Robotic Animal Assisted Therapeutic Device

Team 13
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1 Introduction

1.1 Objective

Therapalz is in the process of creating a robotic therapy animal that will serve as a companion for Alzheimer's patients. Currently, the project needs to have a more realistic design where managing the electronics doesn't disturb user experience. Specifically, opening a robotic animal's stomach to replace batteries isn't ideal. Sensory input through capacitive touch on the current design has also proven to be ineffective and doesn't produce reliable stimuli to the system. Lastly, the device lacks a useful user interface for caregivers that would allow them to monitor and potentially control the animal for specific needs during periods of patient stress.

Our objective for this project is to improve on the current prototype, increase realism, and provide point-of-care abilities for caregivers. We plan on implementing wireless charging to make the device more realistic and using a microprocessor to improve on its convenience factor. The microprocessor can analyze data from sensors, change the purring habit of the device, and transmit data to and from the caregiver via a web app/mobile app. Wireless charging will be achieved by placing a primary coil in the pet bed and a secondary coil in the stomach of the pet and will use resonant inductive charging. The microprocessor will gather data from the accelerometer, gyroscope, and microphone sensors to determine general distress of the patient and adjust the purring output to the speaker. This data will be sent to a server which will relay the information to the corresponding caregiver's phone via a mobile app. The caregiver will then be able to read the data and send commands(such as increase purring) to the device.

1.2 Background

Currently, Alzheimer's is the 6th leading cause of death in the United States [1]. According to the Alzheimer's Association [1], 1 in 3 seniors dies with Alzheimer's or another dementia. There are 7.7 million new cases every year. Clearly, this is a very pressing issue.

Over the past few decades, researchers have been exploring alternative, non-pharmaceutical methods of treatment for patients with Alzheimer's and related diseases. Animal-assisted therapy(AAT) is gaining popularity and has been proven to be extremely effective on patients: it improves their apathetic state, decreases their irritability and depression, and boosts their social interaction[2]. Studies also show that AAT helps lower blood pressure and increase neurochemicals related with relaxation and bonding[2].

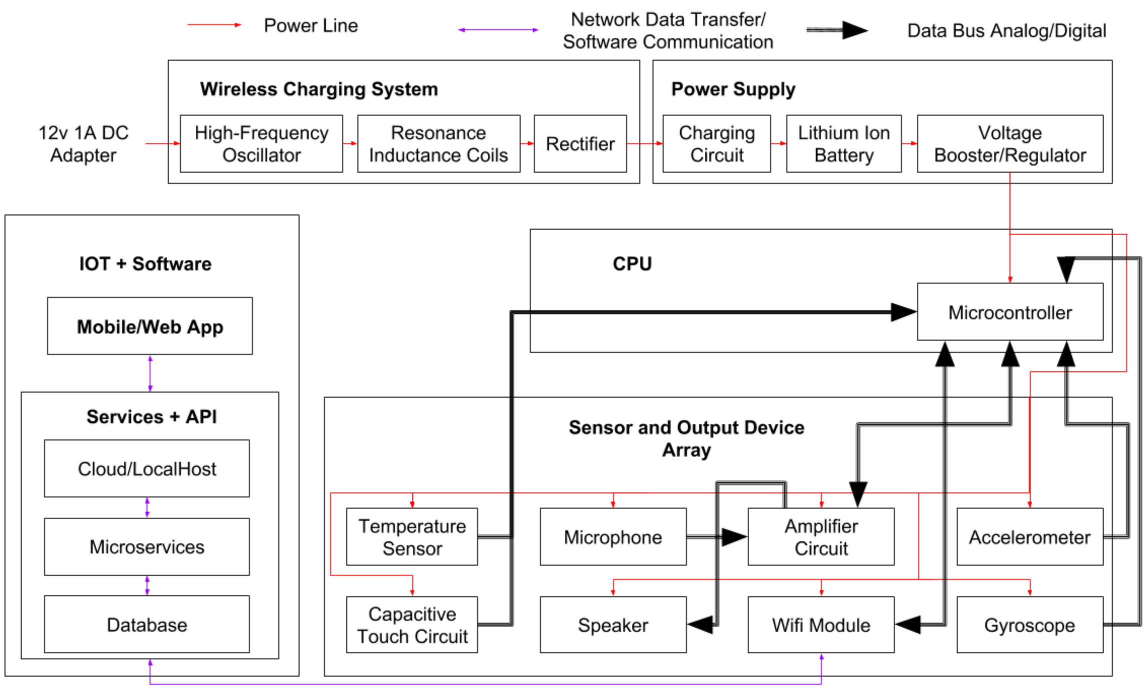
Therapalz aims to provide the benefits of AAT without the burdens: using robotics lowers the cost of animal care and reduces possible threat of abuse or neglect towards service animals. We intend to implement a cheaper option than the current AATs that cost several thousand dollars, so many patients are able to receive the benefits by using sensors and components that aren't more precise than are needed.

