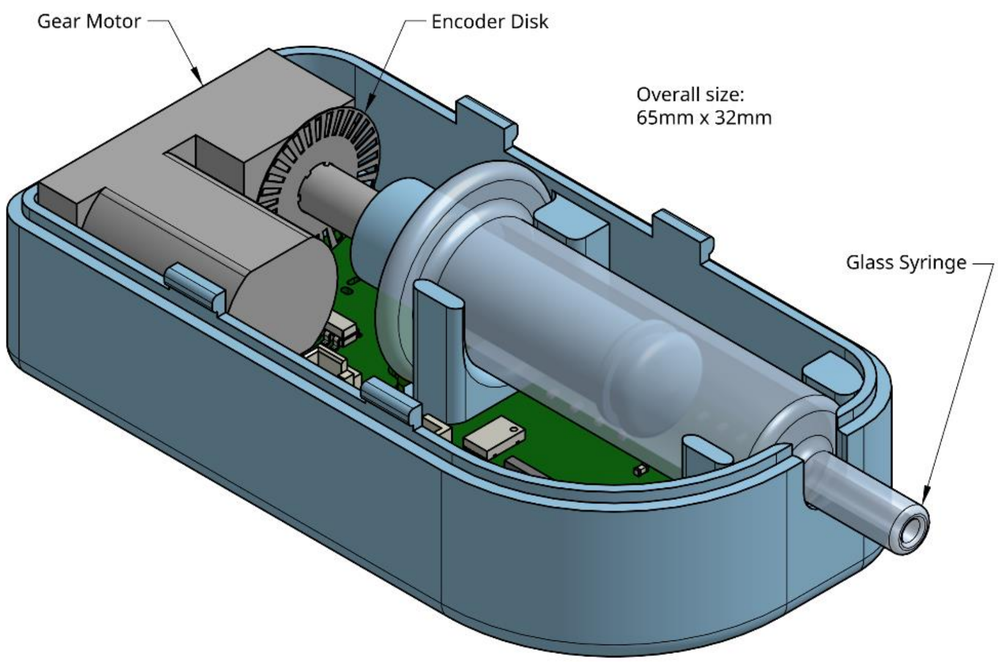

Figure 3 - Physical Design Diagram

2.3 Schematic Design

The schematic for the pump PCB is relatively simple. Whenever possible, part count was kept to a minimum because the PCB is relatively small (65mmx32mm). Due to the low sleep power consumption required, pullup/down resistors are 100K instead of the normal 10K. This minimizes losses through these resistors which add up quickly.

An RGB status LED is included for debugging and indication to the user. Since 1.8v is below the forward voltage for most LEDs, logic level low side NMOS switches are used connect them to raw battery voltage. The illumination LED for the optical encoder has a low enough forward voltage that it can be switched directly by a microcontroller GPIO pin.

The battery charger IC, accelerometer, and the fuel gauge IC both have interrupt pins which are used to signal battery charging and battery events such as undervoltage/overvoltage. These pins are open drain and are therefore pulled high and connected directly to a microcontroller GPIO pins.

The microcontroller circuit includes a high frequency clock for when the Bluetooth is active as well as a very low speed 32.768KHz crystal for keeping track of time while the main CPU is asleep. This allows for significantly lower power consumption when Bluetooth is inactive.

