ROBOTIC ANIMAL ASSISTED THERAPEUTIC DEVICE

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Abstract

Therapalz has produced a functional prototype of its robotic therapeutic device to streamline caretaking of Alzheimer's patients. Equipped with haptic feedback, audio response, and wireless charging capabilities. Therapalz mimics the benefits of a real service animal for its users. Also equipped with internal sensory equipment and internet capabilities, Therapalz enhances caretaking by providing a system to monitor patients and alert medical staff during an incident. Initial results of development revealed that sensor data could be recorded and transmitted to a server. It was also shown that the device could react to touch input with vibrational and audio responses. Further, Therapalz was capable of wirelessly charging its battery when settled in a pet bed.

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1. Introduction

1.1 Objective

Therapalz' objective was to create a prototype of a robotic therapy animal that could monitor and enhance treatment of Alzheimer's patients. Therapalz previously used a prototype with limited feedback response and no patient data recording that also lacked realism when interfacing with electronics. Presented here is the new prototype which addressed all of the aforementioned shortcomings of Therapalz' previous design.

This new design features a two-part wireless charging mechanism which takes power from conventional outlets to recharge the device without having to remove the battery pack. The process is masked through the use of a pet bed to simulate "sleeping" during the recharge cycle. The charging mechanism also features controls to withhold power from the device while charging to increase efficiency.

The new design contains a sensor array for recording touch, voice, and acceleration data. It also includes a speaker. The array is managed by a host controller which also drives vibrational and audio response mechanisms. The whole system communicates with a WiFi SoC to transmit sensor data and alerts to a server hosted on the cloud. The WiFi SoC can also receive instructions from a mobile app, relayed by the server. Following development and production, we conclude that the new Therapalz device successfully executes the functionality outlined in the objective.

1.2 Background

Currently, Alzheimer's is the sixth leading cause of death in the United States [1]. According to the Alzheimer's Association [1], one in three seniors dies with Alzheimer's or another form of dementia. With 7.7 million new cases annually, 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 an extremely effective treatment for 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 toward 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 are not more precise than are needed.

1.3 High-Level Requirements

- The device must be able to charge using the embedded wireless charging circuit and a corresponding pet bed(that contains the transmitter) to charge a lithium ion battery that will be used to power the rest of the robot when it is not 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 should be sensed by the gyroscope/accelerometer and continuous loud sounds(heard via microphone) will result with sending a distress signal to caregivers via the Wi-Fi module.
- The device's Wi-Fi module should be successfully able to connect to a Wi-Fi 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 and accelerometer), and if distress has been detected. Data received includes instructions to change default setting such as purring sound level.

2 Design

2.1 Design Introduction

The Therapalz prototype consists of 5 major systems: wireless charging system, power supply, MPU, sensor and output device array, and software and Wi-Fi (as shown in Figure 1). The wireless charging system has a 12 V 1 A power supply as an input and can supply 5 V at up to 300 mA. This system is directly responsible for providing the power to charge the lithium ion battery. The power supply system has two functions: to charge the battery when wireless charging system is operating and to provide power to the MPU and the variety of sensors being used. While charging the battery the rest of the robot is turned off to ensure that an excess current is not drawn from the wireless charging system. The MPU system processes all of the data collected by our sensors. It also communicates with the Wi-Fi module and, by extension with the server and phone app. The sensor and output device array system contains all the sensors we are using to determine patient distress and calm the patient as well as contains a Wi-Fi module to relay data between the microcontroller and the server. The last system, the software and Wi-Fi services system, retrieves the data from the Wi-Fi module and stores it on a server before transmitting the data to our iPhone app. This system can also transmit commands from the phone app to the robot to elicit a response from the Therapal such as a purring sound.

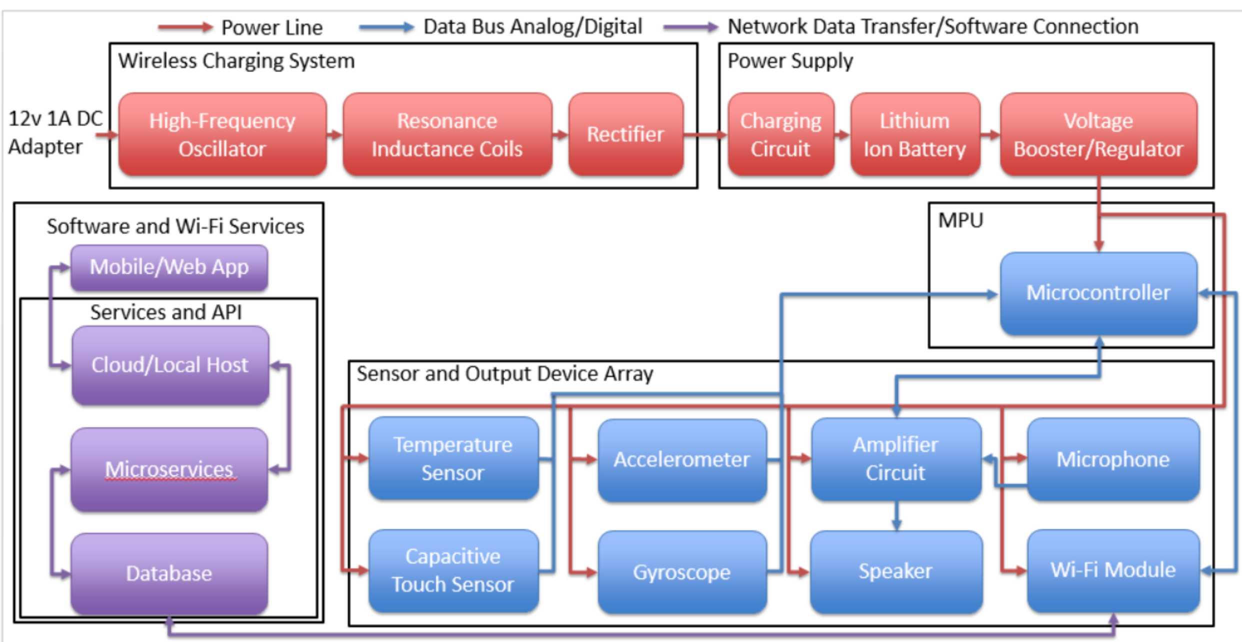

Figure 1: Block Hardware Diagram

2.2 Design

2.2.1 High-Frequency Inverter

The high-frequency oscillator converts the DC 12 V 1 A supplied from a purchased wall adapter into a 35 kHz sinusoidal signal. A square wave generated by a PICAXE microprocessor turns on and off the mosfet. In figure 2, when the frequency of the square wave matches the resonance frequency of the primary coil and the capacitor, a nearly perfect sinusoidal wave is formed. We initially tried using a Class

E type inverter to generate the AC voltage; however, during our testing, we were unable to produce an alternating voltage at all [10]. When the circuit was simplified to that seen in figure 2, an alternating voltage was measured across the primary coil. We used LTspice to test different inductances and capacitances to adjust the AC voltage until we had a maximum a peak to peak voltage of ~36 V. We decided to use a coil with an inductance of 25 µH and a capacitor with capacitance of .47 µF.

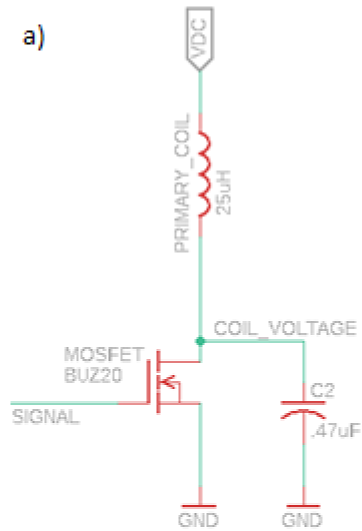

Figure 2: Circuit Schematic of high-frequency inverter.

2.2.2 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. The circuit effectively acts as a transformer with an air core. The primary side design was restricted by the design for the high-frequency inverter, but the secondary side had several design choices. For example, the secondary side could have the coil in series or parallel with a capacitor. We ultimately chose to have a capacitor in parallel (appendix figure 10) with the coil to optimize the design for longer distance transfer [10]. The resulting topology of the wireless charging system was S-P (capacitor in series with the primary coil - the capacitor in parallel with the secondary coil). Adjusting the values of the capacitors allowed us to select a resonance frequency that was lower to match the S-P design, which also is optimized at lower frequencies.

When we first built and tested the circuit, we were able to transfer 5 V and about 50 mA across a distance of about 1 cm. We were initially using coils with a quality factor 25. We then tried to use coils that had a quality factor of 80. We were able to draw about 250 mA from the 5 V voltage regulator before its output voltage dropped. When we tapped ferrite sheets to the backside of each coil, the current that could be drawn from voltage regulator increased to about 300 mA. We found that the coils with the higher quality factor, despite having half the inductance, were able to transfer power more efficiently.

2.2.3 Rectifier

The rectifier converts the AC voltage induced on the secondary coil into a DC voltage. The output of the rectifier fed into the input of a 5 V voltage regulator. According to the datasheet of the voltage regulator, any voltage between 6 and 24 V could be used to power it. Therefore the output of the rectifier must be at least greater than 6 V and the input RMS voltage must be greater than 7.65 V.

2.2.4 Charging Circuit

The charging circuit regulates the charging of the lithium ion battery [13]. 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. Figure 3 below shows the general circuit that will be implemented following the 5 V voltage regulator on the secondary coil side of the circuit. We decided to use the MAX1811 battery charger IC for several reasons. First, the MAX1811 has two SELI modes to allow for 100 mA charging. Second, the MAX1811 has internal safety measures to ensure the battery is charging correctly (including a thermal loop to prevent overheating). Lastly, this IC is relatively easy to integrate. The one issue we had while integrating the MAX1811 was that we accidentally shorted pin 1 and 2. This forced SELI to draw 500 mA which was significantly more than our system could provide. It resulted in components overheating and eventually shutting down.

