ECE 445 Senior Design Project

Electric Dog Teeth Cleaning Toy

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1. Introduction

1.1 Problem

Many dog owners don't put in the effort to manually brush their dog's teeth more than a couple of times a week. They either use a dog teeth cleaning treat or liquid that can remove some of the plaque rather than all. Nowadays, at least 80% of dogs over the age of three have oral problems [1]. To combat this pet health issue, dog owners need a tool that is able to conveniently clean dogs' teeth and regulates the frequency of cleaning.

1.2 Solution

The solution we have is to develop a log-shaped electric dog toy that is capable of cleaning the dog's teeth and monitoring the cleaning. When the timer reaches two minutes, the treat dispenser will produce a buzzer sound and dispense a treat. This will be used as a training mechanism, so the dog will eventually realize that biting the toy will dispense a treat. Treats are also used as the incentive in the dog toy to interest the dog to continue biting the bristles.

The dog toy has a nylon plastic encasing covered in dog-safe bristles. Under the exterior cover, there is a layer of thin pressure sensors to detect dog bites. Internally, the toy is equipped with a vibration motor that will create moderate motions in the dog's mouth for cleaning. When turned on and being bitten, the toy will vibrate and adjust the force according to the data from the pressure sensor. The dog toy will be attached to the separate box containing the treat dispenser and circuit components. It can be hand-held or left standing on the floor. When the treat is dispensed, the toy then enters a sleep state and stops responding to biting until a preset time interval has passed. After recess time, the toy will be available for cleaning again. Overall, the dog will be able to play with the toy and get their teeth cleaned two times a day.