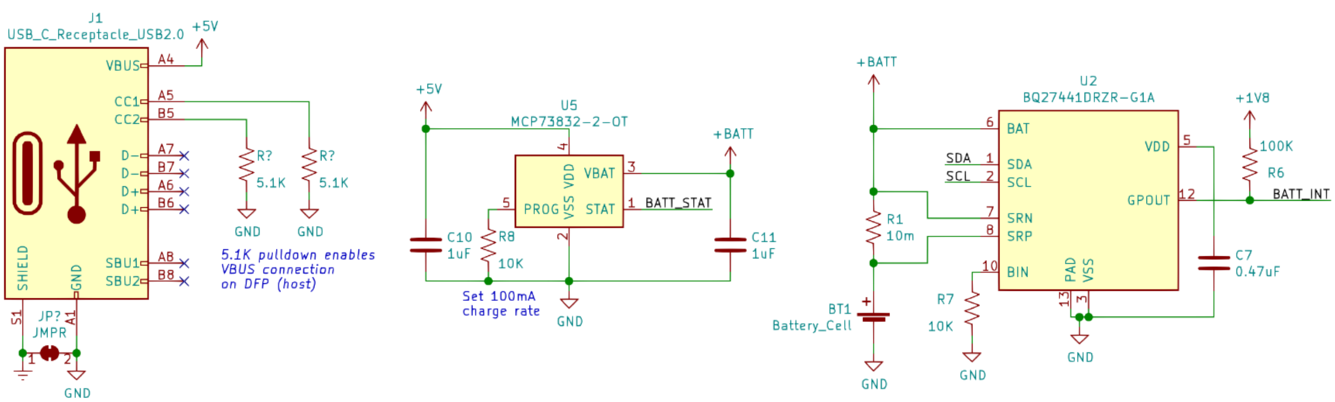

Figure 4 - Power Management Schematic

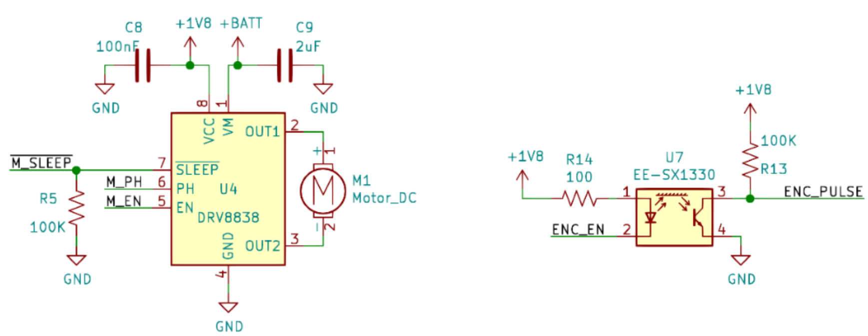

Figure 5 - Motor Driver and Encoder Schematic

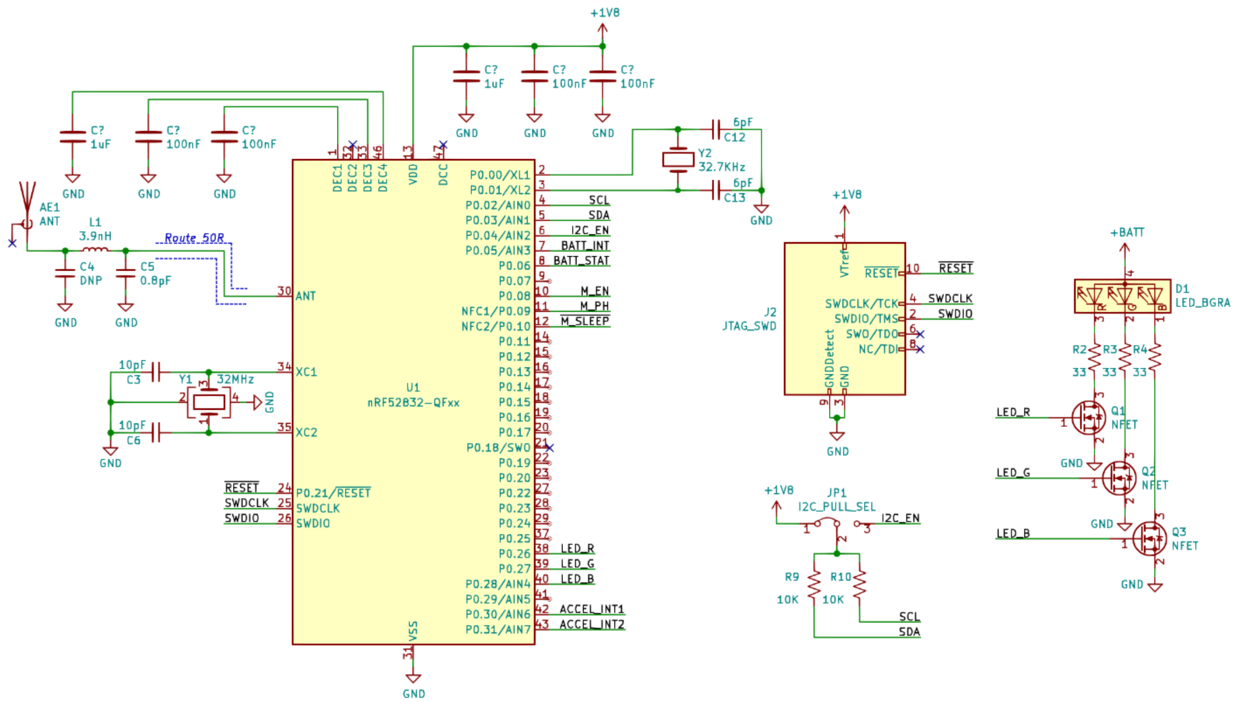

Figure 6 - Microcontroller Schematic

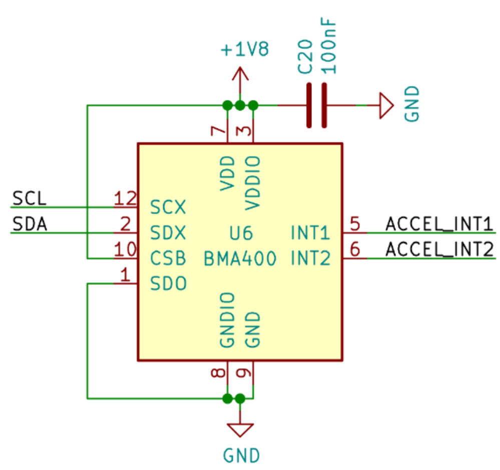

Figure 7 - Accelerometer Schematic

2.4 Power Consumption

The microcontroller will have three power modes. Sleep Mode means that the microcontroller is in its deepest level of sleep and is waiting for a timer interrupt to trigger which transitions it into Standby Mode. In Standby Mode, the microcontroller has temporarily awoken from Sleep Mode to search for a Bluetooth Low Energy connection with the Android phone. If a connection is established data transfer may take place. The phone may also command the microcontroller to enter Active Mode. Active Mode means that the microcontroller is fully awake and actively driving the motor and monitoring the rotary encoder.

