Improving Pet Ownership with the PetAid Harness

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***Abstract* — The PetAid Harness aims to log a variety of biometric data for a household pet. It then provides the pet owner with an easy way to access and act on this biometric information. Using Wi-Fi capabilities, and ThingSpeak integration the PetAid harness will constantly update the information available to the owner remotely and without requiring a deep background in electronics.**

***Index Terms* — Integrated Circuits, Linear Circuits, Microprocessors, Transmitters, Power Amplifiers.**

I. Introduction

The 2019-2020 National Pet Owners Survey conducted by the American Pet Products Association (APPA) states that about 67% of all U.S. households own a pet, which denotes a very large demand for adequate pet healthcare. According to this same survey, the average American household will spend $426 on surgical vet visits and $212 on routine vet checkups annually, totaling $642 of yearly vet fees [1]. The fact that an overwhelming majority of vet fees went towards surgical procedures was the initial motivation for our project. Often these surgical procedures are invasive and preventable if the health issue is detected early on, or the pet is put through a system of preventative treatments before-hand. Problems arise, however, when owners are not aware of the early stages of pet health issues, or when they are aware but cannot detect them. Pet owners are usually not as well versed as vets at detecting signs of health issues, and the pets may not be displaying these signs as obviously or they may be misconstrued as symptoms of anxiety during the rare vet checkup. This leads to health issues developing to a point of surgical intervention and a big spike in vet fees for the pet owner. Our project aims to provide a product that both lowers annual vet fees for the pet owner and improves the quality of life of the pet by creating a log of biometric data both the pet owner and vet can analyze. We also believe that by saving the pet owner money, more of that money can be dedicated to the quality of life of the household pet. To do this our product will be composed of multiple hardware elements. The PetAid Harness will include a temperature sensor, a heartbeat sensor, an accelerometer, a WI-FI module, and a microcontroller. These components will be soldered onto a PCB and attached to a regular dog harness.

II. Basic Theory

A. Heartbeat Sensor

A basic heart rate sensor includes a light emitting diode and a detector. The detector can either be a light detecting resistor or photodiode, and when the tissue of the body, for example a finger is struck with the light, it is mirrored or reflected. The light is then received by the detector and based on the reflection, the detector will transmit an electrical signal that is proportional to the heart rate, which is exactly what we want for the PetAid harness. This basic concept will be used to apply a heart rate sensor in the PetAid harness. Today, the optical heart rate monitors are the most common pulse sensors in wearables. So, the group decided to go with an optical heart rate monitor. By choosing the optical heart rate monitor, we will need to consider the placement of the device on the owner's pet. It would need to be placed on the body where there is no or very little dog fur to obtain the best results from the sensor.

B. Temperature Sensor

Thermometers are widely used to sense the temperature in just about any environment. They all work in a similar way but have small different features. Typical Thermometer devices are Thermocouples (TCs) or Resistance Temperature Detectors (RTDs). TCs work by using two metal wires to make a voltage relative to the temperature present in the junction between them. There are different special kinds of TCs, which can integrate different metals to measure temperature ranges and produce specialized calibrations. An RTD sensor works by measuring temperatures based on the resistance changes in a metal resistor side. The most used RTDs are called PT100 sensors, which use platinum and possess a resistance of 100 ohms at 0 °C. Besides the RTDs and TCs, there are other options such as integrated circuit temperature sensors, which can be digital ICs and analog ICs. An integrated temperature sensor is a two terminal integrated circuit temperature transducer that generates an output current proportional to absolute temperature. For the case of digital ICs, digital IC sensors provide an output that has been computed through an integrated A-D converter and is available for input into digital control and monitor systems. The IC sensor does not need any external circuitry done and is much cheaper than RTDs. The three biggest advantages for IC sensors are they are the most linear, have the highest output, and are inexpensive.