1.3 Visual Aids

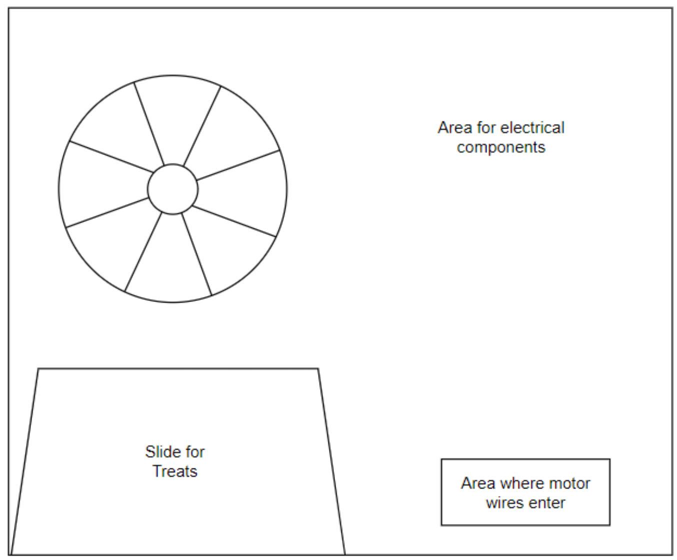

Fig. 1 Front View of Treat Dispensing System

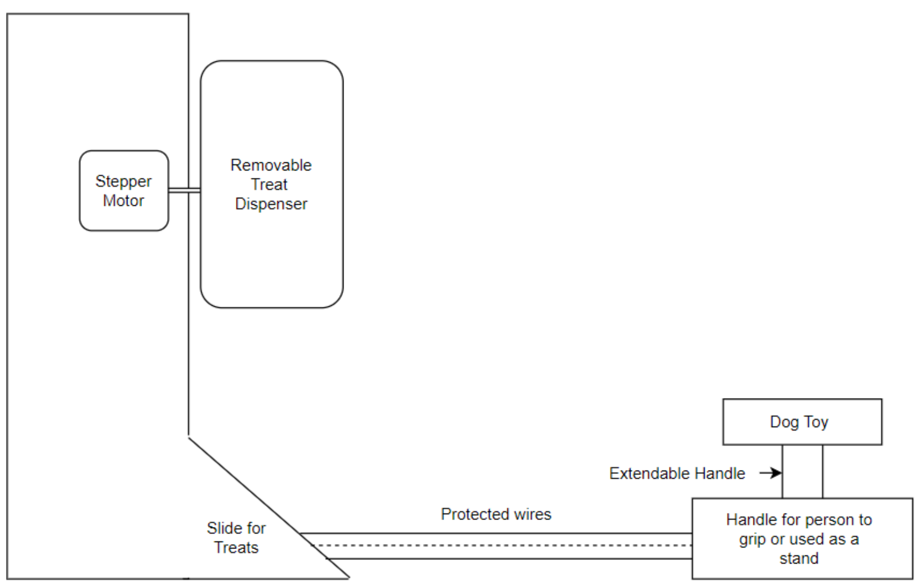

Fig. 2 Side View of System

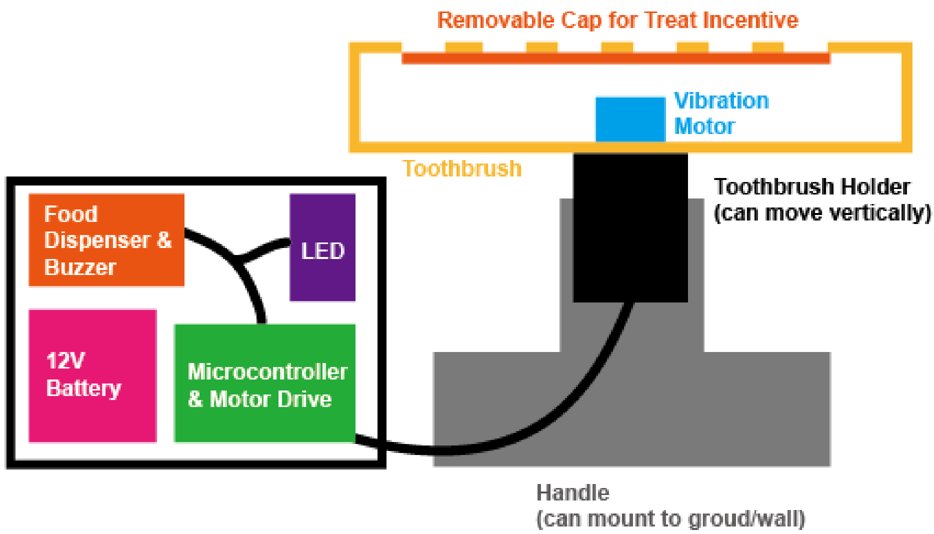

Fig 3. Visual Aid for Subsystems

1.4 High-Level Requirements List

1. The dog toy will be able to brush away food with similar properties of plaque off model teeth through the vibration of the bristles.
2. The dog toy will use treats and a buzzer sound to help make brushing their teeth a habit for dogs.
3. The electronic system will be solid enough to withstand the vibration, and the shell should be strong enough to withstand a small dog's bite.