1.3 High-Level Requirements List

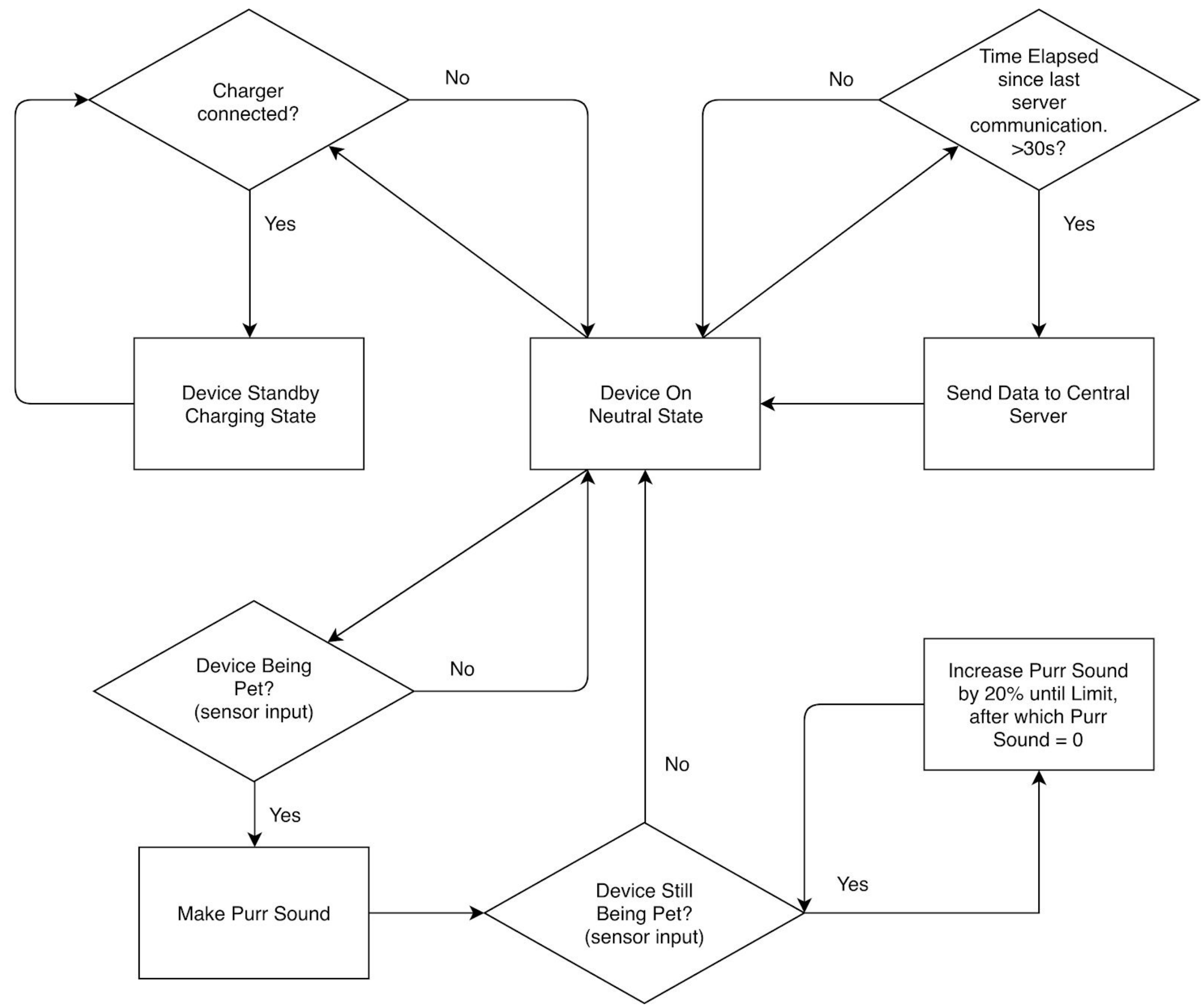
- The device must be able to charge using the embedded wireless charging circuit and a corresponding pet bed(that contains the transmitter) to charge it. The device will make a LED light up when the device is charging.
- The device must be able to process and route data from input sensors to output devices. Input from the touch sensor should cause the speaker to emit a purr sound. Sudden violent movement of the gyroscope/accelerometer or continuous loud sounds(heard via microphone) corresponds to sending a distress signal to care services via the WiFi module.
- The device's Wi-Fi module should be successfully able to connect to a WiFi network. It should also be able to transmit and receive data from services on the cloud. Data sent includes diagnostics on how many times the robot has been stroked, how often it has been interacted with(gyroscope) etc. Data received includes instructions to increase purring.