C. Accelerometer

The accelerometer module will be one of the main components for the PetAid harness. An accelerometer module is a sensor used to sense both static and dynamic acceleration. An example of static acceleration is gravity and for dynamic acceleration is sudden starts/stops. One of the most used applications for accelerometers is tilt-sensing. That is, because accelerometers are affected by the acceleration of earth's gravity and the accelerometer module can inform you how it is being oriented with respect to the earth's surface. In addition, an accelerometer can be used to sense if a device is in a state of free fall. For this project the accelerometer is implemented to monitor the different levels of activity in dogs in terms of speed of movement. Because accelerometers can detect changes in specific activities or behaviors, these devices can help indicate early signs of possible health problems for the dog. Some characteristics our group considered when searching for an accelerometer were Range, Interface, Number of axes measured, and Power usage. We also took in consideration the size, cost, and compatibility with our choice of microcontroller for this project.

D. Wi-Fi Module

Wi-Fi will play an important part in the Pet Aid harness as it will provide wireless communication. Wi-Fi provides high- speed internet access for transmitting logged biometric data. Based on the information obtained, the owner will be able to make clear observations whether his/her pet is healthy or not and can make better decisions with his/her pet. Also, the Veterinarian can use the information in the database either through an application or website to help the owner understand what is wrong with his/her pet. For the PetAid harness Wi-Fi module, there are a few important key factors to consider. Those key factors include: Bandwidth, Frequency, Protocol, Voltage Supply, Current receiving, Current Transmitting, Frequency range, Dimension, Operating temperature range, and Cost.

II. System Components

A. Microcontrollers

Our microcontroller is the ATmega328P from the Arduino Uno rev 3. It operates at 2.7-5.5V and 5.8µA and operates at 8 or 16MHz depending on the input voltage. For our case we our powering it with a 5.5V input leading to a 16MHz speed grade. We chose this microcontroller because we knew it was very versatile and were most familiar with its integrated development environment (IDE), Arduino Software. The Arduino IDE and chip also have a lot of open source information that makes modulating our design much easier. Since the PetAid harness will use sensors, it is important for the MCU to have enough ADCs, in which the Arduino UNO has 6. This microcontroller will deal with collecting the temperature sensor, accelerometer, and heartbeat sensor data and sending them to an archive over Wi-Fi.

A. Temperature Sensor

The temperature sensor we went with was the DS18B20 from Maxim Integrated Products. It provides 9-12bit Celsius temperature measurements an communicates over a one wire bus. If needed, each sensor has its own serial number allowing multiple sensors to be controlled over one bus. This allows us to potentially in the future add multiple “hot spots” for a complex temperature reading all over the pet’s body. At smaller than a quarter the sensor is perfect for our design, and it is available to purchase as a waterproof type, which is great for the sweaty environment that may impact the device. This device is also very accurate with a 0.5°C to 2 °C reading accuracy.

B. Wi-Fi Module

The Wi-Fi module that we decided to incorporate is the Espressif ESP8266. It can be applied to any microcontroller design as a Wi-Fi adaptor through SPI or UART communication and uses a Tensilica L106 Diamond series 32-bit processor. It features 802.11 n support up to 72.2 Mbps which means it operates at the 2.4GHz band of Wi-Fi. While active it operates at 2.5-3.6V and draws 170 mA of current.

C. Accelerometer

Our accelerometer for the PetAid Harness is the MMA8451. The version we ordered was the MMA8451 Breakout. One of the main reasons for this group decision was that the module was extremely easy to connect to the Arduino Uno. The module uses the I2C communication standard and therefore has a SCL, SDA, Vin, and GND pins. This device has small full-scale ranges, which are ±2g, ±4g, and ±8. Having small full-scale ranges means there is a more sensitive output, which means we will get a more precise reading out of this accelerometer. This device is a digital accelerometer; therefore, it is less susceptible to noise and can be integrated to any microcontroller. This device uses 1.95V to 3.6V and draws up to 165µ. The dimension of this device is 21mm x 18mm x 2mm.