2. Design

2.1 Block Diagram

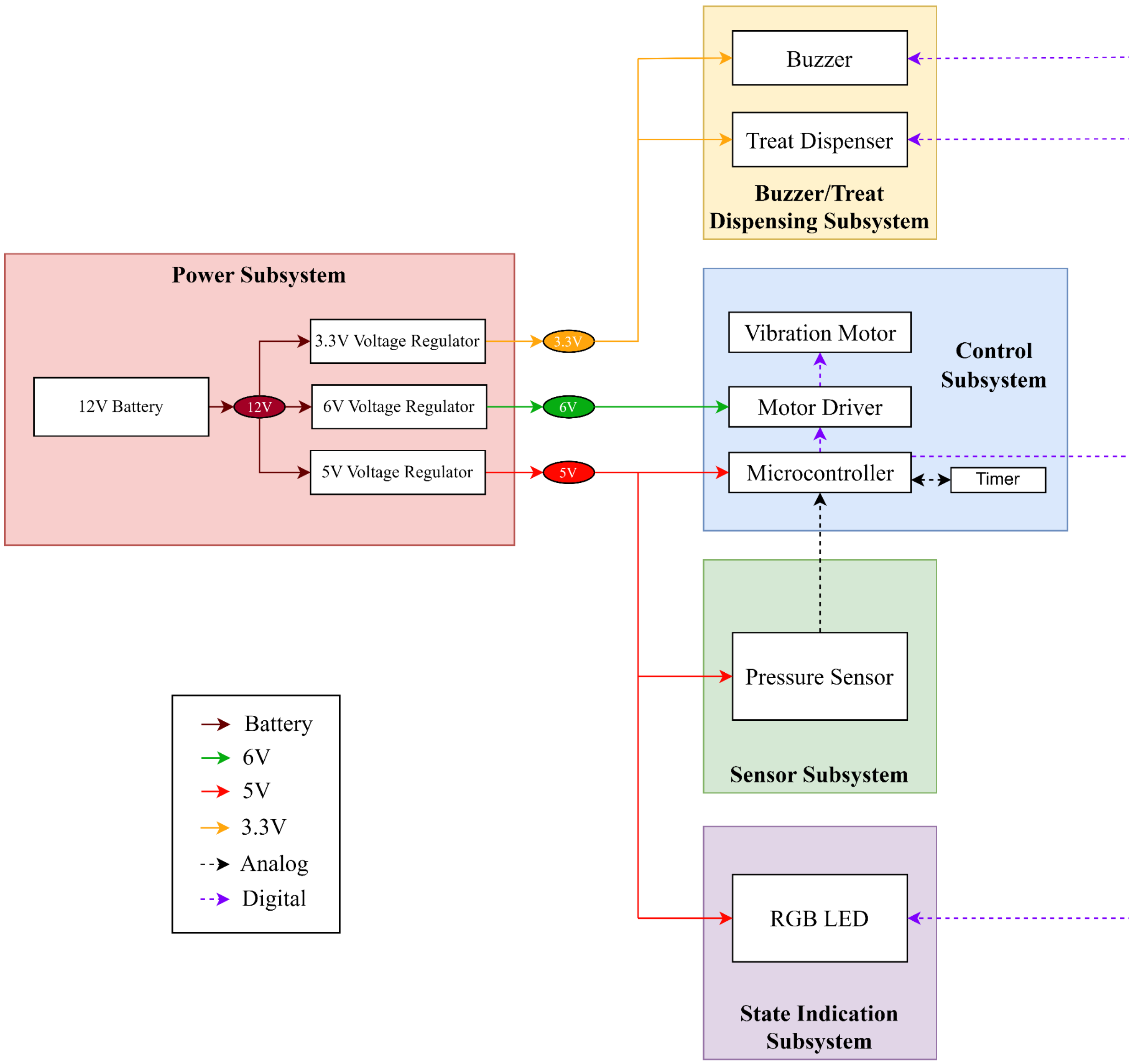

Fig. 4 High Level Block Diagram of the Solution

2.2 Subsystem Overview

2.2.1 Sensor Subsystem

The dog toy will use several flexible film pressure sensors that will be wrapped around the nylon plastic encasing and underneath the thick bristles. The pressure sensors are quintessentially resistors that change resistance according to the applied pressure. The sensors are used in a circuit that outputs an analog voltage level. By characterizing the pressure-resistance or pressure-voltage relationship, we can determine the applied force using an algorithm programmed in the microcontroller.

2.2.2 Control Subsystem

The dog toy will be using an ATmega328P microcontroller as its control system. The input of the controller will be data from the pressure sensor. When pressure data exceeds a certain threshold, indicating that the dog is biting the toy, the microcontroller will send a signal to the vibration motor to start the vibration process and start counting the actual brushing time (about two minutes, twice a day). When the time exceeds the brushing time for that bidaily cycle, the microcontroller will stop the vibration, send a signal to the buzzer/treat dispensing subsystem to dispense the treats, and light up the LED to indicate the end of that session.

The control system will have three states:

1. IDLE - When a new brushing session has started, but the pressure sensor is not triggered. This occurs when the brushing either has not started or has not been completed. The microcontroller will be powered to record time with a memory to keep the maximum brushing time on a daily basis.

2. VIBRATION - This occurs when the dog is biting the toy and the brushing time hasn't been exceeded. The microcontroller will tell the motor to vibrate and record the pressure data for calculation.