2 Design

The entire system will be run off of a single cell lithium ion battery providing a constant voltage between 3.7 and 4.2 volts with a 10 AHr capacity. The system must last for a maximum of 10 hours and therefore must draw at most 1 Amp of current continuously. The four current drawing systems are the sensors, the microprocessor unit, the Wi-Fi module, and the voltage regulators to step up the battery voltage to 5 volts and step it down to 3.3 volts. The battery will be charged using resonant inductive wireless charging across a gap of about 1-2 cm and must charge the battery in less than 14 hours.


Power Line
Network Data Transfer/ Software Communication
Data Bus Analog/Digital
12v 1A DC Adapter
Wireless Charging System
High-Frequency Oscillator
Resonance Inductance Coils
Rectifier
Power Supply
Charging Circuit
Lithium Ion Battery
Voltage Booster/Regulator
IOT + Software
Mobile/Web App
Services + API
Cloud/LocalHost
Microservices
Database
CPU
Microcontroller
Sensor and Output Device Array
Temperature Sensor
Microphone
Amplifier Circuit
Accelerometer
Capacitive Touch Circuit
Speaker
Wifi Module
Gyroscope

Sample Software Control Flow Diagram



The control block diagrams above satisfies the high level requirements. The charging control flow will verify if the device is charging successfully or not when it goes to Standby state. Processing and routing of sensors is verified by touch input and corresponding purr sounds. Sending of diagnostic data is indicated by the 30 second transmit loop.

2.1 High-Frequency Oscillator

The high-frequency oscillator will convert the DC 12v 1A supplied from a purchased wall adapter into a high frequency signal (in the order of around 10-50kHz depending on the resonance frequency of the coils). The sine wave is generated by a PICAXE microprocessor and will be amplified by a transistor.

Requirement: Must produce a tunable sine wave between at least 10-50kHz. This will be measured using an oscilloscope.

2.2 Resonance Inductive Coils

The resonance inductive coils are the portion of the wireless charging circuits that creates the magnetic field and induces the current in the secondary coil. There is a ~12sin(2**π**(f_c)*t) volt wave that enters the primary coil (where f_c = the resonance frequency = 10 to 50kHz).

Requirement: A sine wave with amplitude of around 12 volts should be produced on the secondary coil side. This will be measured by using an oscilloscope.