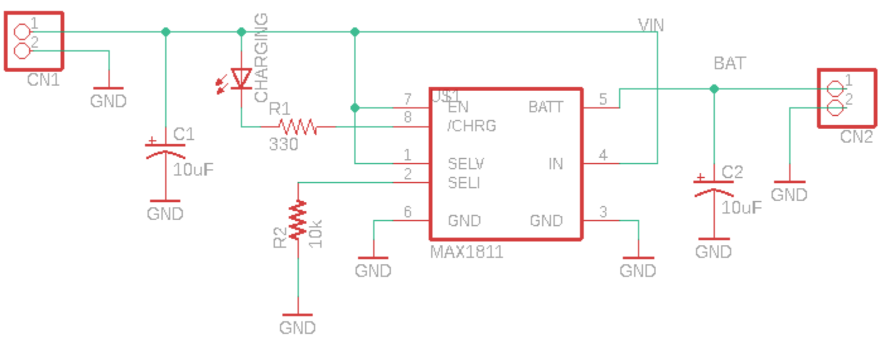

Figure 3: Circuit Schematic MAX1811 charger IC

2.2.5 Lithium Ion Battery

The lithium ion battery is the power source for the robot when it is not on the charging pad. It must be able to last for 10 hours and supply voltage for the 5 V voltage booster circuit and the 3.3 V voltage regulator to power the MPU and Wi-Fi module.

2.2.6 Voltage Booster/Regulator

A DC-DC converter is used to convert the 3.7-4.2 V from the battery to a constant 5 V to supply optimal voltage to the MPU. The battery voltage must also be stepped down to a constant 3.3 V supply for the Wi-Fi module. Each of these devices is treated as a singular IC that will be implemented in the overall circuit.

2.2.7 Microcontroller

The ATMega328P hosts the primary programming used to drive the device. The controller interfaces with all other input and output devices: taking data from environmental sensors, storing it, and driving motor and speaker control signals. The 328P was chosen primarily due to its versatile set of features and small footprint. It contains a 32 KB program memory and operates in a 5 V regime. This microcontroller offers full I2c and SPI communication support, multiple pwm drivers, and internal analog-to-digital converters which satisfy the needs of the host controller. The 328P was also chosen because of its high compatibility with the Arduino development environment which made software integration much easier.

2.2.8 Accelerometer and Gyroscope

The MPU6050 tracks linear and rotational acceleration of the device in 6 axes. Based on hard-coded thresholds, data from the device can indicate when the device is likely being thrashed or thrown. The MPU6050 was chosen because of its low power consumption and I2c compatibility, and because it operates at 3.3 V with a typical current draw of 3.9 mA.

2.2.10 Microphone

The MAX9814 paired with an electret microphone is used to record volume and speech. The preamplifier was chosen because of its automatic gain control feature which takes microphone input and adjusts the gain to fit within a certain range to avoid clipping loud signals, and losing quiet signals.

2.2.11 Speaker

The speaker is used to achieve audio playback of cat purring in response to user interaction. A common 8 Ohm speaker rated for 1 W was used with an SPL rating of 90 dB resulting in a realistic purring volume [7].

2.2.12 Amplifier

The LM386 audio amplifier is used to boost pwm signals from the microcontroller to the speaker which is needed because signals coming from the controller are too weak to be audible by themselves. The 386 was chosen because it is specifically designed for audio applications. It features an adjustable gain between 20 and 200 as well as internal bypass mechanisms for filtering. The LM386 operates between 5 - 12 V. We found that 9 V gave us optimal sound quality.

2.2.13 Temperature Sensor

The MCP9808 monitors the ambient temperature around the device. This sensor is a safety measure to prevent overheating. The 9808 was chosen because it can measure stable values beyond 70 degrees celsius which is the average temperature for thermal runaway. This component also features an external interrupt pin which is used to trigger immediate shutdown during overheating.

2.2.14 Capacitive Touch Circuit

The CAP1188 is used to track interaction with the device. This is the primary component for tracking interaction and controls most of the device's response logic. The CAP1188 was chosen because it has 8 individual channels which are dispersed around the prototype. Each channel runs independently allowing more multi-touch detection on any combination of channels.

2.2.15 Wi-Fi Module

The wireless module is used to connect the therapal to services on the cloud. This adds the ability to monitor patients, collect data on how they use the robotic animal, and trigger remote actions on the fly. We will be using a variant of ESP8266, namely the ESP01, which is an SOC Wi-Fi module that also has a 1MB flash disk.

2.2.16 Software: Connected Services, Mobile/Web App

A REST API backend stack is required to consume, send, and delegate data between the device and app users. This backend stack should be able to receive data securely from the device and store it in a database. It should also be able to relay information to the app user.

A mobile app is required to demonstrate proof of concept and display device data. Spring Boot is selected as the backend stack for its easy deployment on the cloud, and scalability. AWS is selected for the cloud platform due to its free tier offerings. Apple iOS is selected as the target mobile environment to develop the app.

3. Design Verification

In the following subsections, we will verify the functionality of each individual component. As a whole, the device is able to collect sensor data correctly, and send this over to the Wi-Fi module. The Wi-Fi module then encrypts this data and sends it over to the server. The mobile app is able to fetch is data and initiate remote purr commands. Notifications, when distress is detected, are sent from the server and received on the mobile app. Figures 19 and 20 (in appendix B), verify data collection integration.

3.1 High-Frequency Inverter

We chose a coil with an inductance of 25 µH and a capacitor with capacitance of .47 µF resulting in a resonance frequency of 46.4 kHz. We purposefully reduced the switching frequency of the mosfet so that the power through the mosfet decreases. Operating at resonance maximizes efficiency, but through our tests, we found that, at 35 kHz, the secondary side coil could still provide the 5 V and 100 mA required by the battery charger. Operating at resonance would increase the temperature of the mosfet while not offering any useable increase in power on the secondary side. Figure 4 shows the voltage measured across the primary coil by the oscilloscope. The linear region at the peak shows the consequence of not operating at resonance.The RMS voltage was 13.4 V. We measured the RMS current being drawn while charging the battery to be .237 A by placing an ammeter in series with the coil.

Figure 4: Measured voltage across primary coil. The linear region occurs because the mosfet is not switching at the resonance frequency of the primary coil and C_{-2} capacitor.

3.2 Resonance Inductive Coils

The resonance inductive coils are primarily measured by their power transfer efficiency. This can be computed by dividing the power injected by the secondary coil by the power lost by the primary coil. Each of these powers can be computed by measuring the RMS voltage drop across them and the RMS current through them when the coils are 1 cm apart and are charging the battery. The RMS voltage across each coil was measured by attaching an oscilloscope to each terminal of the coil. Both figures 4 and 5 show the voltage across each coil as well as the RMS voltage. The current through each coil was measured by placing an ammeter in series with each coil (appendix table 4). The power consumed by the primary coil was calculated to be 3.74 W, while the power injected by the secondary coil was calculated to be 1.53 W. This resulted with a power transfer efficiency of about 41%.

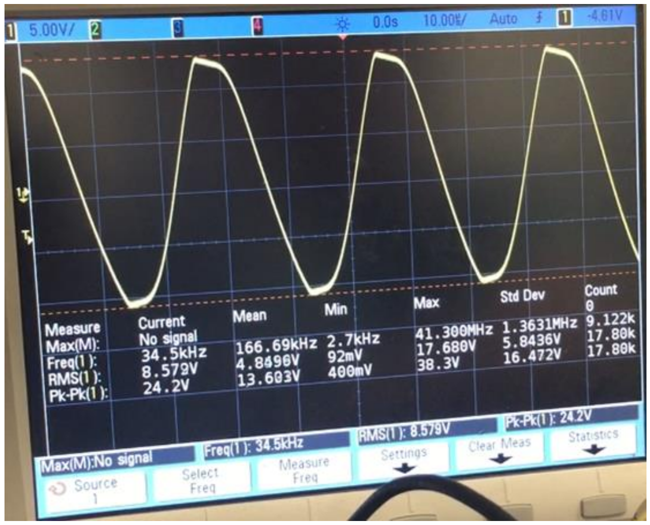

Figure 5: Voltage across the secondary coil.

3.3 Rectifier

The rectifier needed to convert the AC voltage induced on the secondary coil into a DC voltage with very little ripple voltage. Both the output and ripple voltage of the rectifier needed to be measured to ensure that the output would be sufficient to turn on the 5 V voltage regulator. By placing an oscilloscope across the input voltage of the 5 V voltage regulator and ground, we were able to measure the output voltage of the rectifier. We measured an output voltage of 10.72 V which is well inside the input voltage range of the 5 V voltage regulator (6 - 24 V). The ripple voltage was measured to be less than 70 mV. This ripple is sufficiently small to be stable for powering the voltage regulator.

3.4 Charging Circuit

The charging circuit charges the lithium ion battery with about 100 mA of current. It requires an input of 4.35 - 6.5 V and about 100 mA to charge the battery. We could qualitatively observe that it was charging the battery because the red LED turned on when the coils were close enough to transfer power. The LED would then turn off when the coils were separated. To quantitatively observe the battery charging, we used an ammeter to measure the current going into the battery while charging. When the battery was at 3.7 V, according to the datasheet (appendix figure 11), about 80 - 90 mA should be flowing into the battery. We measured 82.2 mA being used to charge the battery. Furthermore, when the battery was 4.2 V, the current being used to charge the battery was only 36 mA. This demonstrated the MAX1811 entering the constant voltage mode and leaving the constant current mode.

3.5 Lithium Ion Battery

The lithium ion battery did not require much verification. We needed to ensure that the battery we purchased could last 10 hours powering the robot. To test this we measured the current draw from the battery as it was powering the MPU and all the sensors. We measured this to be about 120 mA. We initially bought a 6 Ahr battery so that it would not need to be constantly charged during out testing, but we could have actually used a 1200 mAhr battery. If we were to use a 1200 mAhr battery, it would take the MAX1811 about 13.5 hours (equation 2) to charge the battery from zero percent capacity to completely charged.

3.6 Voltage Booster/Regulator

Since the 5 V voltage booster and the 3.3 V voltage booster were purchased, the only testing that needed to be done was to confirm that they produced a constant voltage at their rating. This was done by attaching them to the lithium ion battery and measuring the open circuit voltage. Comparing the measured voltages to the expected values confirmed that they were working correctly.