3. COMPLETE - The target brushing time has been reached. The system will turn back to idle, but it will first set off the buzzer, dispense a treat, and light up the LED to indicate its bidaily state.

2.2.3 Buzzer/Treat Dispensing Subsystem

After cleaning is complete, a buzzer will sound, and a treat will be released. The treat release is controlled by the microcontroller, and a counter/sensor is used to detect when there are no more treats left. This will light up an LED to let the owner know it's time to refill the dispenser.

2.2.4 State Indication Subsystem

The state indication subsystem consists of an RGB 4-pin LED and three current-limiting resistors. The LED is controlled by the microcontroller to produce the corresponding colors for different states by blending the three colors. A different color is assigned for each of the states described in the Control Subsystem section. In addition, users can be notified to replace the battery when the LED is off.

2.2.5 Power Subsystem

The power subsystem consists of one 12-V battery, one 3.3-V linear voltage regulator, one 5-V linear voltage regulator, and one 6-V linear voltage regulator. The purpose of the subsystem is to provide proper supply voltage to other subsystems. The 12-V battery directly provides an input voltage to the linear voltage regulators. The 3.3-V DC voltage will power the treat dispenser and the buzzer. The 5-V DC voltage would be the supply to the microcontroller, the pressure sensor, and the LED. The 6-V DC voltage is connected to the motor driver.

2.3 Subsystem Requirements

2.3.1 Sensor Subsystem

The sensor subsystem involves two to three 1738-SEN0293-ND thin film pressure sensors that will be wrapped around the nylon plastic encasing. The thin film pressure sensor is a variable resistor used in a non-inverting amplifier. This non-inverting amplifier uses an LT1097 op-amp. The amplifier is the output device that provides an analog voltage depending on pressure. The circuit is shown in Fig. 5. To provide the 1V reference voltage, an ADR510 voltage reference is used, as shown in Fig. 6.

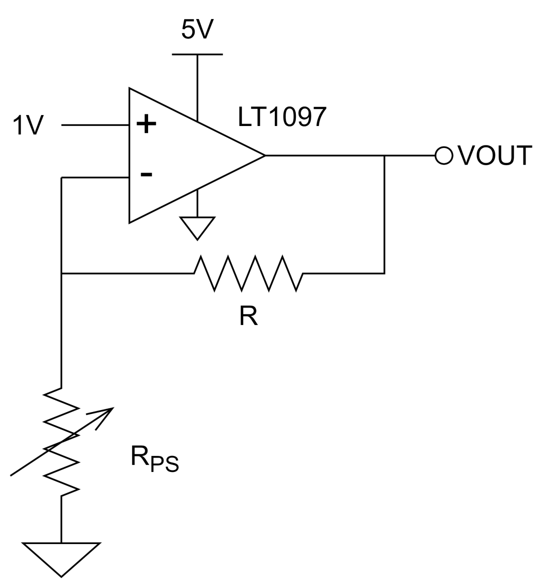

Fig. 5 Pressure Sensor Circuit

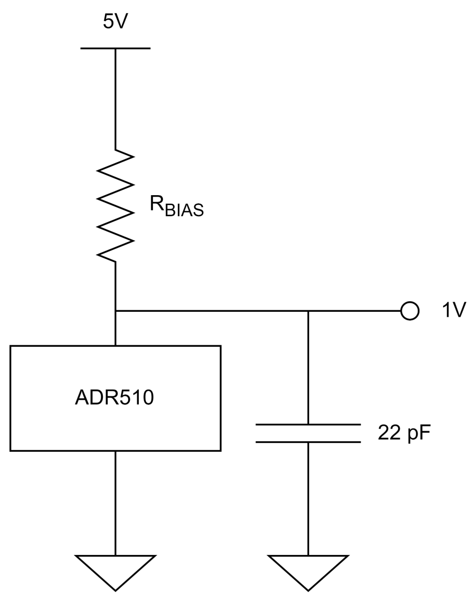

Fig. 6 1V Reference Circuit

The output of the amplifier is VOUT $= 1 + \frac{R}{R_{PS}}$ [V]. The specific range of VOUT depends on the specific resistor values, but it is within 1V - 5V, given the biasing. The output is connected to the analog input of the microcontroller. The microcontroller will measure the voltage level and determine whether an external pressure is applied.