D. Heartbeat sensor

The SEN 11574 pulse sensor is a low-cost optical heart rate sensor that is compatible with Arduino and other microcontrollers. It was designed and made from the World-Famous Electronics. The great thing about this heart rate sensor is that it is easy to use and can be used by anyone who wants to incorporate live heart rate data into their projects. The sensor is perfectly sized and can clip onto a fingertip or earlobe. It also includes an open-source monitoring app that plots the pulse in real time. The dimensions of the heart rate monitor are 16 mm x 3.8 mm (W x H). Sparkfun.com also provides plenty of open source resources such as codes and schematics for the SEN 11574. It runs on 3V - 5.5V and draws 3-4mA while active. It includes a pulse sensor board, a 24-inch color- coded cable with standard male headers, a Velcro finger strap, and transparent stickers to protect the sensor.

E. ThingSpeak

Thing speak is an Internet of Things (IoT) analytics service that allows us to collect sensor data, store it privately to the cloud, analyze data with MatLab, and trigger a reaction or response. ThingSpeak enables sensors, instruments, and websites to send data to the cloud where it is stored in either a private or a public channel. Using online analytical tools, we can discover trends and calculate data. We can also represent this data in neat visuals that are easy for the user to read. Calculations can even be scheduled to run at certain times, like giving a daily or weekly overview. Channel data can be combined with other channels to create complex analyses. ThingSpeak allows us to react to these analyses by alerting the user via tweet.

F. Harness

The harness attached to the hardware components of the PetAid Harness is the RabbitGoo Adjustable Oxford No Pull Dog Harness. It comes with multiple rings attached to the harness so that the owner can attached at different points for different walks. It has four easy adjusting straps around the body which allow a perfect fit for your dog along with some room for growth. The harness is made of a durable nylon oxford and padded with soft cushioning for a pleasant dog walk each and every time. It also has reflective strips for safe nighttime walks. We believe this is excellent for our design as the adjustable harness allows for room for the installation of our Pet-Aid electronic devices. We also appreciate the versatility that comes with the multiple different rings in different places on the harness. This will carry on to the consumer and allow them flexibility when using our product with the Pet- Aid electronics incorporated in it. The breathable mesh will help prevent the electronics from breaking our temperature standards and harming the dog. It also comes in multiple colors which allows for customization.

III. System Concept

A flowchart and state machine were developed by the group in order to get a better understanding of the project as a concept overall.