3.7 Microcontroller

The ATmega328P needed to provide correct functionality of its advertised features to insure that the prototype would behave as intended. Mainly, the I2c communication bus needed to properly interface with 3 devices. This was tested by wiring said devices and using an I2c scanning program to probe for the devices.

3.8 Accelerometer and Gyroscope

The MPU6050 needed to accurately measure acceleration data within a 2 g regime to be able to detect thrashing and throwing. This was tested by measuring the z axis acceleration while the sensor was idle. Data showed approximately 1 g in the -z direction confirming that the device could accurately measure acceleration due to gravity.

3.9 Microphone

The microphone system needed to accurately measure dB readings coming from the patient to assess loud noises such as screaming [6] as well as record human speech. Volume readings were tested by taking voltage readings from the microphone and comparing them to rated dB readings from the datasheet. Verification of speech recording was more qualitative. Samples were taken and replayed showing adequate quality in the recordings.

3.10 Speaker

Like the speech recordings, audio playback was also largely qualitative. We were able to confirm the functionality by listening to the device make purring noises that were adequately realistic between 5 to 10 ft.

3.11 Amplifier

The amplifier in the final prototype was tuned for a gain of 200. This was tested by measuring voltages at the input and output of the device and calculating the approximate gain across the chip. Equation 3 shows how gain was calculated.

3.12 Temperature Sensor

The temperature sensor needed to continue stable operation up to 70 degrees celsius. This was tested by first taking measurements at room temperature and then with a heat gun set to 100 degrees celsius pointed at the device. In both cases, the device accurately returned the referenced temperature.

3.13 Capacitive Touch Circuit

The capacitive touch sensor was also verified qualitatively. Console output from the controller accurately returned the channels being touched during testing.

3.14 Wi-Fi Module

The Wi-Fi module is programmed with a WiFiManager library, allowing it to broadcast its own hotspot network. After connecting to the hotspot through their phone or laptop, users can easily enter the SSID and password of a local Wi-Fi network through the interface shown in Figure 6. Once entered, the Wi-Fi module will automatically connect to that network. This ensures that users or caregivers can easily connect the device to the internet, no matter where they are.

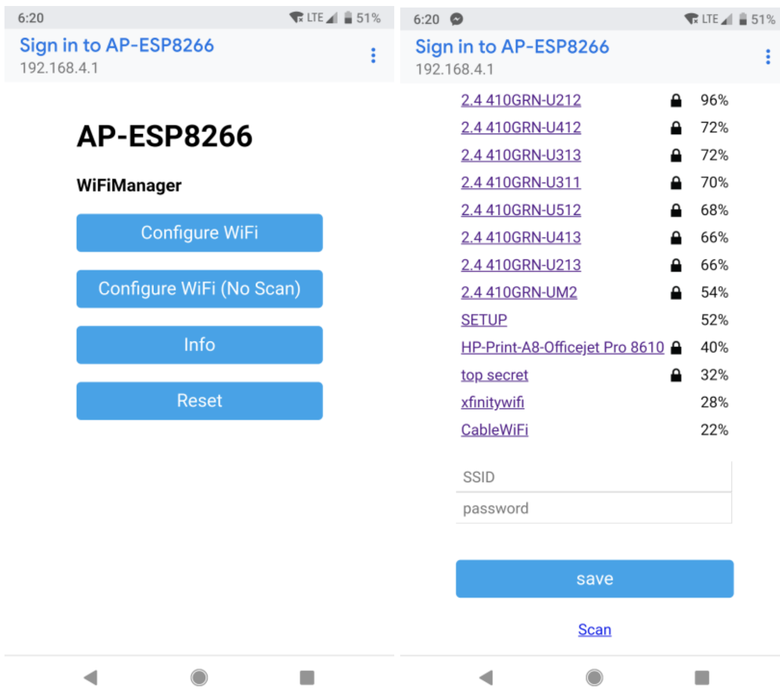

Figure 6: WiFi Module Connecting to the internet

3.15 Software: Connected Services, Mobile/Web App

An entire software stack has been built, as shown in Figure 7. Backend services are hosted on the cloud server(AWS) and can be accessed from anywhere. The device posts encrypted data to the data receiver endpoint which decrypts it and saves it to a JPA database. The device also fetches remote commands from the device purr request retrieval endpoint. When the patient is in distress (manic episode or panic attack) and screams loudly or throws the device, the distress flag is set on the data sent to the server.

A native iOS app has been built to demonstrate proof of concept as seen in Figure 7. The target audience for this app are caregivers and loved ones. Through the app, they can view therapal device details which are fetched from the server, and send remote purr requests. They will also receive push notifications when the distress flag is set for a device.

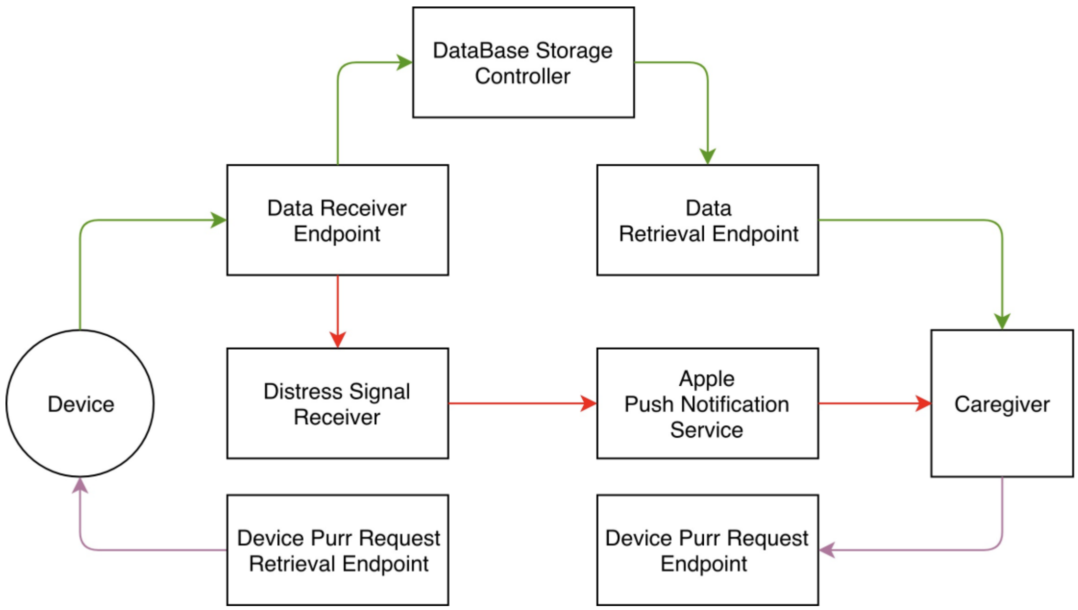

Figure 7: Software Stack Diagram

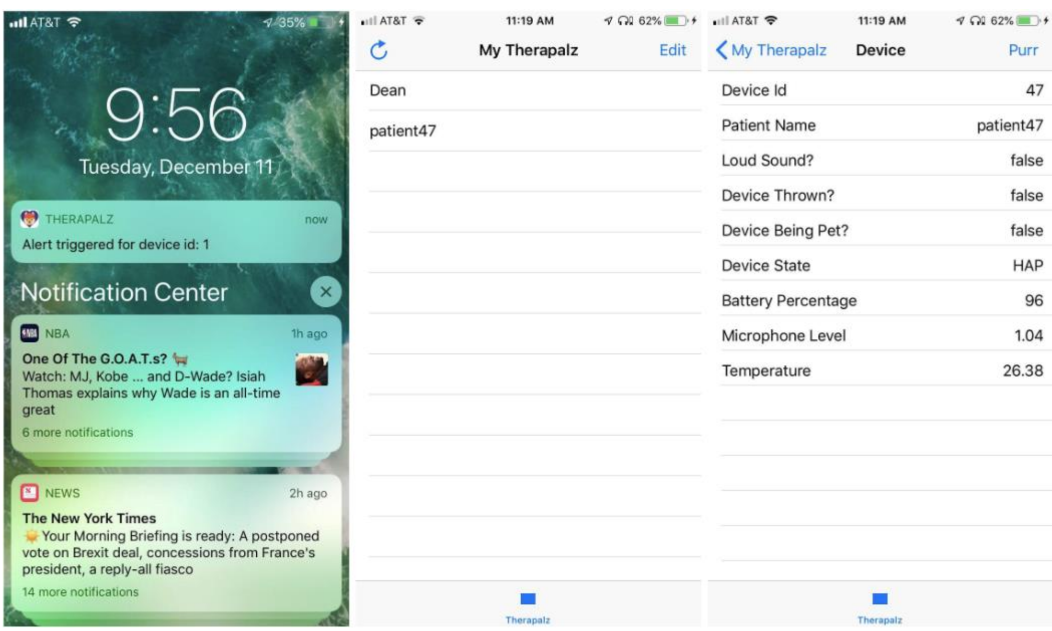

Figure 8: Mobile App Interface

4. Costs

4.1 Parts

Description	Quantity	Backup Quantity	Part Number	Manufacturer	Vendor	Cost/unit	Total Cost
Arduino Mega	1	0	Mega 2560 R3	SunFounder	Amazon	$14.99	$14.99
Electret Microphone Amplifier	1	1	MAX4466	Adafruit	Amazon	$8.99	$17.98
SparkFun ESP8266 Thing	1	0	N/A	SparkFun	Amazon	$15.75	$15.75
Capacitor (22 uF +- 10%)	2	2	490-17935-ND	Murata Electronics North America	Digikey	$1.40	$5.60
Capacitor (.47 uF +- 10%)	2	2	445-2643-ND	TDK Corporation	Digikey	$0.64	$2.56
Capacitor (.15 uF +- 20%)	1	1	399-4343-ND	KEMET	Digikey	$0.36	$0.72
Capacitor (4.7 nF +- 10%)	2	2	445-5250-ND	TDK Corporation	Digikey	$0.29	$1.16
Capacitor (6.8 uF +- 20%)	1	1	565-4733-1-ND	United Chemi-Con	Digikey	$2.47	$4.94
Resistor (22 kOhm +- 1%)	1	1	BC3259CT-ND	Vishay BC Components	Digikey	$0.24	$0.48
Resistor (10 kOhm +- 5%)	1	1	10KQBK-ND	Yageo	Digikey	$0.10	$0.20
Diode (.7 V FW voltage)	4	2	641-1411-1-ND	Comchip Technology	Digikey	$0.54	$3.24
Capactive Touch Sensor Controller	1	1	CAP1188-1-CP-TR	Microchip Technology	Digikey	$1.15	$2.30
DAC	1	1	MCP4921	Microchip Technology	Digikey	$2.03	$4.06
Amplifier	1	1	LM386N-3	Texas Instruments	Digikey	$1.01	$2.02
Speaker	1	1	CLS0231-L152	CUI Inc	Digikey	$4.64	$9.28
2.2 X 6.5 Inch Breadboard	1	0	103-1100	N/A	ECE Supply Center	$14.07	$14.07
Wireless Charging Coils (47 uH +- 10%)	2	0	710-760308101303	Wurth Electronics	Mouser	$12.43	$24.86