2.3 Rectifier

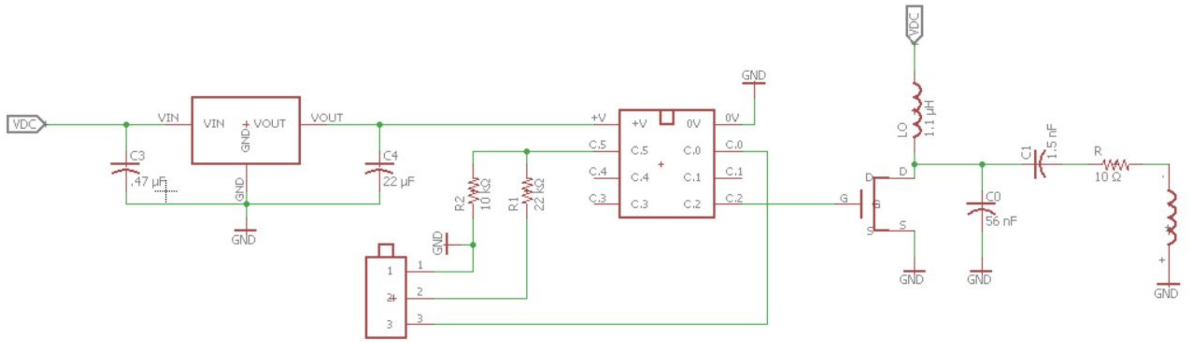
The Full-Bridge rectifier converts the AC voltage output from the secondary coil into a dc voltage. This voltage is used to power the charging circuit and the rest of the robot while the robot is on the pet bed. The voltage doesn't need to have the ripples completely attenuated since it'll be feeding into a Fixed Output Linear Regulator that can take any voltage up to 30v. A fluctuation of upto 10% should be sufficient. The charging circuit requires between 4.35-6.50v.

Requirement: Provide between 4.35+10% and 6.50-10% voltage on the output of the rectifier. This will be measured using an oscilloscope to observe the peak to peak ripples.

2.4 Charging Circuit

The charging circuit regulates the charging of the Single Cell Lithium Ion Battery. It maintains a constant current during the linear charge phase of the charge cycle and a constant voltage to finish charging the battery. It will also turn off the charging when the battery is fully charged.

Requirement: Provide 4.168-4.232 volts during the constant voltage phase of the charge cycle and 15-500mA of current during the constant current phase. The maximum temperature must be under 125 degrees celsius but should be designed to maintain temperature around the "typical" operating value of 25 degrees. The voltage and current will be measured across and into the battery as it charges and a temperature sensor hooked up to a separate arduino will monitor the temperature through charge cycles.



The charging circuit is composed of two major parts the primary and secondary sides. The primary side consists of a 12V 1A AC-DC wall adapter, a 5v voltage regulator, a square wave frequency generator (PICAXE), and a Class E Inverter to produce a sinusoidal current. The secondary side has a receiver coil that has an induced current and a full bridge rectifier to convert the AC wave into a DC voltage. It also contains another voltage regulator and a battery charging IC.

2.5 Lithium Ion Battery

The lithium ion battery is the power source for the robot when it isn't on the charging pad. It must be able to last for 10 hours and supply voltage for the voltage booster circuit and step down voltage regulator to power the MPU and Wi-Fi module.

Requirement: Provide 3.7-4.2 volts and at least 400mA to 1A of current for 10 hours. The current will be measured by having an ammeter in series with the battery as the entire robot is being operated to ensure the current is in the appropriate region. Voltage will simply have a voltmeter across the battery terminals at full charge.

2.6 Voltage Booster/Regulator

A DC-DC converter to convert the 3.7-4.2v from the battery to a constant 5v to supply optimal voltage to the MPU. Must also step down the battery voltage to a constant 3.3v supply for the Wi-Fi module.

Requirement: For the booster it must provide a constant 5(∓.1)v and at least 100mA for sensors and the MPU. For the step down battery voltage the circuit must supply 3.3(∓.1)v and at least 215mA. A 50 and 15 ohm resistor will be placed across the 5v and 3.3v side respectively to ensure the required currents can be delivered.