Device	**Active Mode (mA)**	**Standby Mode (mA)**	**Sleep Mode (mA)**
nRF52832	10	.781	.0048
Motor	20	0	0
DRV8838	0.7	.0003	.0003
BMA400	.0145	.0145	.0145
BQ27441	.093	.021	.021
MCP73832	.001	.001	.001
EE-SX1330	5	0	0
RGB LED	10	0	0
TPS706	.05	.0013	.0013
TOTAL	**45.85 mA**	**.822 mA**	**.0456 mA**

Table 1 - Power Consumption

The weighted average current consumption can be calculated by estimating the time spent in each power mode. Most of the time, the microcontroller will be in sleep mode. Every 100ms, the microcontroller will wake up and enter standby mode to check for any BLE activity for 5ms. Twice a day, the device will enter active mode to deliver an infusion for up to 5 minutes. This weighted average can estimate the total energy usage over three days. To ensure long term battery health, discharging a lithium polymer battery to 0% state of charge should be avoided. Reducing the depth of discharge to 50% should allow significant margin to protect the battery health. The closest lithium polymer battery in this capacity range with the correct form factor is 100 mAH.

$$\left[\frac{10\ min}{24\ hrs \times 60\ min} \times 45.85\ mA\right] + \ [5\% \times\ .822\ mA] + \ [94\% \times\ .0456\ mA] = \ 0.402\ mA$$

Equation 1 - Weighted average of Current Consumption

$$0.402\ \text{mA} \times (24\ \text{hrs} \times 3\ \text{days}) \times \frac{1}{50\%} = 57.8\ \text{mAH}$$

Equation 2 - Energy Consumption Estimate

2.5 Software Design

The software component of this project consists of an Android app that we will develop as well as the use of Google's Firebase data storage service. The app is responsible for providing the user of our product a means of controlling the board while it is attached to the canine. The app consists of three primary functions: establishing a BLE connection with the board, retrieving sensor data from the board, and commanding the board to deliver the insulin infusion. While the app is performing these functions, the board will remain in the Active power mode, however once the user either disconnects or has not interacted with the app for some time, it will allow the board to return to its Standby/Sleep cycle.

2.5.1 Establishing the BLE Connection

Generally, when the user enters the app, they are not actively connected to the board. Therefore, the primary screen will provide an interface that allows the user to initiate an attempt to connect to the board on their dog, if it is within range. After the user initiates the connection, the app will check to see if Android BLE permissions are enabled and ask the user to allow them if they are not. It will then scan for the board which is in the Sleep Mode and is occasionally moving into the Standby Mode to advertise itself as a BLE device. If no device is found for several seconds, it will report an error to the user. If the board is found, the app will begin establishing a connection. If the device found is unrecognized by the app, it will have to establish encrypted communication with the device via an authentication request/response. After this, the devices will be able to communicate over encrypted BLE. Finally, the app informs the board that it should enter the active state as further actions may be performed by the user.

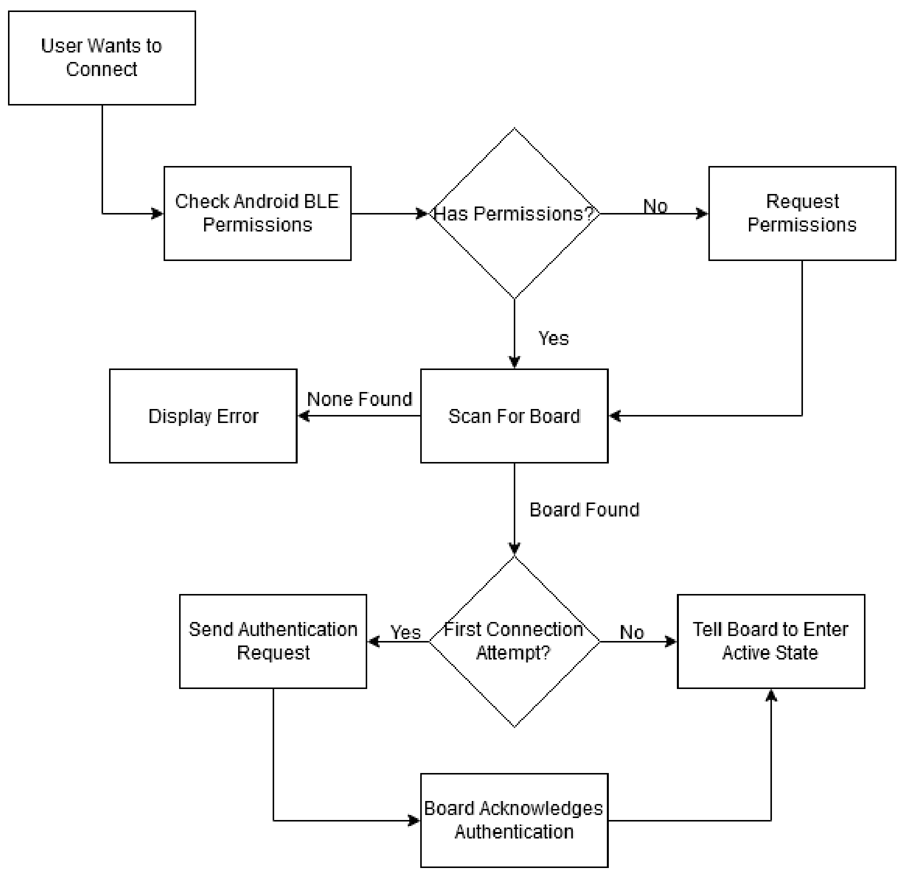

Figure 8 - Establishing BLE Connection

2.5.2 Retrieving Sensor Data

There are several sensors present on the board that the app will collect upon user request. This data may include battery state of charge, accelerometer data, estimated liquid remaining, and other data points. Assuming the app has already established a BLE connection with the board, upon user request it will send a data request to the board. The board will respond with all the data collected since the last time a request was made. The app will then respond again to confirm that it is safe for the board to delete the data that it is currently storing. The app will then display the data to the user, encrypt it, and send it to Firebase.