Inductor (1.6 uH +- 5%)	1	1	807-1782R-25JTR	API Delevan	Mouser	$2.44	$4.88
3.5 mm audio jack	1	1	490-MJ-3502N	CUI	Mouser	$1.24	$2.48
MOSFET 150V Vds 20V Vgs TO-220	1	1	78-SUP80090E-GE3	Vishay / Siliconix	Mouser	$3.09	$6.18
5 V voltage regulator	2	1	926-LM2940T-5.0/NOPB	Texas Instruments	Mouser	$1.55	$4.65
Board Mount Temperature Sensor	1	1	MCP9808-E/MS	Microchip Technology	Mouser	$1.17	$2.34
General Resistors TBD	1	0	N/A	N/A	N/A	$12.00	$12.00
General Capacitors TBD	1	0	N/A	N/A	N/A	$12.00	$12.00
Pololu 3.3V, 500mA Step-Down Voltage Regulator D24V5F3	1	1	D24V5F3	Pololu	Pololu	$3.95	$7.90
Pololu 5V Step-Up Voltage Regulator U3V12F5	2	1	U3V12F5	Pololu	Pololu/Amazon	$3.95	$11.85
Logic Level Converter - Bi-Directional	1	1	BOB-12009 ROHS	SparkFun	SparkFun	$2.95	$5.90
Lithium Ion Battery - 6Ah	1	0	N/A	SparkFun	SparkFun	$29.95	$29.95
Battery Babysitter - LiPo Battery Manager	1	0	PRT-13777	SparkFun	SparkFun	$19.95	$19.95
PICAXE 08M2 Microcontroller (8 pin)	1	0	N/A	SparkFun	SparkFun	$2.95	$2.95
Triple Axis Accelerometer and Gyro Breakout	1	0	MPU-6050 / SEN-11028	SparkFun	SparkFun	$29.95	$29.95
2.5mm DC Power Jack	1	0	490-PJ-002BH	CUI	Mouser	0.75	$0.75
12v 1A Power Adapter	1	0	675-TE10B1203F02	Ault/SL Power	Mouser	14.12	$14.12
Battery Management IC	1	1	700-MAX1811ESA	Maxim Integrated	Mouser	4.49	$8.98

	$268.07

Table 1: Parts List Table

4.2 Labor

Name	**Hourly Rate**	**Hours**	**Total**	**Total x 2.5**
Brian Wilens	$40.00	300	$12,000.00	$30,000.00
Divij Nagpaul	$40.00	300	$12,000.00	$30,000.00
James Brown	$40.00	300	$12,000.00	$30,000.00
Labor Total				**$90,000.00**

Table 2: Cost of Labor Table

4.3 Total Cost

As shown in Tables 1 and 2 above, the total cost of development for this prototype is $90,000.00 + $268.07 = $90,283.97. Assuming pick and place manufacturing, the cost per additional prototype would approximately be $180.

5. Conclusion

In summation, the new Therapalz device successfully executes the functionality outlined in the objective.

5.1 Accomplishments

We successfully integrated all our sensors with our microprocessor. The vibrational motor and speaker react to touch and remote phone command. Data is encrypted and successfully posted to the server. We can wirelessly charge the battery. The phone app is operational and can fetch data and send remote command. We can also record patients, and save that data to a SD card.

5.2 Ethical Considerations

The biggest ethical concern we have correlates to guideline #1 of the IEEE code of ethics: health and safety. Transferring power, especially over the wireless coils, increases the risk of heating up the system. The therapal is covered in fur and has very little air flow, therefore overheating and possibly catching on fire is a concern. This risk is reduced 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 type of battery used and charging. A Lithium ion battery is an ideal choice for the device since it is able to charge and discharge many times, provide stable voltage, and last for long periods of times. The Max1811 is an exemplary IC for safe charging: it can monitor and control the charge of lithium ion batteries.

Another concern correlates to guideline #5 of the IEEE code of ethics: our robot is recording patient data, in terms of motion and speech, to alert the caregiver. This patient data cannot be stolen. To mitigate for this, the device encrypts the payload, using AES CBC 128-bit encryption, before sending it to the server. This ensures that no man-in-the middle attack or eavesdropping can occur.

5.3 Shortcomings

The initial design of the system did not account for necessary circuit protections resulting in critical failure of our PCB. The final prototype was thus integrated using development boards. Furthermore, the Wi-Fi module we selected did not have dedicated security circuitry. This posed a problem since patient data sent to the server needs to be secure. The short fix for now was implementing security using AES, which is symmetric. However, if this key is ever obtained by a malicious agent or accidentally released, it will undermine the security of the patient data.

5.4 Uncertainties

While all intended functionality was accounted for however, soldering QFN packages proved to be a large obstacle which rendered our initial controller design useless. Another issue during integration was that we were running out of memory in the Atmega. Ultimately, the final prototype was completed by using development boards and an Arduino Mega (which has a lot more memory).

5.5 Future work

Going forward, the product will use a different IC for the charging circuitry that supports a 250 mA charging mode, thus cutting charging time down by half. The next prototype version will have an upgraded 32 bit ARM processor chip with in-built Wi-Fi capabilities. This will avoid software interrupt problems and include HTTPS support. It will also feature an improved audio circuitry that supports clearer 16-bit and 24-bit audio files. We aim to improve the iOS app aesthetics and implement an OAuth2 login and corresponding provider services to further strengthen security and adhere to industry standard. Going forward, we intend on utilizing the recording functionality of the device to start a creating a large data set. Our hope is to be able to build a deep learning algorithm that can detect when a patient is about to have a manic episode, help calm them down instantly, and notify caregivers.

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Appendix A

Requirement	Verification	Verification Status
2.1 High Frequency Oscillator $V_{AC,RMS}$ = 12[v] + 15% $I_{AC,RMS}$ < 1[A] f = 35kHz ± 1%	Verification Process: (a) Connect 12[V] 1[A] power supply to inverter. (b) Apply a dummy load to the primary coil by placing a secondary coil that is in parallel with a capacitor and 10kΩ resistor about 1cm away. (c) Use an oscilloscope to measure the RMS voltage across the primary coil and frequency of the voltage through it. (d) Place an ammeter in series with the coil to measure the RMS current through the coil.	Verified
2.2 Resonance Inductive Coils Power transfer efficiency > 40% $V_{S,RMS}$ > 7.65[v]	Verification Process: (a) Connect 12[V] 1[A] power supply to inverter. (b) Place the secondary coil that is in parallel with a capacitor and a 10kΩ resistor about 1cm away. (c) Measure the RMS voltage and current through each coil on the primary and secondary side. (d) [illegible] = Power transfer efficiency	Verified
2.3 Rectifier and 5v Voltage Regulator 6 ≤ V_{OUT} ≤ 24 V_{RIPPLE} < .05V_{OUT} I_{OUT} = 100 ± 10% [mA]	Verification Process: (a) Connect a function generator that outputs a sine wave with frequency of 35kHz and V_{RMS} that is greater than 7.65v to the input. (b) Connect a 50Ω resistor to the output of the voltage regulator. (c) Using an oscilloscope to measure the voltage and ripple voltage	Verified

	across the output to the voltage regulator. (d) Connect an ammeter in series with the output of the voltage regulator and the resistor.	
2.4 Charging Circuit $4.35 \leq V_{OUT} \leq 6$ I_{IN} = 100 ± 10% [mA] I_{OUT} = 100 - 10% [mA]	Verification Process: (a) Connect 5v power supply and limit the current to 110[mA]. (b) Measure the input voltage into the Max1811 IC. (c) Place an ammeter in series between the voltage regulator and the input of the Max1811 IC. (d) Place and ammeter in series between the output of the Max1811 IC and the input of the battery.	Verified
2.5 Lithium Ion Battery $I_{OUT} \leq 600$ [mA] to provide at least 10 hours on power	Verification Process (a) Plug battery into circuit with ammeter in series to measure current.	Verified
2.6 Voltage Booster/Regulator Booster: Provide a constant 5(±.1)[V] and at least 100[mA] for the sensors and MPU Regulator: Provide a constant 3.3(±.1)[V] and at least 215[mA] for the Wi-Fi module and additional sensors.	Verification Process (a) These don't need to be verified since they'd work according to their datasheet.	Verified
2.7 Microcontroller Provide Analog/Digital data processing for sensors and output devices. Support 4 Analog devices using I2C addressing. Use a clock frequency of 20 MHz.	Verification Process (a) Use a basic LED debug circuit connected to reserved digital ports and a blink program to test digital functionality. (b) Use function generator connected to Analog pins and check that digital conversion is accurate using step function chart. (c) Use an I2C scanner program to	Verified

	ping multiple devices over I2C bus and confirm detection of all devices. (d) Use a basic digital pulse program on one digital port and read the pulse on an Oscope to determine clock frequency.	
2.8 Accelerometer Must be able to detect at least 1g of acceleration. Must have 3 axis detection.	(a) Place accelerometer on each of its axis on the table. (b) Measure the acceleration and confirm that it is $9.8\frac{m}{s^2} \pm 1\%$	Verified
2.9 Gyroscope Must be able to detect rotations up to 360 degrees / second.	(a) Place gyroscope on swivel chair and make one rotation in <1s (b) Confirm that data read shows that gyroscope has rotated 360 degrees$\pm 1\%$(to account for human error in stopping the chair)	Verified
2.10 Microphone Must have a sensitivity of at least 20 dB $\pm 1\%$ and a max frequency response of 20 KHz. Operates at a maximum of 0.5 mA.	Qualitative Tests (a) Place microphone on table and whisper at a distance of 3ft away from it. (b) Play a 20kHz noise from laptop near the microphone. (c) Observe if audio is recorded. (d) Place ammeter in series with microphone to measure current drawn Quantitative Tests (a) Place microphone and sound meter 3ft away from a speaker. (b) Play a 20dB sound on speaker. (c) Compare readings from sound meter and microphone. (d) Should be accurate within 1% of sound meter.	Verified
2.11 Speaker Must have comparable volume to a vacuum cleaner (about 70 dB.) Has an operating power of 1 Watt.	Qualitative Test: (a) Set volume of speaker to >70dB. (b) While speaker is playing a noise, measure the voltage and current to calculate the power. (c) Noise from speaker should sound about as loud as a vacuum cleaner. Quantitative Test (a) Set volume of speaker to >70dB.	Verified

