Design Document – Canine Insulin Pump

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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 the 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 doctor 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 doctor only can adjust dosages every time the dog is taken in 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 app, it becomes easier for the owner to track these measurements. This paper 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 High Level Requirements

- The device must be able to deliver bolus infusions of 5-15 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 ion 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.

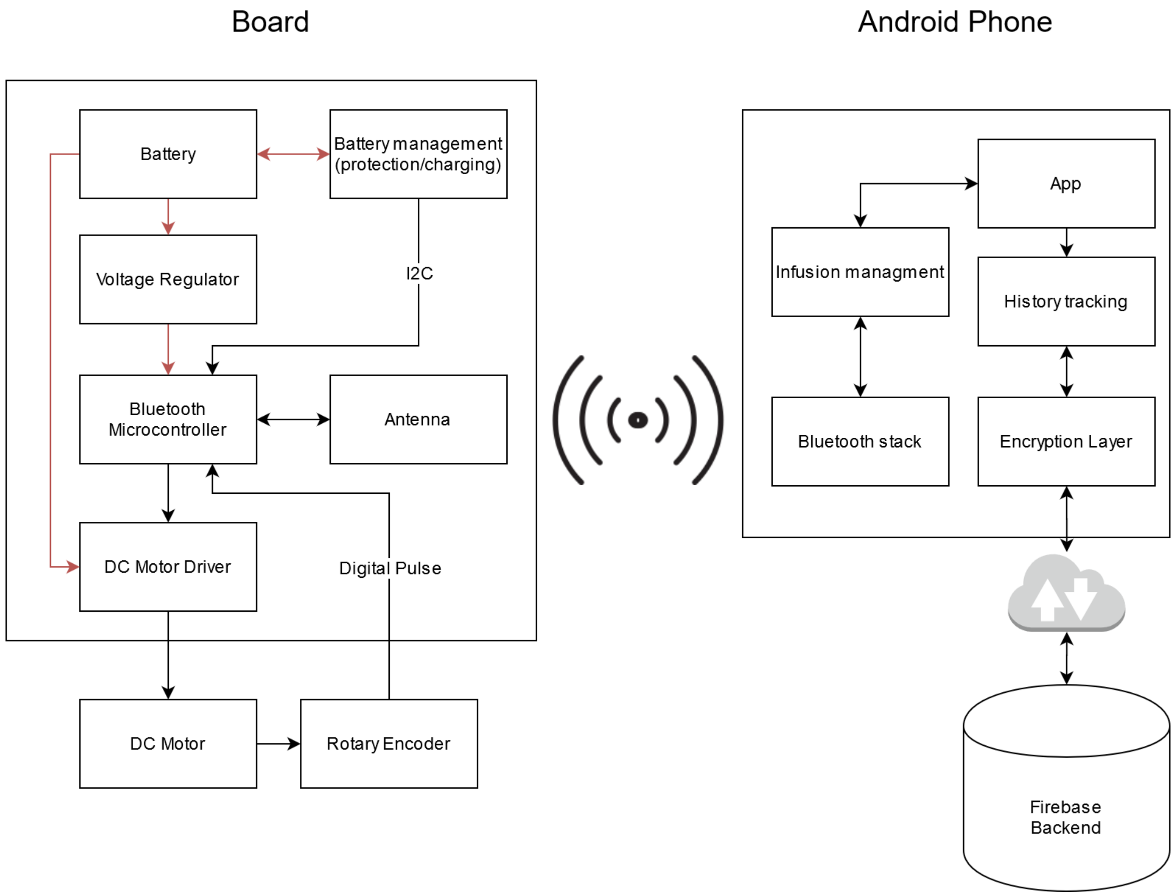

Figure 1 - Block Diagram

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.