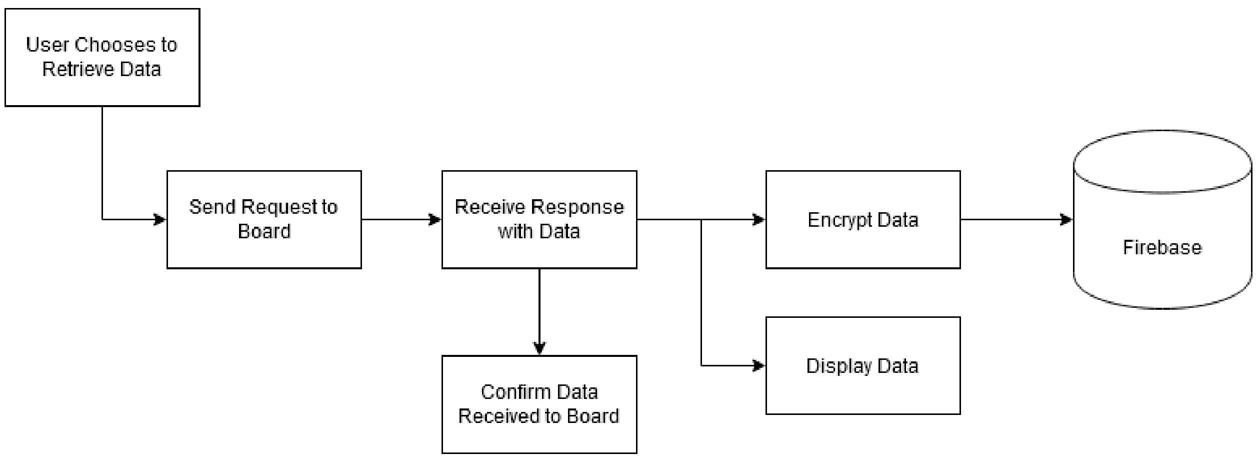

Figure 9 - Retrieving Sensor Data

2.5.3 Delivering Insulin

Delivering an appropriate amount of insulin is the primary focus of the project. The user can decide when to deliver the insulin and how much insulin to deliver. After providing this information to the app, it will send a request to the board to perform the infusion. The board responds with an acknowledgement initially, and then a secondary message when the infusion process has completed. Meanwhile, the app will record the time that the infusion began, and the amount of insulin being delivered. This data will then be encrypted and uploaded to Firebase. A message will also display to the user once the entirety of the desired insulin amount is delivered.

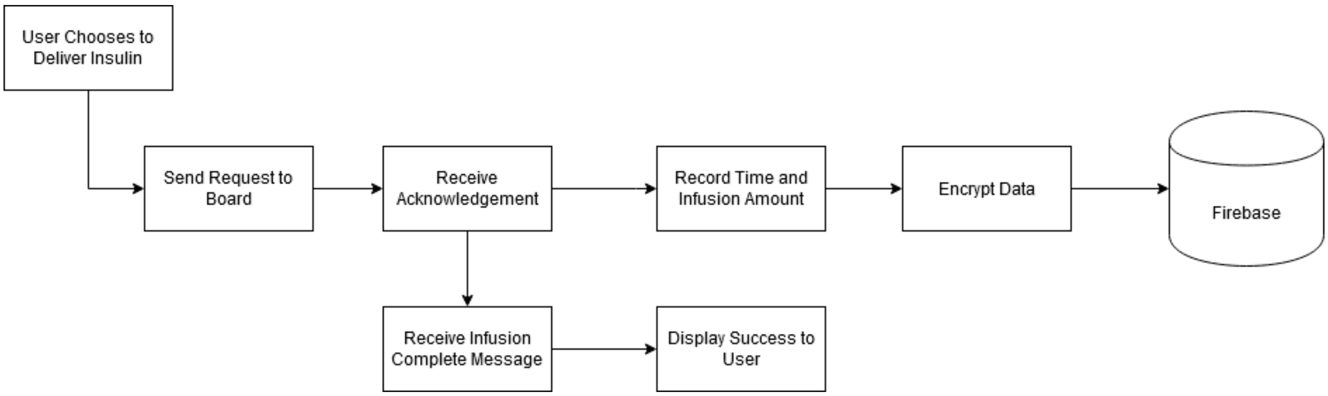

Figure 10 - Insulin Deliver Process

2.6 Requirements and Verification

2.6.1 Voltage Regulator

The voltage regulator is responsible for converting the voltage from the battery to a stable supply voltage for the microcontroller. This allows the microcontroller to function over a variety of battery voltages. Since most of the time the system is in a very low power state, the regulator must have a very low quiescent current. At a current draw of 50mA, the max power dissipation of a linear regulator is $(4.2\text{ v} - 1.8\text{ v}) \times 0.05\text{ A} = 120\text{ mW}$. At this level of power dissipation, the SOT-23-5 package will be 25 degrees Celsius above ambient temperature which keeps it well below the maximum operation temperature of 125 degrees [7].