	(b) While speaker is playing a noise, place sound meter next to speaker to confirm that the sound pressure level is larger than 70dB	
2.12 DAC/Amplifer DAC: Must convert digital audio to analog output. Amplifier: Speaker amplifier must provide up to 2 watts to speaker.	(a) Examine digital waveforms alongside analog outputs and observe if analog conversion is consistent. (b) Measure power of output signals from dac on amplifier using Oscope.	Verified
2.13 Temperature Sensor Must be accurate and function at temperatures above 100 degrees Celcius.	(a) Use a heat gun to bring sensor to 100 degrees celsius and take readings onto a serial console. Check that they are consistent.	Verified
2.14 Capacitive Touch Circuit Supplies signal to controller when any sensor detects a capacitive change of approximately 20 femto Farads (a human touch).	(a) Attach wires to capacitive touch circuit. (b) Observe if the LED turns on when the corresponding wire is touched.	Verified
2.15 WiFi Module	Verification Process a. Use oscilloscope to ensure that V_in is 3.3V, and GND is 0V b. Connect microcontroller to computer and run initialization script on Wifi Module c. Open up serializer and look at responses for nearby WiFi access points d. Connect to WiFi access point with credentials	Verified
2.16 Software	Verification Process a. Connect to WiFi access point as shown on step 2.15. b. Run connect script to connect to MicroServices. c. Send test diagnostic to server d. Try to connect to server on computer. Check logs to confirm test diagnostic was received e. Go to phone/computer. Log into account corresponding to device. f. Confirm test diagnostic received	Verified

	g. Send “sound” command to device h. Confirm server receives command i. Confirm device receives command, device makes “sound”	

Table 3: Requirements and Verification Table

Appendix B

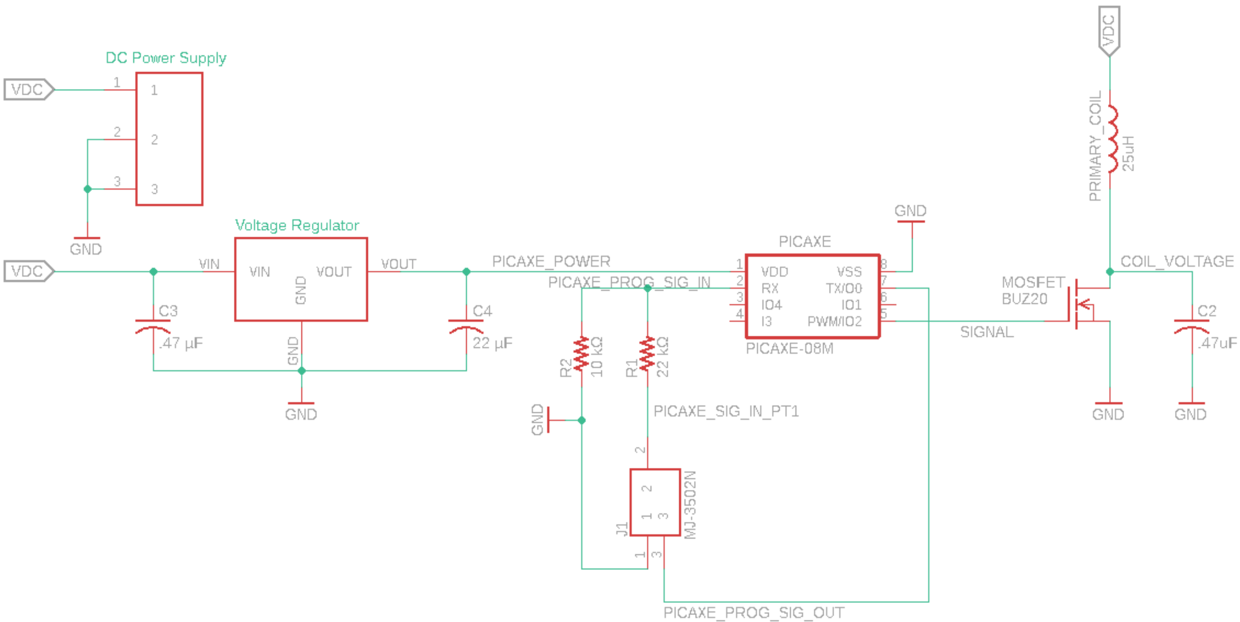

Figure 9: Primary side circuit. The PICAXE microcontroller produces the square wave to turn on and off the mosfet for the high frequency inverter.

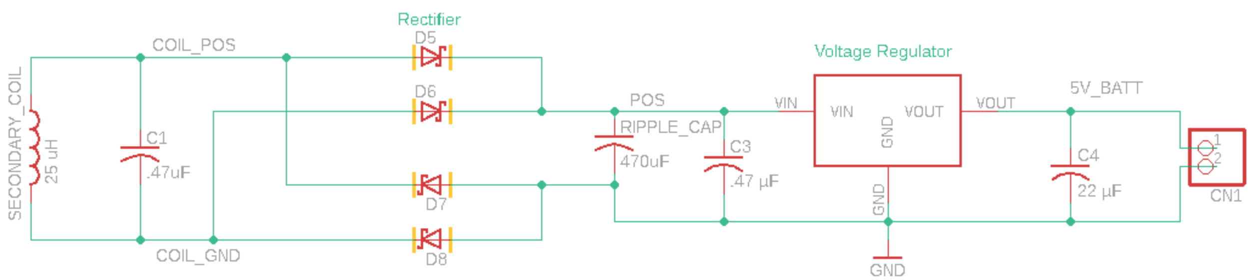

Figure 10: Secondary side circuit: Contains the secondary coil

Equation 1:

$$6 \leq .637(V_{Max,AC} - 1.4)$$

$$V_{Max,AC} \geq 10.819\ V$$

$$V_{RMS} \geq 7.65\ V$$

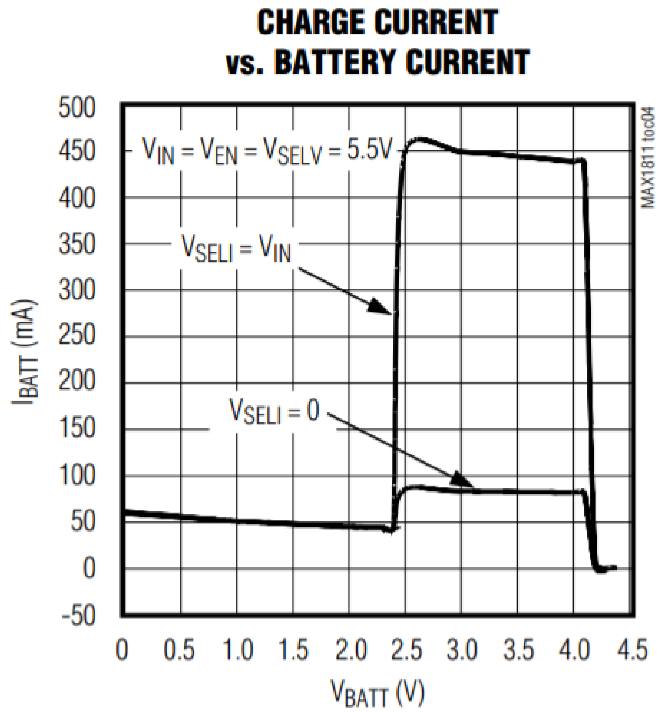

Figure 11:

Equation 2: $$\frac{1200\ mAhr}{89\ mA} = 13.49\ hr$$

Object Being Measured	Measurement
$V_{Primary\ Coil,\ RMS}$	13.7 V
$I_{Primary\ Coil,\ RMS}$	.273 A
$V_{Secondary\ Coil,\ RMS}$	8.5 V
$I_{Secondary\ Coil,\ RMS}$	.180 A
f	34.5 kHz
$V_{Rect,\ OUT}$	10.72 V
V_{Ripple}	70 mV

Table 4: Measurements for wireless charging system requirements and verification.