Each pressure sensor should consume ≤ 10 mW to make sure that the device has a reasonable battery life.

2.3.2 Control Subsystem

The control subsystem includes an ATmega328P microcontroller, a DS3231 timer, and one small DC/vibration motor that has at least 6000 RPM. The microcontroller should be working at 5V and 16MHz during the VIBRATION state, while being able to enter sleep mode during the other two states to save power. In the IDLE state, the microcontroller will stay in sleep mode "ADC noise reduction" to read input from the pressure sensor, which requires about 10mA of working current. In the COMPLETE state, the microcontroller will enter sleep mode "power down", which is the most power-saving mode, and will only require a working current of ~0.15mA. The transition of control states is decided by the pressure sensor and the timer. When pressure sensor reads are raised significantly, the microcontroller will transfer from the IDLE state to the VIBRATION state. In the VIBRATION state, the microcontroller will set up two alarms in the timer; one will interrupt in two minutes to tell the microcontroller to enter the COMPLETE state, and the other one will interrupt in 12 hours to transfer the microcontroller back to the IDLE state.

Except for the power subsystem, the control subsystem must connect with all the other subsystems for data communication. Two to three analog input ports should be used to read from the sensor subsystem. Five digital output ports should be used to control the buzzer/treat dispensing subsystem, with one controlling the buzzer and four controlling the stepper motor. Another three digital output ports are needed to control the state indication subsystem. At last, to communicate with the timer, two analog ports are necessary (pin 28 for SCL, pin 27 for SDA).

2.3.3 Buzzer/Treat Dispensing Subsystem

The Buzzer/Treat dispensing subsystem involves a PS1440P02BT buzzer, a stepper motor, a treat dispensing wheel, and five AO3401 PMOS Transistors. The step motor has four inputs, each connected in series with a PMOS to the 3.3V supply voltage. Each PMOS gate receives a digital signal from the microcontroller in the control subsystem. Similarly, the buzzer is also connected in series with a PMOS to the 3.3 V supply voltage. This PMOS gate receives a PWM signal from the microcontroller. The treat dispenser will use a wheel of 5-9 compartments with an opening at one end. After a cleaning is done, the buzzer will sound, and the stepper motor will rotate to the next treat slot. The microcontroller will count the number of treat releases and light up the LED when it reaches a treat count of zero and reset.

The buzzer should draw ≤ 20 mA when operating at 100% duty cycle.

2.3.4 State Indication Subsystem

The state indication subsystem consists of a WP154A4SUREQBFZGC RGB LED and three AO3401 PMOS transistors in series with individual internal LEDs. Each PMOS transistor is connected to the 5V supply voltage, and its gate receives a distinct PWM signal from the microcontroller in the control subsystem. The LED should be able to convey if the cleaning requirement has been satisfied for each day through different colors.

Each LED should draw ≤ 20 mA when operating at 100% duty cycle, totaling to ≤ 60 mA of continuous current.

2.3.5 Power Subsystem

The power subsystem provides four levels of DC voltages–12V, 6V, 5V, and 3.3V. This subsystem is electrically connected to other subsystems as the power supply. The 12V is provided by a 12V battery, and it serves as the inputs to three internal voltage regulators that step the voltage down. The 6V is provided by an LM7806 voltage regulator; it is the supply to the motor driver in the control subsystem. The 5V is provided by an LM7805 voltage regulator; it is the supply to the microcontroller in the control subsystem and the pressure sensors in the sensor subsystem. Similarly, the 3.3V is provided by an LD1117V33 voltage regulator; it is the supply to the treat dispenser in the treat dispenser subsystem and the RGB LED in the state indication subsystem.

The 12V DC voltage should be maintained at 12V +/- 0.24V.

The 6V DC voltage should be maintained at 6V +/- 0.12V. When the toy is in vibration mode, the regulator needs to be able to provide at least 500 mA of current to the motor driver.

The 5V DC voltage should be maintained at 5V +/- 0.1V. For the correct operation of the microcontroller, the voltage ripple needs to be less than 50mV peak-to-peak.