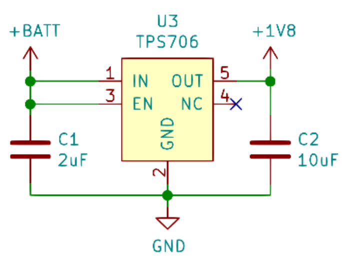

Figure 11- Voltage Regulator Schematic

Requirement	Verification
1. *The voltage regulator shall provide 1.8v (+/- 5%) at up to 50mA from a 3.0v-4.2v supply.*	1. a. Measure the open circuit voltage of the regulator. Confirm that it is within +/- 5% of 1.8V

2. The voltage regulator shall have a quiescent current of less than 10uA. *3. The voltage regulator must always stay below 125 degrees Celsius.*	b. Apply a 50mA load and confirm voltage is within +/- 5% of 1.8V 2. With no load connected, confirm the input current to the regulator is less than 10uA 3. Using an IR thermometer, ensure that the regulator never exceeds 125 degrees Celsius during tests one and two.

2.6.2 Rotary Encoder

The rotary encoder is connected to the output shaft of the DC gearmotor and provides a digital pulse to the microcontroller for each step. With 64 pulses per revolution, we can measure fluid quantities in discrete steps of 657 nL. See 2.7 (Tolerance Analysis) for more details on the pump accuracy and precision.

Requirement	Verification
1. The encoder shall have at least 64 pulses per revolution.	1. a. Attach an oscilloscope to the rotary encoder across the ground pin and the encoder pulse pin and have the microcontroller drive the motor. b. Observe on the oscilloscope that 64 pulses are made over one complete rotation and that the duty cycle is 50%.

2.6.3 Battery

The battery is responsible for powering the microcontroller, pump and other devices over the three days of continuous operation. The must be enough energy storage to deliver two infusions each day.

Requirement	Verification
1. The battery shall provide at least 100mAh of stored energy with a nominal voltage of 3.7v.	1. a. Connect the battery to a constant current DC load set to 10mA. b. Ensure that the battery voltage stays above 3.0v for at least 10 hours of continuous discharge.

2.6.4 Motor

The motor must have a geared output that spins slow enough that we do not overshoot the required dose. Assuming a typical dose of 100uL, we should be able to dispense this amount in 5 seconds. This corresponds to a rotational speed of 30 RPM. See 2.7 for more details on the pump speed and accuracy.

Requirement	Verification
1. The gearmotor output shall spin at less than 30 RPM at 3.7V.	1. a. Connect the motor directly to a DC power supply set to 3.7v and no current limit. b. Observe no more than 30 revolutions of the output in 60 seconds.

2.6.5 Motor Driver

The motor driver is responsible for controlling the brushed DC motor that drives the syringe pump. The motor driver connects to the microcontroller with simple digital pins to specify direction and enable/sleep. The motor controller must have a very low sleep current because the majority of its time is spent in sleep mode.

Requirement	Verification
1. *The motor driver shall be able to drive a brushed DC motor in both directions.* 2. *The motor driver shall be able to drive the motor with up to 100mA of current.* 3. *The motor driver shall have a shutdown/sleep current of less than 10uA.*	1. a. Flash the microcontroller with custom firmware that runs the motor for five seconds in both directions. b. Confirm that the motor correctly changes direction after five seconds. 2. a. Connect the output of the motor controller to a DC load set to 100mA. b. Connect the motor controller input to a power supply set to 3.7v/500mA. c. Command the motor controller to run at 100% output power. d. Confirm that the motor controller output measures 3.7v and the DC load is drawing 100mA. 3. a. Connect the motor controller to a DC power supply set to 3.7v. b. Command the motor controller to go to sleep by pulling the sleep pin low. c. Ensure the measured current consumption is less than 10uA.

2.6.6 Antenna

A simple 2.4GHz surface mount chip antenna provides enough gain for a stable BLE connection in almost all conditions. We are not designing a custom antenna for this application, so calculations of exact link budget are beyond the scope of this project.

Requirement	Verification
1. *BLE shall be capable of connecting at 15 feet.*	1. a. Confirm that the android phone can connect to the pump at a distance of 15 feet with clear line of sight.

2.6.7 Accelerometer

The accelerometer is used to detect and quantize the canine's physical activity. Because this device is always powered and running, it must have a very low quiescent current. The accelerometer chosen (Bosh BMA400) contains an integrated digital signal processing unit that can classify motion and count steps automatically. Because of this, the exact accelerometer performance is not important in this application.

Requirement	Verification
1. *The accelerometer shall have a normal operating current of less than 50 uA.*	1. a. Connect the board to a DC power supply set to 3.7v. b. Measure the current consumption in sleep mode with the accelerometer desoldered from the board. c. Measure the current consumption in sleep mode with the accelerometer soldered to the board. d. Ensure that the current difference between b. and c. is less than 50uA.

2.6.8 Microcontroller

The microcontroller on the board must be able to receive Bluetooth commands and drive the motor driver with a digital signal. It must be able to count encoder ticks and stop the motor once the correct infusion amount has been delivered. The microcontroller must also communicate with the battery management IC using I^2C to track the battery state of charge, and charger status.

An nRF52832 was selected due to its attractive combination of a low power ARM core and a fully featured Bluetooth hardware stack designed for internet of things (IoT) applications. The microcontroller will be programmed using a Black Sphere Technologies Black Magic Probe which connects using serial wire debug (SWD). At a maximum clock speed of 64 MHz, this processor is easily capable of precise PWM generation and high speed I2C.

Requirement	Verification
1. *The microcontroller shall have a sleep current of less than 50uA.* 2. *The microcontroller shall be able to communicate with the battery management IC and the accelerometer over I^2C at 400KHz.* 3. *The microcontroller shall be able to generate a PWM signal for the motor driver with a frequency of at least 1 kHz and a variable duty cycle.*	1. a. Connect the board to a 3.7V DC power supply. b. Flash custom firmware that puts the microcontroller in a deep sleep state. c. Observe that the measured current going into the microcontroller is less than 50uA. 2. a. Flash custom firmware to the board that configures the I^2C to operate at 400kHz. b. The firmware should read the device ID from the battery management IC and the accelerometer. c. If the device IDs match the expected values, the status LED should be green, else red.