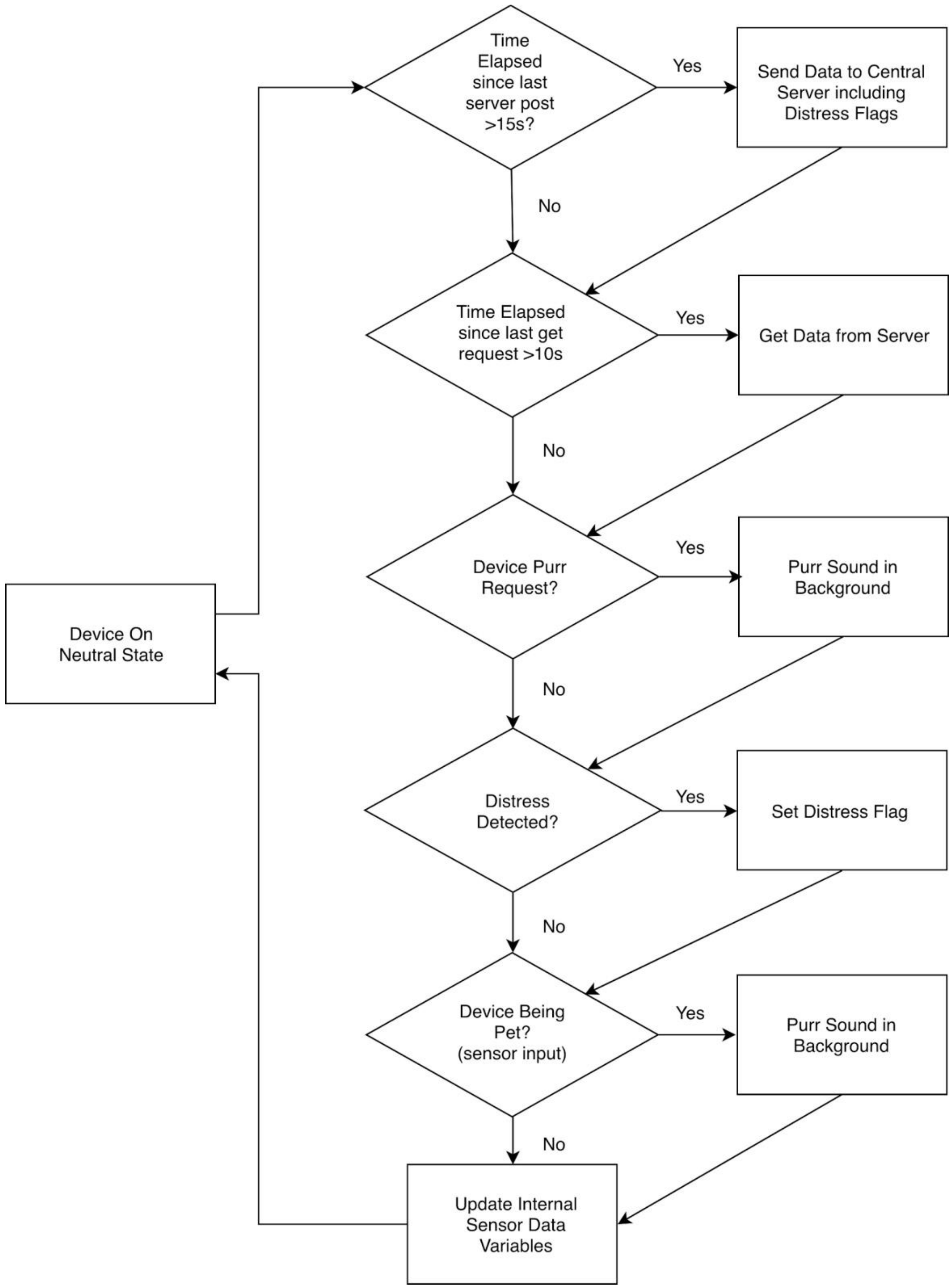

Figure 12: Control flow

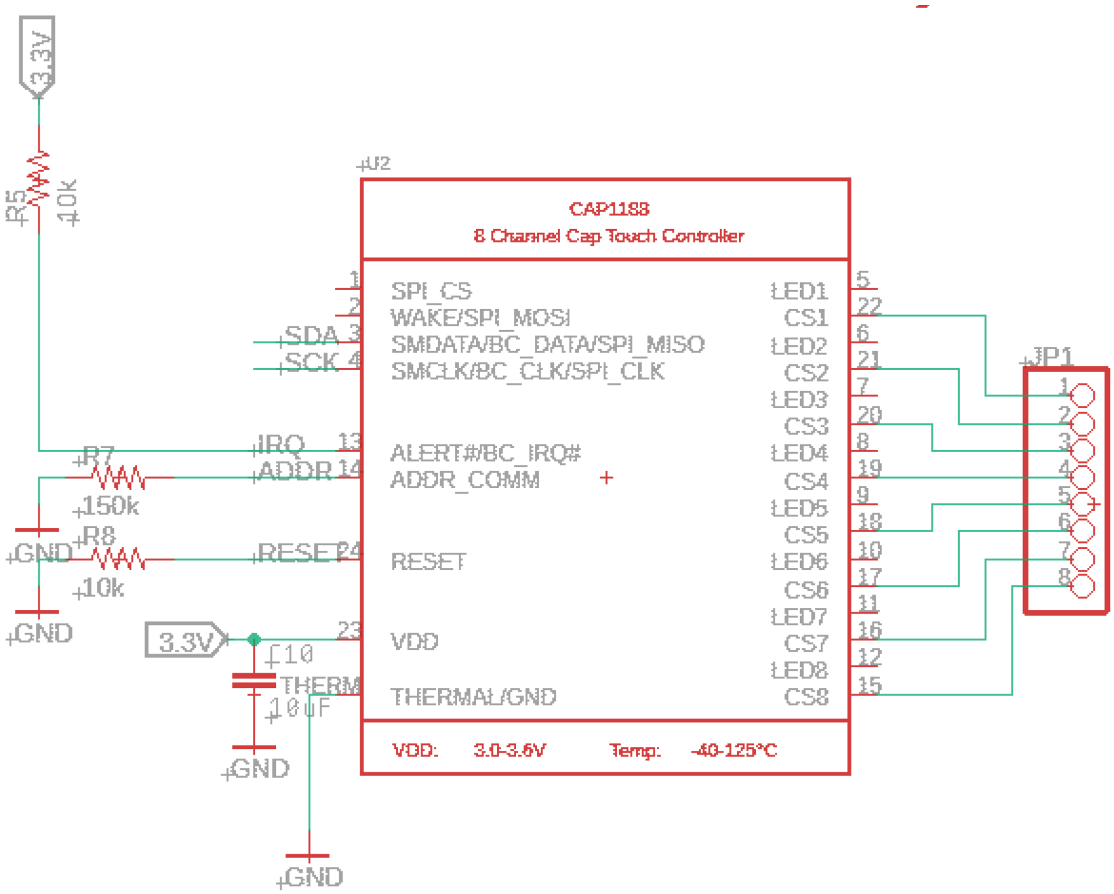

Figure 13: CAP1188 Circuit

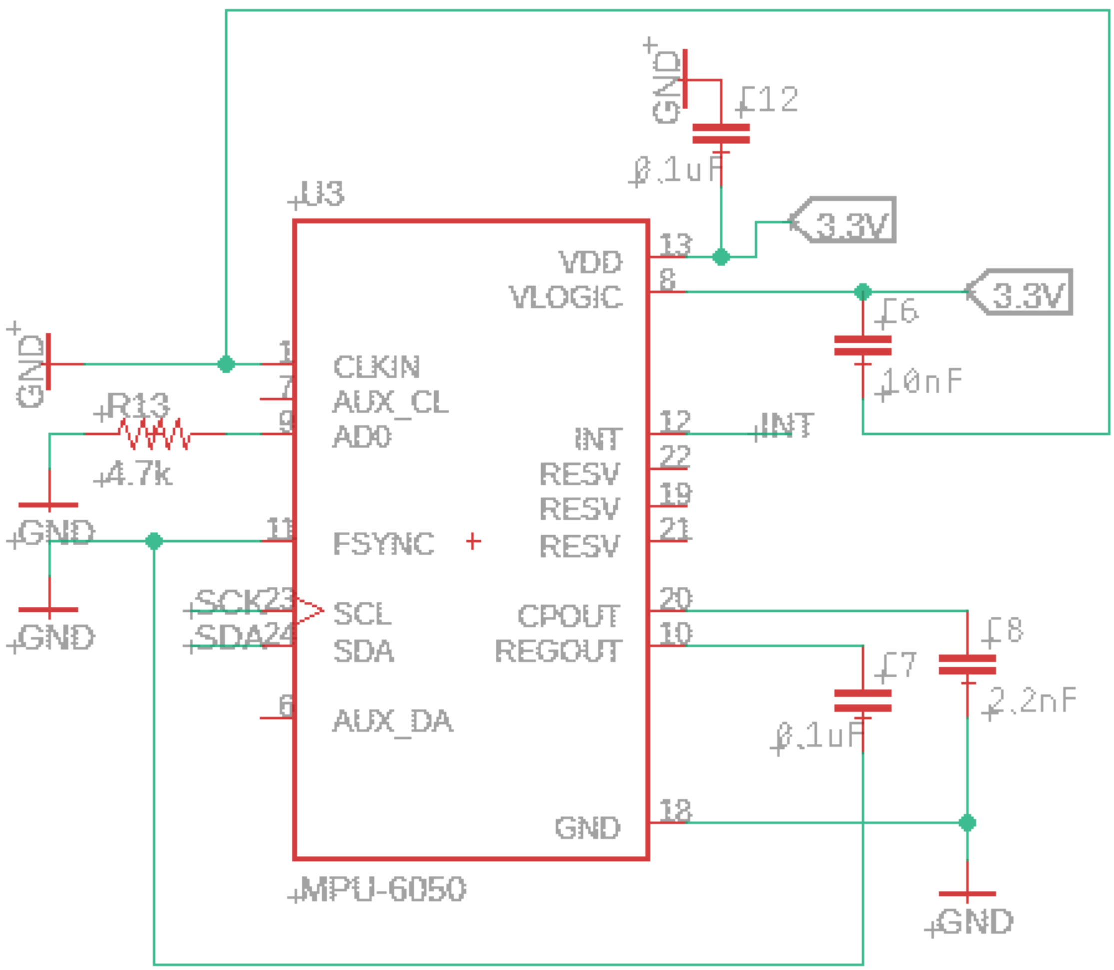

Figure 14: MPU6050 circuit

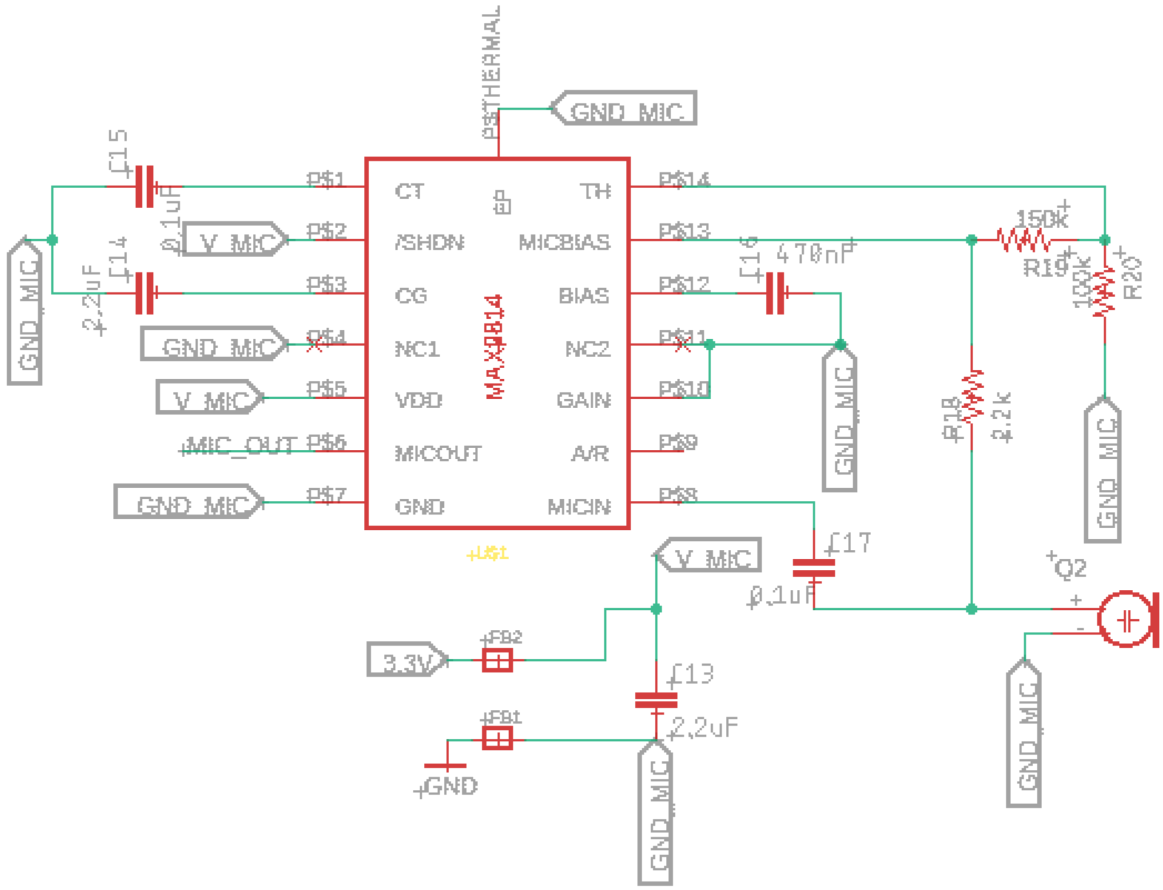