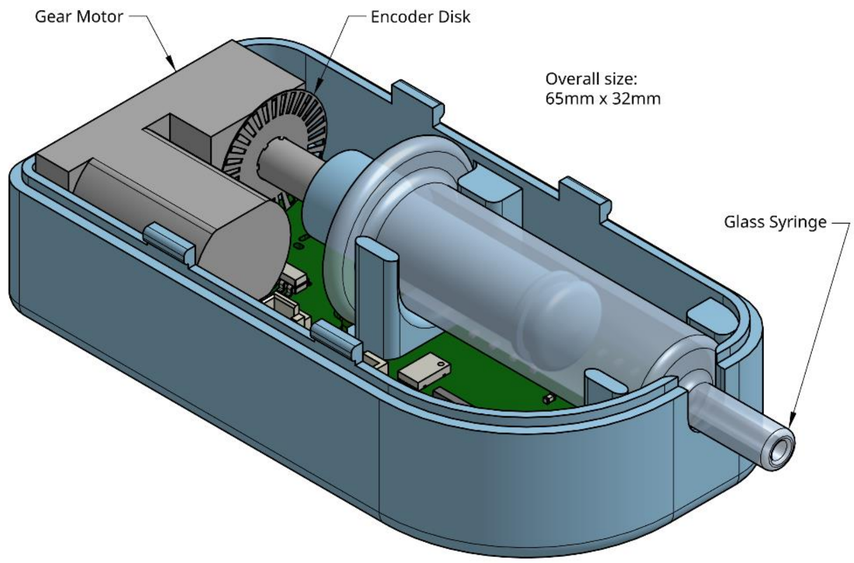

Figure 2 - 3D Model of Physical Design

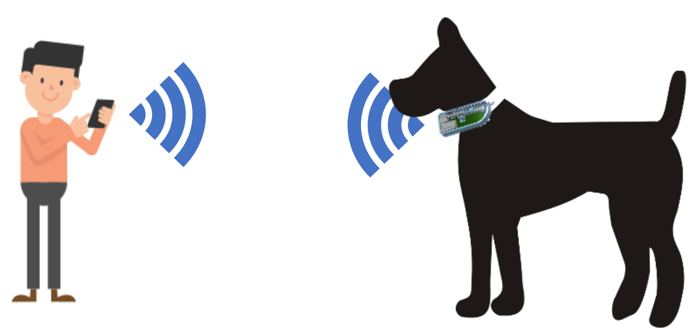

Figure 3 - System Overview

2.3 Schematic Design

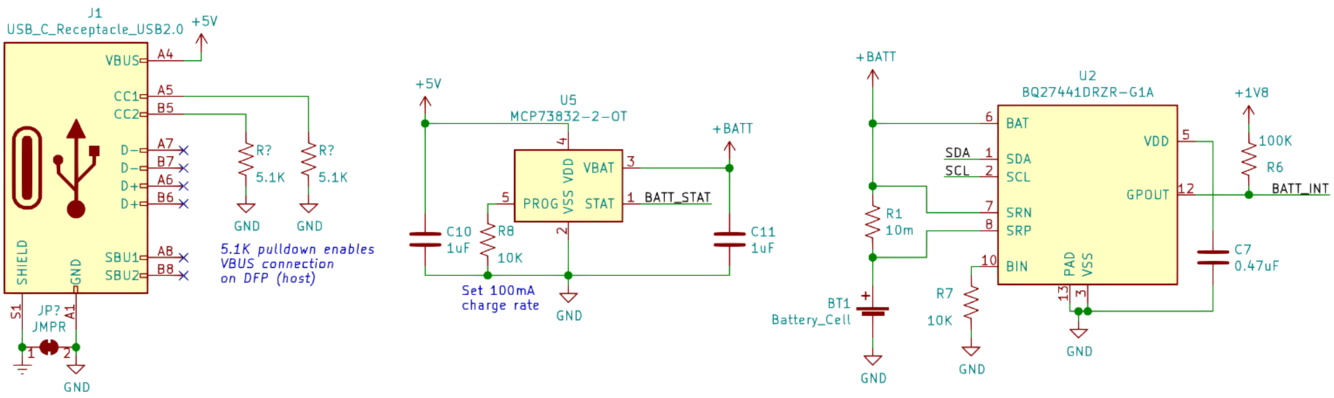

Figure 4 - Battery Management Schematic

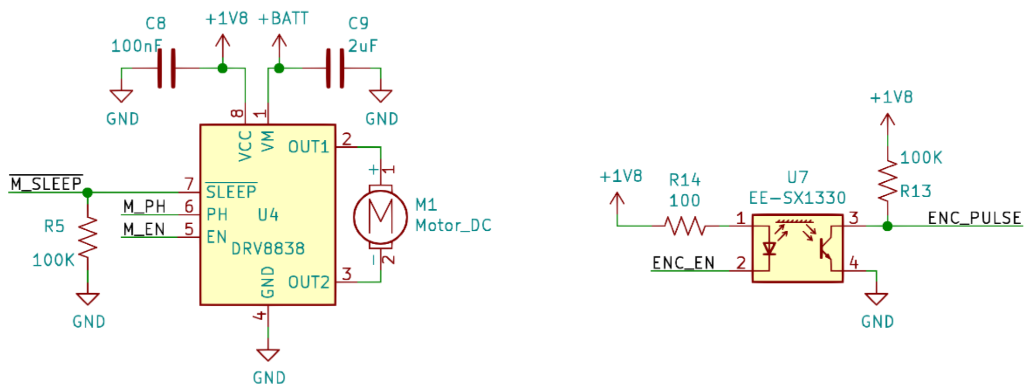

Figure 5 - Motor Driver and Encoder Schematic

2.4 Power Consumption Table

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 fire 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**

2.5 Requirements and Verification

2.5.1 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.

Requirement	Verification
1. *The voltage regulator shall provide 1.8v (+/- 5%) at up to 100mA from a 3.0v-4.2v supply.* 2. *The voltage regulator shall have a quiescent current of less than 10uA.*	1. a. Measure the open circuit voltage of the regulator. Confirm that it is within +/- 5% b. Apply a 150mA load and confirm voltage is within +/- 5% 2. With no load connected, confirm the input current to the regulator is less than 10uA

2.5.2 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 547 nL. A typical infusion is 100uL, so this corresponds to an accuracy of +/- 0.5%. This is well below the +/-5% we guarantee. This allows for some amount of mechanical backlash to be present in the system.

Requirement	Verification
1. *The encoder shall have at least 64 pulses per revolution.*	1. a. Attach an oscilloscope to the rotary encoder and have the microcontroller drive the motor.

	b. Observe on the oscilloscope that 64 pulses are made over one rotation.

3 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…” [7], 7.8.9 “to avoid injuring others…” [7], and the ACM Code of Ethics section 1.2 “avoid harm” [8] is the risk from using a small Lithium Ion Polymer battery. Such batteries can be extremely dangerous if allowed to overcharge, over discharge, or if they are brought to extreme temperatures [9]. 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 [10]. 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 [11].

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 [7], 7.8.9 [7] and the ACM Code of Ethics section 1.2 [8] as well as 2.9 “design and implement systems that are (…) secure” [8], 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” [8] and in accordance with the basic principle of HIPAA laws [12], 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.

4 References

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5 Appendix