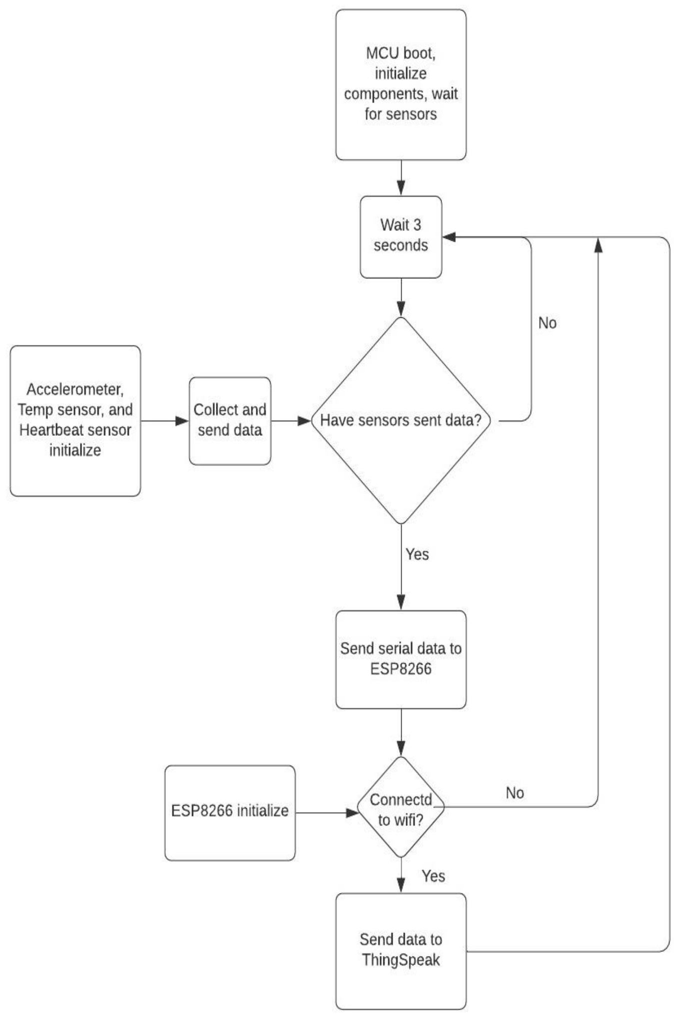


Figure 1. A complete flowchart of the PetAid harness electronics operation

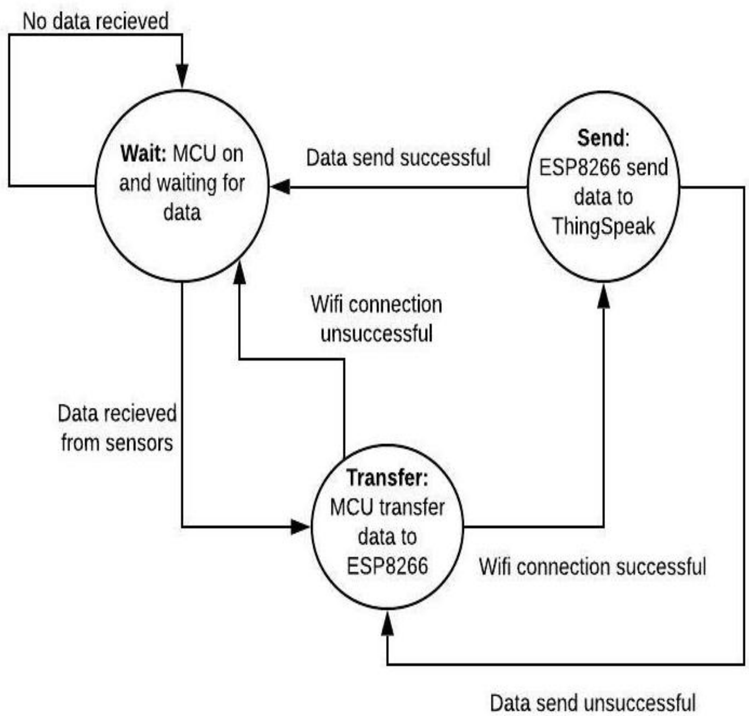


Figure 2. A complete state diagram for the PetAid electronics operation consisting of three states

The flow chart in Figure 1 and the state machine in Figure 2 show a full picture of how the electronics of the PetAid harness operate. The system is cyclical in nature, and the PetAid harness will transition through the wait, transfer, and send states from initial startup until the device is powered down.

The device begins in the wait state once it receives enough power to initialize the sensor components. The PetAid harness will spend almost all of its product lifetime in the wait state. We determined that the important biometric data logged by the PetAid harness did not have a high variation under short increments of time. Therefore, we found three seconds of wait time to be a sufficient amount of time to allow the other components of the PetAid harness to perform their respective data collection. The PetAid harness will almost always move out of the Wait state within three seconds unless the accelerometer, temperature sensor, or heartbeat sensor fails to send data which is an extremely rare occurrence. The PetAid harness can be cycled into the Wait state if the ESP8266 fails to connect to a local Wi-Fi network, however this will trigger the MCU to sample the sensors for data again and the transition out of the Wait state depends ultimately on the sensors not the ESP8266 Wi-Fi module. The Wait state is the most important state because it must be correctly calibrated in order to allow the sensors to send accurate data to the MCU and prevent the PetAid harness from continually looping without producing any useful data.