Figure 15: Microphone circuit including preamplifier and electret microphone

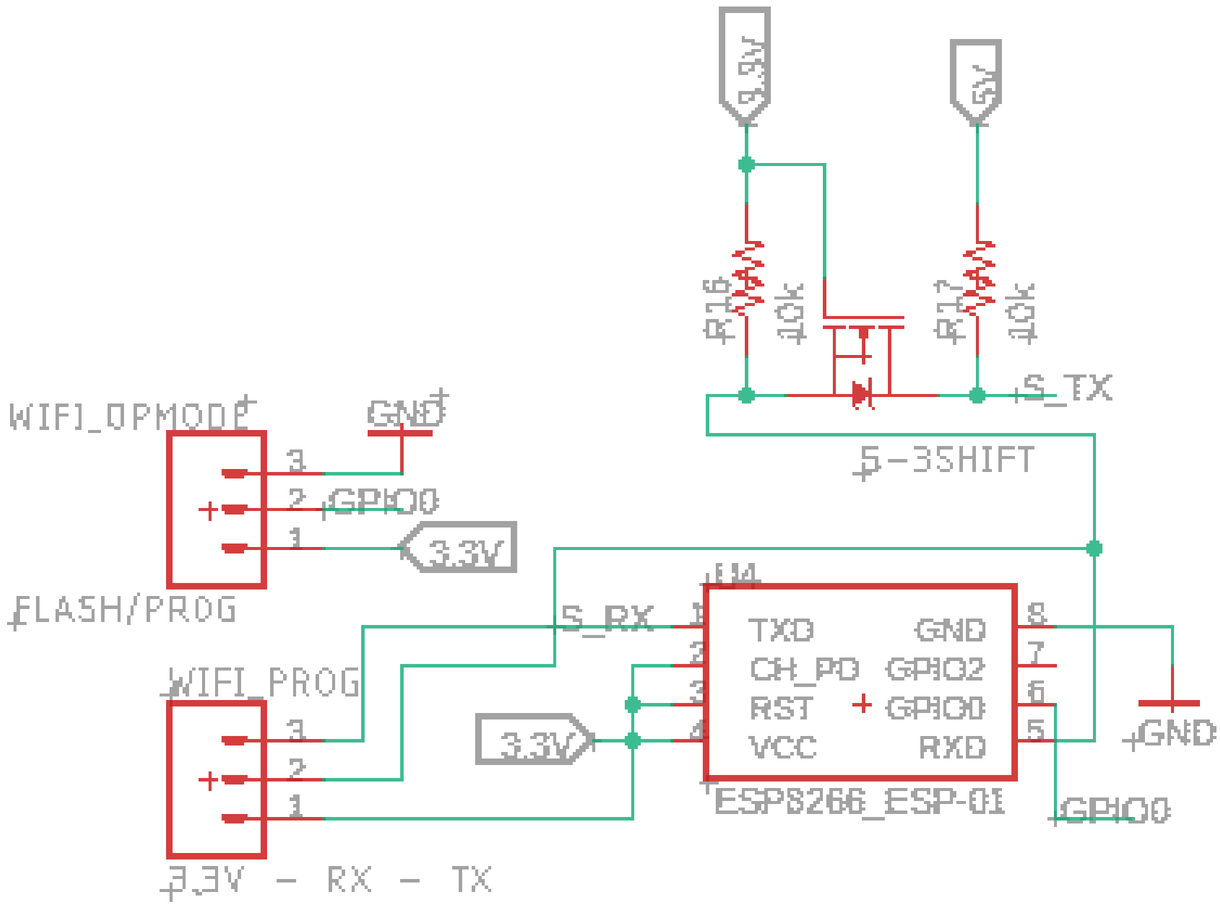

Figure 16: ESP01 and level shifting circuit

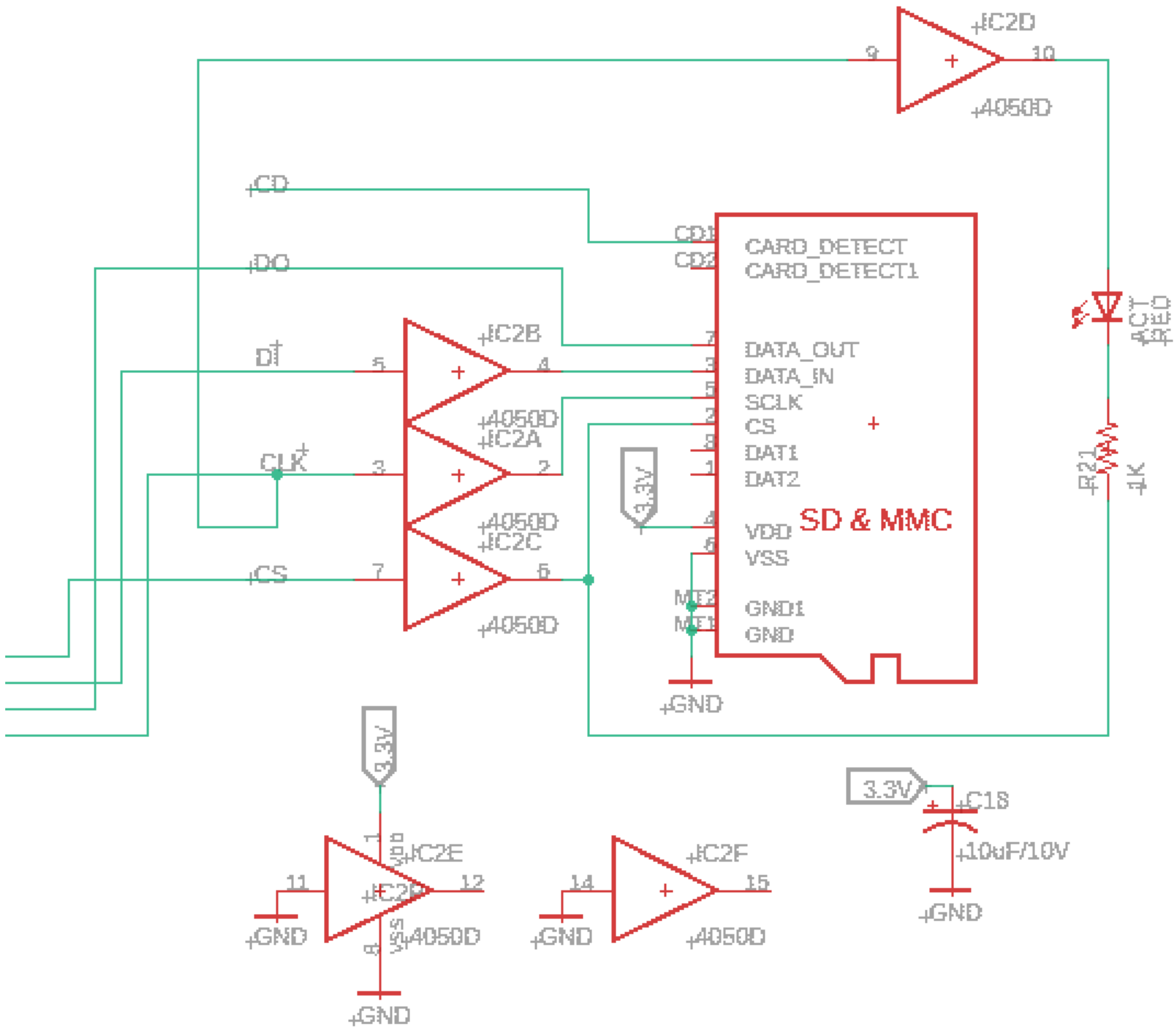

Figure 17: SD module circuit. Added to expand storage of prototype.