2.6.9 Battery Management

The battery management block is made up of two parts, a discrete lithium polymer battery charger IC and a battery gas gauge. The charger IC has a single digital output that indicates charge status which connects directly to a microcontroller general purpose input/output pin. The battery gas gauge connects to the microcontroller over a standard I2C interface and can provide useful metrics about the state of the battery.

Requirement	Verification
1. *The battery charger shall charge a single cell lithium polymer battery from 3.0V to 4.2V (+/-5%) from a 5.0V power source with a maximum charge current of 100mA.* 2. *The battery gas gauge circuit shall provide the battery state of charge (SoC), voltage, temperature, and current to the microcontroller.* 3. *The battery gas gauge shall have a quiescent current of less than 50uA.*	1. a. Discharge the battery to a 3.0V cell voltage. b. Charge the battery via the USB charging port at 5.0V. c. Ensure that the constant current charge mode delivers 100mA. d. Ensure that the final charge voltage of the battery is 4.2V (+/-5%). 2. a. Measure the voltage, current, temperature and calculate SoC of the battery. b. Flash firmware to the microcontroller that reads the SoC, voltage, temperature, and current from the battery management IC and knows the previously measure values. c. If the read values match the hard-coded expected values in the firmware within 10%, turn the status LED green, else red. 3. a. Desolder the battery gas gauge and measure the total board current. b. Solder the battery gas gauge back onto the board. c. Measure the total board current. d. The difference between b and c should be less than 50uA.

2.6.10 Bluetooth Stack

This is the built-in Bluetooth stack available in modern Android phones. We will specifically test on a Google Pixel 3A. However, any Android phone that supports Bluetooth Low Energy could be used. This stack and the provided Android APIs are what we will use to implement the BLE communication between the Android phone and the board.

Requirement	Verification
1. *N/A*	1. N/A

2.6.11 Infusion Management

The Infusion Management System is a layer of the Android application code. It is responsible for managing the delivering of insulin from the app side. It presents an interface to the user so that they can entered the desired amount of insulin for infusion. This information is then sent to the board over the BLE connection. This system will also handle notifying the user that the infusion was successful and recording the relevant data and delivering it to Firebase via the Encryption Layer.

Requirement	Verification
1. *The Infusion Management System must partially satisfy the third high-level-requirement by sending a command over BLE to the board and receiving a status message over BLE indicating that the command was executed, when the user requests it.*	1. a. The user interacts with the provided interface and indicates that the command should be sent. b. The board should receive the command and begin delivering the infusion. c. A status message should be displayed indicating if the operation was successful

2.6.12 Data Tracking

The Data Tracking System is responsible for handling data all data that the board records and storing it in the Firebase database. When the user chooses to receive data from the board, this system is responsible for executing the flow chart described in 2.5.2. Data related to infusion times, optional manual blood-glucose level, amount of liquid, and other sensor data will come back from the board, be encrypted, and be passed onto Firebase.

Requirement	Verification
1. *The Data Tracking System must partially satisfy the third high-level-requirement by sending a request over BLE to the board and receiving sensor data back, displaying it to the user, and delivering it to Firebase, when the user requests it.*	1. a. The user interacts with the provided interface and indicates that they want data to be retrieved. b. The board should deliver the command and indicate that a response was received. c. The system should display the new data received from the board. d. The Firebase backend should update with the new data entries.

2.6.13 Encryption Layer

The Encryption Layer is a responsible for ensuring that all data leaving the Android Phone for the Firebase Backend is properly encrypted and that data coming from the Firebase Backed to the Android Phone has been properly decrypted upon arrival. It is a pass-through module that will use provided Android APIs to implement an encryption scheme that encrypts and decrypts outgoing and incoming data.

Requirement	Verification
1. *N/A*	1. N/A

2.6.14 Firebase Backend

The Firebase Backend is a cloud storage service provided by Google. To satisfy our legal and ethical obligations to keep the data collected by this project secure, all data stored in the Firebase Backend will be encrypted before it is sent to Google's servers, as described in the Encryption Layer requirements.

Requirement	Verification
1. N/A	1. N/A

2.7 Tolerance Analysis

The most critical aspect of this project is the pump accuracy. Delivering an accurate insulin dose is very important towards maintaining a healthy and consistent blood glucose level. Since no commercial pump is within our budget, we constructed our own syringe pump capable of holding 1mL of fluid and delivering normal sized bolus infusions for canines. This is significantly different than a typical human insulin infusion pump due to the higher pump rate and lack of basal infusions. To match the performance of a typical medical grade infusion pump, our infusion delivery should be within +/- 5% of the target dose [8].

For a linear syringe pump, the most significant source of error is the unpredictable mechanical movement on motor startup. This leads to a characteristic flow accuracy curve commonly called a trumpet curve (**Error! Reference source not found.**). Because we measure the displacement of the s yringe plunger directly, flow rate does not matter for our design. Instead, the correlation between encoder tick count and fluid volume is vital to the accuracy of the pump design.

Our encoder is designed to have a resolution of 5.265 degrees per tick (64 ticks per revolution). The thread size of our leadscrew is M4 which corresponds to 0.7 mm per thread. To convert from encoder ticks to milliliters, these factors must be combined with the syringe length and volume. This leads to a volume per encoder tick of 657 nL / tick.