The device enters the Transfer state once the device has received data from all of the sensors connected to the MCU. The device then begins to transfer the data collected by the accelerometer, the temperature sensor and the heartbeat sensor via serial communication to the ESP8266 which controls Wi-Fi functionality. If the serial data transfer is not successful, then the system will transfer back to the Wait state and the MCU will sample new data from the sensors after an additional three seconds of waiting. Once the ESP8266 has received all of the information and the serial communication is finished successfully the ESP8266 will test to see if it has a local Wi-Fi connection. If the ESP8266 does indeed find a Wi-Fi connection, then it will transition the device to the Send state. If it cannot find a viable Wi-Fi connection it will transition the system to the Wait state and the MCU will sample the sensors again after another three seconds.

The final state the device enters is the Send state. After complete transfer of data from the ATmega328P the ESP8266 will begin to send the logged data to our ThingSpeak archive. If the data is successfully sent to ThingSpeak it will be logged and visualized on a neat graphic. If the data is not sent successfully the device will stay in the Transfer state and attempt to send the data to ThingSpeak again.

IV. Standards

Our project has the added component of being used by a living animal and we therefore had to ensure we understood the proper standards for dog safety. We focused on adopting a safe standard for maximum carry weight. Unfortunately, we found no available standard for dog carry weight and therefore had to develop our own standards.

We did this by weighing ourselves and then carrying increasing amounts of books in a backpack. After we had added a book, we rated our comfort from 1-5, with 5 being the highest, and weighed the backpack (results in Figure 3 and Table 1). Finally, we calculated what percentage of our body weight each interval was and decided on a limit. To ensure safety we stopped the experiment when the person carrying the backpack felt a comfort level of 2. We wanted to ensure as conservative of a weight restriction as possible so that the pet can wear the collar over long periods of time without feeling much discomfort.

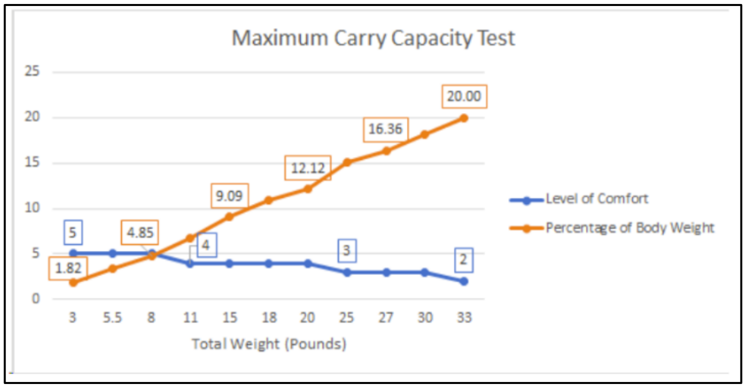


Figure 3. Results of the maximum carrying capacity test.

Total Weight (lbs)	Percentage of Carrier's Weight	Level of Comfort
3	1.82	5
5.5	3.33	5
8	4.85	5
11	6.67	4
15	9.09	4
18	10.91	4
20	12.12	4
25	15.15	3
27	16.36	3
30	18.81	3
33	20	2

Table 1. Data points for maximum carrying capacity test

Therefore, we decided as a group that we would take the first data point with a 3 for discomfort level and go a few data points before that to obtain our maximum carry capacity for the pet as a percentage of its total body weight. We decided that the 18 Ibs/10.91% data point was a good conservative limit and were finally ready to declare our new weight standard for the PetAid Harness.

Standard PAH-1.1: Any product designed to be worn for extensive periods of time by a household pet, or any land-based living animal, shall not exceed 10% of the total body weight of the designated carrier animal. This is to ensure the long-term safety of the designated carrier based on a few experimental trials we conducted on our group members.