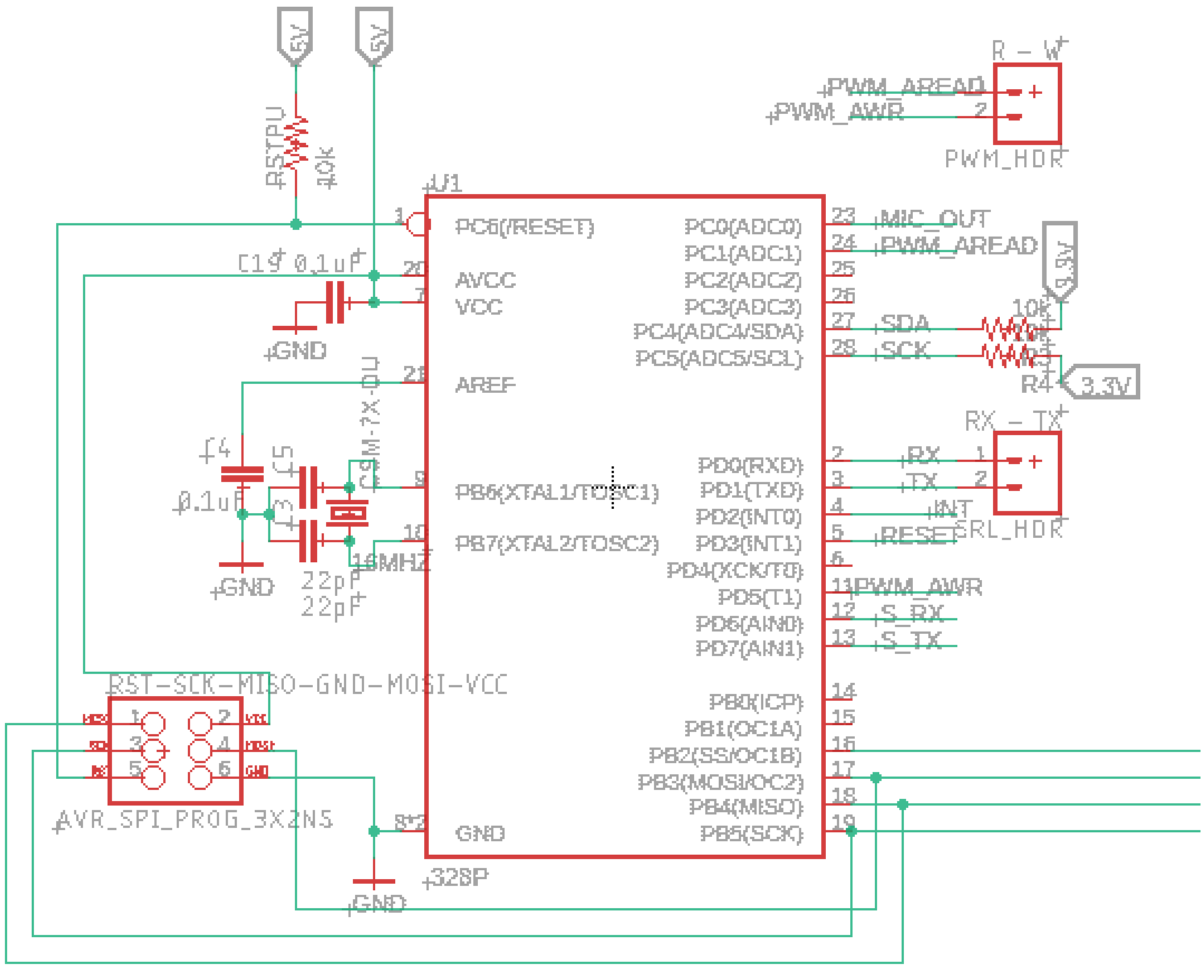

Figure 18: ATmega328 circuit

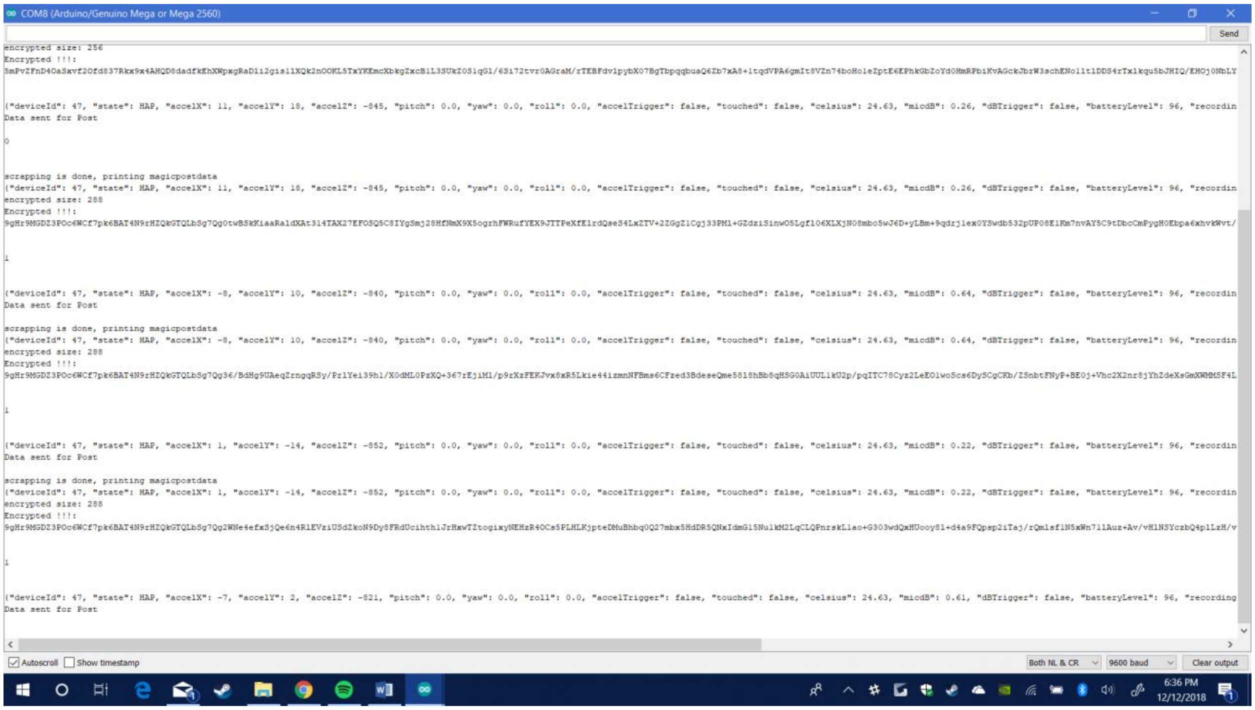

Figure 19: Console output showing post requests and encryption. The single integer designates a variable taken from successful get requests.

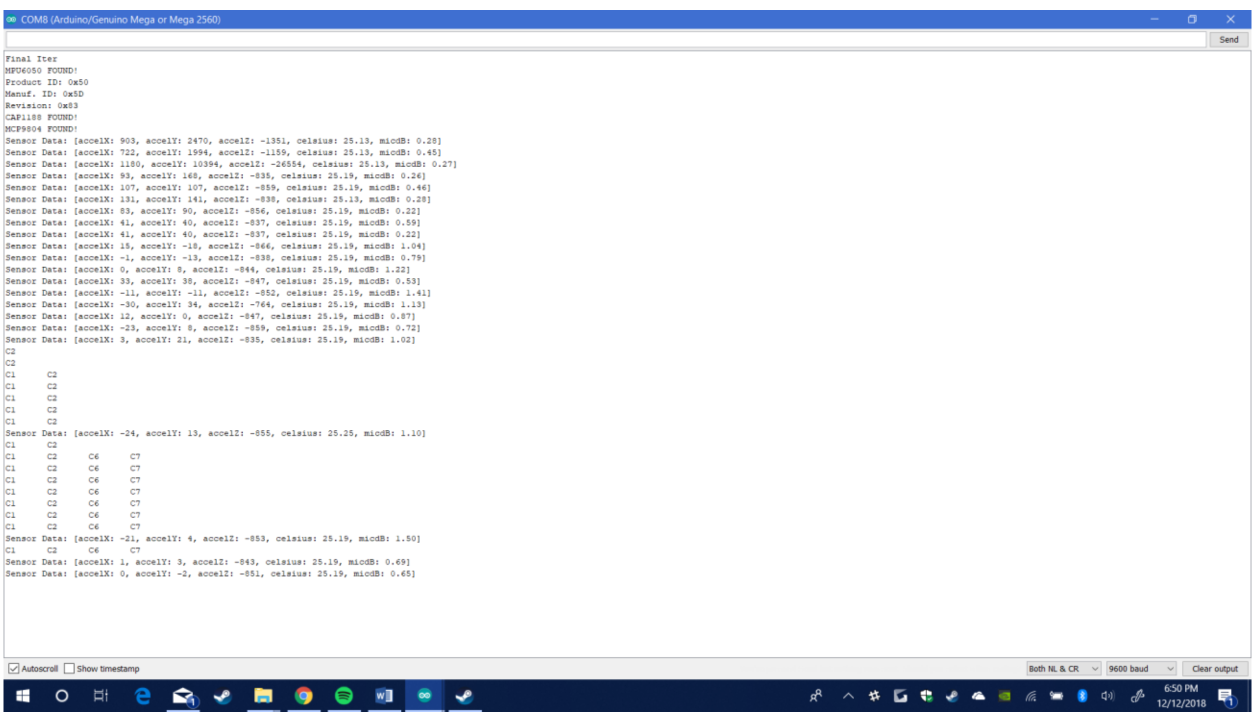

Figure 20: Console output showing sensor data.

Equation 3: $$gain - db \ = \ 20log(\frac{V_{out}}{V_{in}})\ dB$$