The 3.3V DC voltage should be maintained at 3.3V +/- 0.066V.

2.4 Tolerance Analysis

Since our device is operating on a battery and is meant for long-term usage at home, it is vital that our device can operate for a reasonable period of time before the user has to recharge the battery. To confirm that our design is practical, a pessimistic estimation of the battery life is necessary.

First, the pessimistic idle current draw of subsystems that have significant power consumption is shown in the following tables. The current values are taken from respective datasheets.

Power Subsystem		
Device	Maximum Idle Current	Total Current
LM7806	8 mA	26.5 mA
LM7805	8.5 mA	
LD1117V33	10 mA	

Tab. 1 Power Subsystem Idle Current

Control Subsystem		
Device	Maximum Idle Current	Total Current
Microcontroller	0.15 mA	0.825 mA

Timer	0.65 mA	
Motor Driver	0.025 mA	
Vibration Motor	0 mA	

Tab. 2 Control Subsystem Idle Current

Sensor Subsystem		
Device	Maximum Idle Current	Total Current
Pressure Sensor Circuit	0.54 mA	1.62 mA
Pressure Sensor Circuit	0.54 mA	
Pressure Sensor Circuit	0.54 mA	

Tab. 3 SensorSubsystem Idle Current

State Indication Subsystem		
Device	Maximum Idle Current	Total Current
RGB LED	60 mA	60 mA

Tab. 4 State Indication Subsystem Idle Current

The current draw for the pressure sensor circuit is given by a LTspice simulation. The simulation result is shown in Fig. 7:

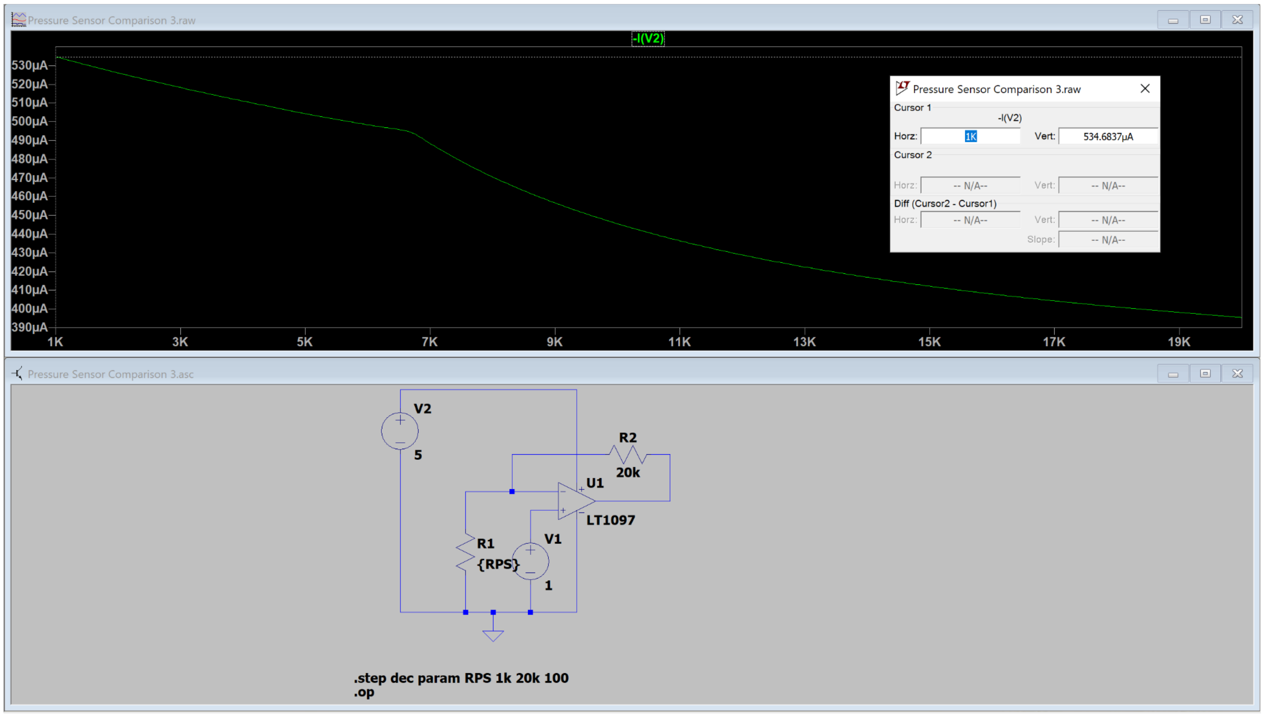

Fig. 7 Pressure Sensor Circuit Current Simulation

Since the Buzzer/Treat Dispensing Subsystem is controlled by PMOS switches and turned off when the device is idle, the current draw is negligible. Therefore, the total pessimistic idle current $I_{Idle,Tot} \approx 88.945$ mA. Under the assumption of using a 7 Ah battery,

$$t_{idle} = \frac{7\ Ah}{78.7\times10^{-3}} \approx 78.7\ h \approx 3.279\ days$$

Therefore, the device can run for approximately 3 days when powered on but not used.

Now, when it comes to the power consumption from the vibration motor, the current draw is 200 mA @ 14V. Then at 6V, an estimation would be

$$i_{Motor} = \frac{200\ mA\cdot14V}{6V} \approx 467\ mA$$

Under the assumption that the device will be active for two times a day for two minutes each time,

$$Consumption_{Motor} = 2\cdot 467 \times 10^{-3}A \cdot \frac{2\ min}{60\ min/h} = 0.03\ Ah/day$$

We assume that the Buzzer/Treat Dispensing Subsystem will have the same consumption for our pessimistic estimation. Therefore,

$$Consumption_{Dispenser} \approx Consumption_{Motor} \approx 0.03\ Ah/day$$

As for the idle consumption,

$$Consumption_{Idle} \approx 88.945 \times 10^{-3}\ A \cdot 24\ h/day \approx 2.13\ Ah/day$$

In total,

$$Consumption_{Total} \approx 2.13\ Ah + 0.03\ Ah + 0.03\ Ah \approx 2.19\ Ah/day$$

Hence the pessimistic battery life would be

$$t_{pessimistic} \approx \frac{7\ Ah}{2.16\ Ah/day} \approx 3.196\ days$$

Thus, pessimistically speaking, our device can run for approximately 3.196 days when operating under recommended cleaning cycles. In the actual implementation, the microcontroller should consume less current than the value listed above. Also, the pressure sensor subsystem should have a lower current draw since the resistance should be higher when it is not used. The LED should also draw less current than the listed value since it will not be run at 100% duty cycle. Thus, the real-world power consumption should be lower than the pessimistic estimation. Considering that the user has to refill the treat dispenser at approximately the same time, the battery life is long enough for practical usage.

3. Ethics & Safety

According to the IEEE Code of Ethics, the safety and health of the public are to be held paramount [2]. We need to pay close attention to the safety aspect of the project due to the interactive nature of our proposed device. In our design, the motor is attached to the dog toy, and there are wires connecting the motor to the treat dispenser. Therefore, it is essential to make sure that the wires and motor are properly secured. Preventing exposure and damage to the battery is also necessary to satisfy the category of safety. Another aspect to keep cautious of is using dog-friendly materials. This is especially true for the bristles and the encasing of the dog toy. To ensure our product uses dog-friendly materials, we will be using materials that have already been used on dogs in the market.

When it comes to ethics, it is noteworthy that the treat dispenser is only compatible with certain kinds of treats, and the product is potentially directing the user to deem those treats as more desirable. One can regard this as an impairment to the user's welfare since the product is forcing the user to have a certain kind of supplementary product. Considering the prototype nature of the product, we should make endeavors to improve the treat dispenser in the future.

References

[1] K. B. Enlund *et al.*, "Dog Owners' Perspectives on Canine Dental Health—A Questionnaire Study in Sweden," *Front. Vet. Sci.*, vol. 7, p. 298, Jun. 2020, doi: 10.3389/fvets.2020.00298.

[2] Institute of Electrical and Electronics Engineers, "IEEE Code of Ethics," *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 09-Feb-2023].