A. Ethical Constraints

We decided to build a device that could be used on live house pets specifically because we believe it fills an important need that will benefit all house pets and their owners' long term. Our dedication to this goal did come with some significant constraints that are not present in other products. Not only is it illegal in the state of Florida to just test a product on a house pet with no regulation or expertise, we also found it very unethical. Risks of testing biometric scanning technology in a dog harness include having a catastrophic failure that could electrocute the dog, or otherwise harm them in ways we did not expect. Therefore, we had to find unique ways of testing the functionality of a product designed for a dog that cannot be attached to one. First, we decided that all sensor testing would be done by a group member that agreed explicitly to the tests. Second, we had to create representations for the physiological actions and responses a dog might have. For the temperature sensor we attached the sensor to a gallon jug of water heated to a predetermined temperature. For the accelerometer we recreated common dog motions like rolling by attaching the device to the end of a cylinder and rolling it. Light breathing as simulated by attaching the device to a group member for a short period of time.

V. Hardware Detail

A. Printed Circuit Board

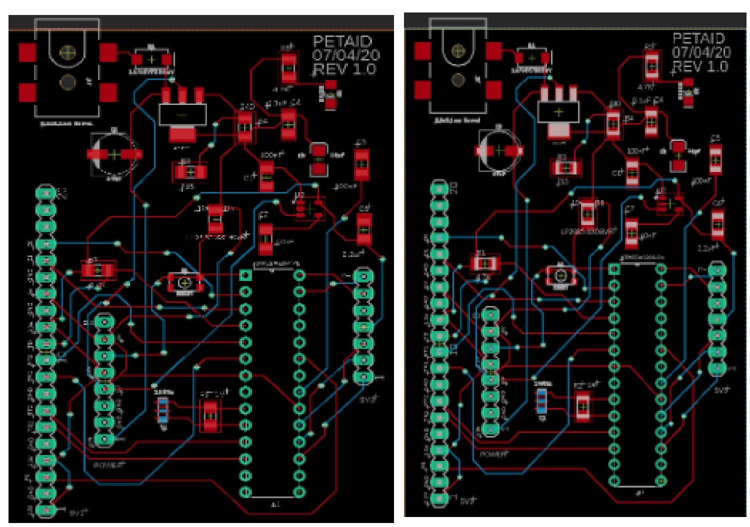


Figure 4. Printed circuit board top layer (left) and bottom layer (right)

The PCB was designed using EAGLE, which is one of many PCB CAD software out there on the internet. One 2-layer design was built for the PetAid Harness. The design is shown in Figure 4 and it features the ATmega328P-PU chip, LM1117, LP2985, MBRA140, 2 0.1 uF capacitor, 4.7 Kohm resistor, 47 uF capacitor, 10 uF capacitor, 2.2 uF capacitor, 10000 pF capacitor, 1 Mohm resistor, 715 ohm resistor, green LED, DC Barrel Power Jack, 16 MHz resonator, push button, and several pin headers for connections. This PCB board will be the most important part of the PetAid harness because it will connect everything and be the component to run the PetAid harness as it was designed for. Our group selected JLCPCB, which is a PCB manufacturer located in Hong Kong. Five boards were ordered and only two were assembled together and the other three were left available and open for us to solder. We soldered two boards, just to be safe because our team was limited on equipment to help solder the boards.