2.7 Microcontroller

The ATmega328p will be handling data acquisition, routing, and output from input sensors to output devices. The controller will be interfacing with analog and digital sensors as well handling audio recording and behavioral logic to trigger audio playback in response to user interaction. The controller will also interface with a wifi module where it will send processed sensor data to be sent to a server.

Requirement: The microcontroller must support at least 4 input sensors and 2 output devices. The controller must also have a clock speed of 20 Mhz.

2.8 Accelerometer

The accelerometer will track acceleration of the device to monitor possible stress events. Based on calculated thresholds, the accelerometer will be used to alert caregivers when the device is likely thrashed or thrown, indicating that the user might be in a panic.

Requirement: Accelerometer has to be accurate up to 3g of acceleration. We can test this by taking data from a serial console while dropping the robot to compare the recorded value to the known value of gravity

2.9 Gyroscope

The gyroscope will track rotation of the device as a second means of monitoring patient conditions. By setting calculated thresholds, the gyroscope be used to alert caregivers when the device is likely being shaken violently, and also thrown, indicating that the user might be in a panic.

Requirement: Gyroscope must be accurate up to 500 degrees / second. We can confirm the needed requirement by reading data through a serial console while rotating the gyroscope by a set amount and comparing if the recorded data matches it.

2.10 Microphone

The microphone will record speech as well as volume data as a third means of monitoring patient conditions. If alerts are triggered by accelerometer and gyroscope data, the microphone will start taking 5 second samples of speech and volume intensity which can be used with the rest of the sensor data to determine the state of the patient.

Requirement: Microphone must be able to pick up audio from up to 10 feet in case patient throws device away from them. Microphone must have SPL of at least 100 dB to be able to clearly distinguish loud screaming[6]. We will be able to view input amplitude on an oscilloscope to confirm the upper range of SPL. Microphone must also be able to operate between 20-20000 hz[8].

2.11 Speaker

The Speaker will be one of the output devices used for behavioral response to user interaction. Input sensors like the capacitive touch mechanism will trigger audio output to replicate common animal sounds such as barking/purring.

Requirement: Speaker must be able to produce at least 40 dB audio to simulate average purring volumes[7]. We can transmit to our microphone while it is hooked up to the oscilloscope to confirm the required volume levels of the speaker.

2.12 Amplifier Circuit

The Amplifier Circuit will have two sections. It will amplify audio waveforms coming from the microphone so that they can be read by the microcontroller, and amplify audio waveforms going to the speaker to achieve the desired specifications for our speaker.

Requirement: The amplifier circuit must have a gain of at least 2 volts. We can use a function generator to create an input signal and an oscilloscope to measure the output signal to observe the gain.

2.13 Temperature Sensor

The temperature sensor will be used as a fail safe for the system. In case of overheating, the sensor will cut power to the system.

Requirement: Sensor must be able to accurately detect temperatures above 90 degrees celsius. Sensor must be kept away from power circuitry as power systems will produce the most heat.

2.14 Capacitive Touch Circuit

The capacitive touch circuit will process data from touch plates on the surface of the device to be used as trigger signals for behavioral logic. The act of touching the device should trigger a response in the form of audio playback.

Requirement: The MPU must be able to receive input from the capacitive touch fur and process a response. We will test this by having the speaker produce some audio when the fur is touched, but not have audio produced when it isn't touched.

2.15 Wi-Fi Module

The wireless module is used to connect the robot pet to services on the Internet. This adds the ability to monitor patients, collect data on how they use the robotic animal, and adjust sensors, on the fly. As of now, we're thinking of using the ESP8266, which is an SOC WiFi module that also has a 1MB flash disk.

Requirement: Input voltage into the Wi-Fi module must be stepped down to 3.3V and max power consumption of Wi-Fi module should not exceed 0.825W. This can be verified using an oscilloscope. Functionality can be verified by connecting to the wireless network broadcasted by the module and sending a packet of data. This is further verified when connected to a local WiFi network.