It is very difficult to estimate potential error of control system at this stage of the design. A reasonable estimate is that the motor will stop to within 10 ticks of the desired setpoint. This corresponds to a maximum error of 6.57%. This assumes that there is no mechanical error in the acme lead screw or the syringe itself. Until further testing is done, the only conclusion that we find is that with minimal mechanical problems, the pump should perform close to the +/- 5% error commonly found for medical pumps.

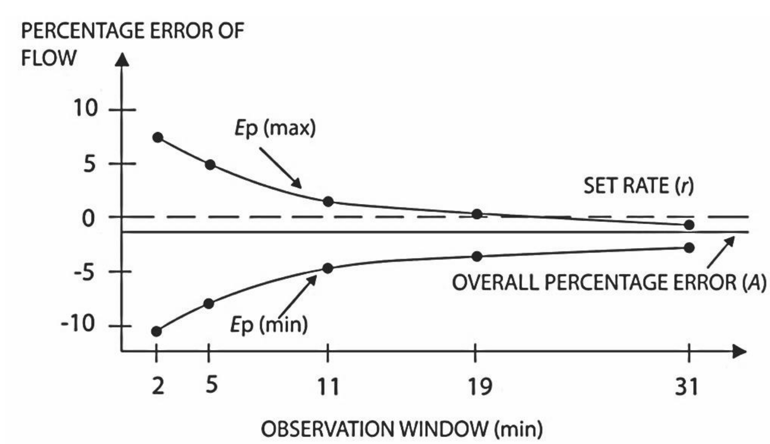

Figure 12 - Flow Rate Error Trumpet Curve

3 Cost and Schedule

3.1 Labor

We estimate our fixed development costs at $45/hour for 10 hours/week over 15 weeks (one of the weeks in the semester is spring break). We then multiply by a factor of 2.5 to account for other overhead in a real engineering organization, such as administrative costs.

$$2 \times \frac{\$45}{\text{hour}} \times \frac{10\text{ hr}}{\text{week}} \times 15\text{ week} \times 2.5 = \$33{,}750$$

Equation 3 - Estimated Cost of Labor

3.2 Bill of Materials

Manufacturer	Description	Digi-Key Part Number	Quantity	Unit Price	Extended Price
Abracon LLC	RF ANT 2.4GHZ CHIP SOLDER SMD	535-14095-1-ND	1	$ 0.53	$ 0.53
JST	CONN HEADER SMD 2POS 2MM	455-1734-1-ND	1	$ 0.55	$ 0.55
KEMET	CAP CER 0.8PF 50V NP0 0603	399-14752-1-ND	1	$ 0.26	$ 0.26
KEMET	CAP CER 0.1UF 50V X7R 0603	399-7845-1-ND	6	$ 0.10	$ 0.60
KEMET	CAP CER 10PF 25V C0G/NP0 0402	399-7746-1-ND	2	$ 0.10	$ 0.20
KEMET	CAP CER 10UF 6.3V X5R 0805	399-3138-1-ND	1	$ 0.16	$ 0.16
Samsung	CAP CER 1UF 16V X7R 0603	1276-6524-1-ND	5	$ 0.10	$ 0.50
KEMET	CAP CER 0.022UF 100V X7R 0603	399-3476-1-ND	1	$ 0.10	$ 0.10
KEMET	CAP CER 2.2UF 16V X5R 0603	399-7886-1-ND	1	$ 0.14	$ 0.14
Yageo	CAP CER 6PF 50V NPO 0402	311-3714-1-ND	2	$ 0.10	$ 0.20
Kingbright	LED RGB CLEAR 4SMD	754-1967-1-ND	1	$ 1.05	$ 1.05
Samtec Inc.	CONN HEADER VERT 10POS 1.27MM	SAM8909-ND	1	$ 2.78	$ 2.78
Hirose Electric Co Ltd	CONN RCP USB3.1 TYPEC 24P SMD RA	H125778CT-ND	1	$ 2.53	$ 2.53
Murata Electronics	FIXED IND 3.9NH 450MA 150 MOHM	490-1105-1-ND	1	$ 0.24	$ 0.24
Molex	CONN HEADER SMD 2POS 1.25MM	WM7606CT-ND	1	$ 0.59	$ 0.59
ON Semiconductor	MOSFET N-CH 20V 915MA SOT-416	NTA4153NT3GOSCT-ND	3	$ 0.46	$ 1.38
Yageo	RES SMD 100 OHM 1% 1/16W 0402	311-100LRCT-ND	1	$ 0.10	$ 0.10
Yageo	RES SMD 100K OHM 1% 1/16W 0402	311-100KLRCT-ND	3	$ 0.10	$ 0.30
Yageo	RES SMD 10K OHM 1% 1/16W 0402	311-10.0KLRCT-ND	4	$ 0.10	$ 0.40
Yageo	RES 0.01 OHM 1% 0.3W 0603	311-0.01NRCT-ND	1	$ 1.04	$ 1.04
Yageo	RES SMD 3.3K OHM 1% 1/16W 0402	311-3.30KLRCT-ND	3	$ 0.10	$ 0.30
Yageo	RES SMD 5.1K OHM 1% 1/16W 0402	311-5.10KLRCT-ND	2	$ 0.10	$ 0.20
Bosch Sensortec	ACCELEROMETER 2-16G 12LGA	828-1081-1-ND	1	$ 4.49	$ 4.49
Texas Instruments	IC BATT FUEL GAUGE LI-ION 12SON	296-39941-1-ND	1	$ 2.62	$ 2.62
Texas Instruments	IC BRIDGE DRIVER PAR 8WSON	296-40081-1-ND	1	$ 0.86	$ 0.86
Omron Electronics	SENSOR OPT SLOT PHOTOTRANS MODUL	Z6364CT-ND	1	$ 1.46	$ 1.46
Microchip Technology	IC LI-ION/LI-POLY CTRLR SOT23-5	MCP73832T-2ACI/OTCT-ND	1	$ 0.56	$ 0.56
Texas Instruments	IC REG LINEAR 1.8V 150MA SOT23-5	296-47896-1-ND	1	$ 0.78	$ 0.78
Nordic Semiconductor	IC RF TXRX+MCU BLUETOOTH 48VFQFN	1490-1069-1-ND	1	$ 5.32	$ 5.32
ECS Inc.	CRYSTAL 32.7680KHZ 6PF SMD	XC1945CT-ND	1	$ 0.95	$ 0.95