2.16 Software: Connected Services, Mobile/Web App

An entire software stack will be built, as shown in the block diagram. This involves managing a database, writing services, and hosting them on the web. A mobile/web app will also be built that uses the api (services) as its backend.

Requirement: The robot should be able to connect to the micro services and send data to it. Related users should be able to view this data on their phones via web/mobile app. Users should be able to remotely control the robot through the app. This will be verified by creating data and pushing it to the web/mobile app and actually accessing the data and then sending a request for the robot to purr on the other way around.

2.17 Risk Analysis

The block that poses the biggest is the wireless charging system. A group in the past tried and failed to create a wireless charging pad to charge a laptop. The biggest concern with the wireless charging pad is that it won't be efficient enough to charge the battery. They tried to transfer a significant amount more power than we require. The battery for our system needs at most 3 W meaning allowing a low need for efficiency. The low need for efficiency enables a more simplistic design. The wireless charging depends upon the secondary (receiver) coil having an induced current from the magnetic field produced by the primary (transceiver) coil. We need to ensure that the resonance frequency matches in both coils as well as with the sine AC signal that is creating the magnetic field in the primary coil and inducing the current in the secondary coil. Ensuring these frequencies match can be difficult as many coils we would buy online don't have complete datasheets to include the capacitance between the wires in the coil. This capacitance varies from coil to coil and could greatly affect the resonance frequency. Measuring the capacitance of the system and tuning the frequency by adding capacitors in parallel with the coils can help improve efficiency. Another issue with the wireless charging could be the distance between the coils while charging. Magnetic fields decrease as $\frac{1}{r^2}$, meaning that the further away the secondary coil is from the primary the more energy is lost. We need to ensure that the coils are close enough that the field doesn't decrease so much as to reduce efficiency too much.

3 Cost Analysis

3.1 Labor:

Brian Wilens: \$42 x 2.5 x 120 = \$12,600
Divij Nagpaul: \$42 x 2.5 x 120 = \$12,600
James Brown: \$42 x 2.5 x 120 = \$12,600
Labor Total: \$37,800

3.2 Parts:

Parts Estimate Total: $200 * 3 (backup parts) = $600
GRAND TOTAL = LABOR + PARTS = $38,400

3.3 Schedule

Schedule: Include a time-table showing when each step in the expected sequence of design and construction work will be completed (general, by week), and how the tasks will be shared between the team members. (i.e. Select architecture, Design this, Design that, Buy parts, Assemble this, Assemble that, Prepare mock-up, Integrate prototype, Refine prototype, Test integrated system).

4 Safety and Ethics

The biggest ethical concern we have correlates to guideline 1 of the IEEE code of ethics. That rule corresponds to the health and safety aspect of the rules. Transferring power in general, especially over the wireless coils, runs the risk of heating up the system. The robot is covered in fur and has very little air flow, therefore overheating and possibly catching on fire is a concern. We intend to reduce this risk by transferring relatively low amounts of power and by having heat sinks across the robot to redistribute the heat. Another fire concern relates to the charging of the lithium ion battery. Lithium ion batteries are great batteries in that they're able to charge and discharge many times, they're able to provide a good voltage, and be able to last for long periods of times. This risk can be minimized by using safe charging methods. There are many ICs that are able to monitor and control the charge of lithium ion batteries. By using one of these we are able to reduce the risk [3].

Another concern correlates to guideline #5 of the IEEE code of ethics, in that our robot is recording patient data in terms of temperature and speech to alert the caregiver. Additionally, the caregiver will be able to use an app to control the robot's animal noises. Care must be used to ensure that no data can be stolen and that the robot's controls can't be hacked. We intend to use RSA + AES standard that is commonly used in the industry[5]. This involves public and private key exchanges along with generation of an AES key that will be used to establish a secure session. This ensures that no man-in-the middle attack or eavesdropping can occur. We hope that by discussing and documenting our work we can demonstrate honest and just engineering practices and share the growth of knowledge.

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