Abracon LLC	CRYSTAL 32.0000MHZ 10PF SMD	535-10946-1-ND	1	$ 1.36	$ 1.36
				Total	**$ 32.55**

Table 2 - Bill of Materials

3.3 Cost Analysis

The overall cost for this project is the sum of all labor costs, bill of material (BOM) costs and 3D printer costs. The BOM is for a single board assembly, but we expect to assemble two boards, one for testing and another as the final demonstration. The 3D printer we use for the enclosure is a FormLabs Form 2 printer. It uses the Tough Resin, priced at $175/Liter. Each case that we print uses 50mL of resin. There is also an additional overhead of 0.5 for maintenance, cleaning, and operation of the printer. The overall projected cost for this project is $33,841.

$$\frac{\$175}{\text{Liter}} \times 50\text{ mL} \times 2 \times 1.5 = \$26.25$$

Equation 4 - 3D Printing Cost

Description	**Cost**
Labor Costs	$33,750
Bill of Materials (for two boards)	$65.10
3D Printer Costs	$26.25
Total	$33,841.35

Table 3 - Overall Cost

3.4 Schedule

Week of	Description	Responsibility
2/23/20	Complete Design Document	Both
3/1/20	Design Review	Both
	Set up Firebase w/ fake data	Dillon
3/8/20	Debug PCB submitted by 3/11	Adam
	Mock app functionality, no BLE	Dillon
3/15/20	Test app usability	Both
3/22/20	Assemble PCB	Adam
	Debug PCB	Adam
	Begin device firmware (functional BLE)	Both
	Improve app based on feedback	Dillon
3/29/20	Finalize PCB design,	Adam
	Order final PCB	Adam
	Implement app/board BLE communications	Dillon
4/5/20	Assemble Final PCB, Debug PCB	Adam
	Debug final PCB	Adam
	Implement board interaction with sensors, pump	Dillon
4/12/20	Bug fixes, testing	Both
4/19/20	Mock Demo	Both
4/26/20	Final Demo and Mock Presentation	Both
5/3/20	Final Presentation and Final Report	Both

Table 4 - Task Schedule

4 Safety and Ethics

There are several possible safety and security hazards present in our project. A threat to physical safety that must be managed in accordance with the IEEE Code of Ethics sections 7.8.1 “to hold paramount the safety (…) of the pubic…” [9], 7.8.9 “to avoid injuring others…” [9], and the ACM Code of Ethics section 1.2 “avoid harm” [10] is the risk from using a small Lithium Polymer battery. Such batteries can be extremely dangerous if allowed to overcharge, over discharge, or if they are brought to extreme temperatures [11]. To meet the requirements of preventing harm, a battery was chosen that provides automated discharge cutoff at under and over voltage as well as protection against output shorts [12]. Additionally, the board will provide temperature protection and the charging circuitry will prevent over charging of the cell. The battery is small enough that runaway discharge is not a concern, in addition to the mentioned mechanisms to prevent that. Charging the battery while the device is in use or attached to any living creature is dangerous and will be expressly prohibited.

Another concern for electronic devices, especially ones using battery power, is protection against water. However, since this project is focused on the design of the pump, we would consider protecting significantly against dust and water to be outside the scope of the design. Therefore, our device will conform to IP31 [13].

The Bluetooth Low Energy communication between the board and the Android app is a serious concern ethically. Theoretically, a malicious actor could abuse such a connection to either prevent the dispensing at the appropriate time or cause too much liquid to be dispensed. To address this concern and meet the requirements of the previously mentioned IEEE Code of Ethics sections 7.8.1 [9], 7.8.9 [9] and the ACM Code of Ethics section 1.2 [10] as well as 2.9 “design and implement systems that are (…) secure” [10], the communication between the Android app and the board will be encrypted.

A final concern to address is that our app and Firebase Backend will be storing protected personal medical data for the dog and possibly the owner. To act in accordance with ACM Code of Ethics section 1.6 “respect privacy” [10] and in accordance with the basic principle of HIPAA laws [14], any data stored on the phone, transmitted between the phone and the Firebase backend, and/or stored in the Firebase backend will be encrypted so that only the user of the app will have access.

Normally a medical device like this one would fall under strict regulations from the Food and Drug Administration and other related organizations, but using this device in anyway except to demonstrate the capability to dispense accurate amounts of liquid into a container is outside of the scope of this project. No human, animal, or actual insulin will be utilized due to the legal and ethical requirements, cost constraints, and time constraints.

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