B. Power Supply

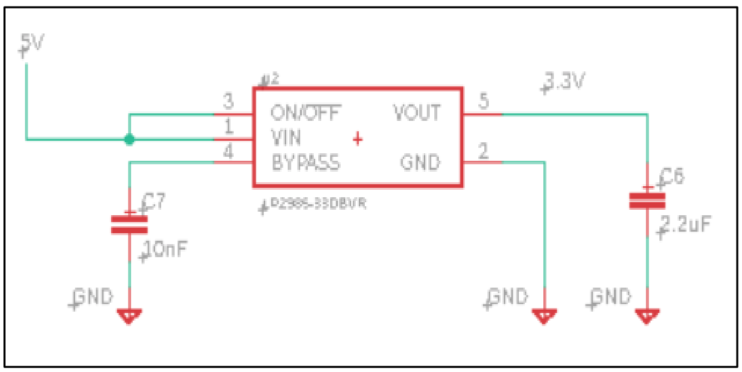


Figure 5. First Voltage Regulator

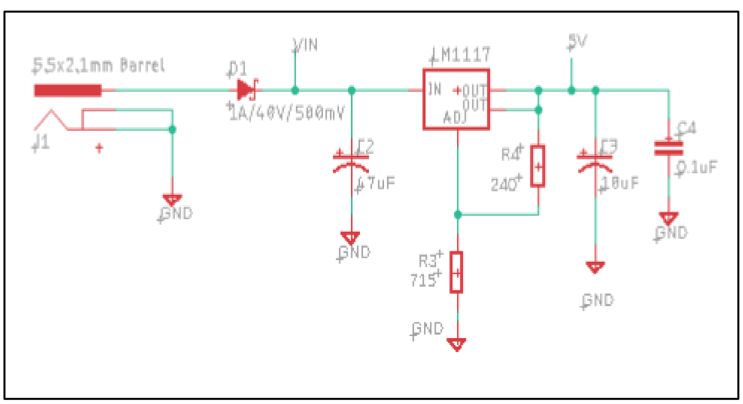


Figure 6. Second Voltage Regulator

There are two DC-DC voltage regulators that are selected for the PetAid Harness. These voltage regulators are determined as LM1117 for 5V regulated output and the LP2985 for 3.3V regulated output. First of all, the LM1117 requires a wide input voltage range 6.5-12V in order to achieve the 5V regulated output. This is the explanation of why the DC barrel jack is chosen to be added on the footprint of the PCB. The use of a DC barrel jack provides common methods to supply the desired amount of higher voltage input such as a 9V DC battery that is used for our PetAid Harness. Figure 5-6 represent the two DC-DC converters used to obtain the desired voltage output into the designed PCB.

Our thought process in deciding the optimal power supply is to get the most battery life for the cost, size, and weight, and to make sure it operates at a temperature that's safe to have on a piece of wearable technology. When the 9V battery was selected to be the primary source of the PetAid Harness, it was assumed to have a battery life sufficiently long enough to be satisfactory for the user or pet owner. Our equation for calculating battery life is,

$$\begin{aligned} &Battery\ Life\ (Hours) \\ &= Total\ Capacity(mAh) \\ &/\ Current\ Consumption(mA) \end{aligned} \tag{2}$$

The total capacity of an alkaline 9V battery is about 550mAh.

Component	Current Draw	Input Voltage
Arduino Uno MCU	50mA	7V-12V
ESP 32 Wi-Fi/Bluetooth module	80mA	3-3.6V
SEN 11574 Heart-Rate sensor	4mA	3V-5.5V
DS18B20 Temperature Sensor	1mA	3V-5.5V
MMA8451 Accelerometer module	11mA	1.95V-3.6V
ESP8266	240mA	3.3V
Resistors, Diodes, etc.	10mA	
Result	Total current is 396 mA	

Table 2. Current and Voltage requirements for various components

According to these numbers listed in the Table 2, the battery is expected to last for about 1hour and 18minutes. Although the length of time is acceptable if needed only for an initial design, if the PetAid harness is desired to be running for a longer time or put into production, then an alternate or secondary power supply source is required.

Iteration of this battery life must be reliable and was decided a secondary power source is needed to meet user requirements in the longer term. The secondary source of power for the PetAid Harness is determined to be from a 5V/3.3 breadboard power supply, which is a very simple board that takes a 6-12V input voltage and outputs a selectable 5V or 3.3V regulated voltage. It contains headers that are 0.1" pitch for simple insertion into a breadboard. Input power can be supplied to either the DC barrel jack or the two-pin header labeled + and -. Output power is supplied to the pins labeled GND and VCC and an On/Off switch allows to turn on but also a voltage select switch between 3.3V/5V. The reason for this decision is due to the current consumption of the ESP8266 that must be met to operate. It's current consumption while searching or using WI-FI communication, is 240mA which does not allow the PCB to run at the 3.3V regulator output of 150mA. Since the ESP8266 must run on 3.3V and not 5V due to Tx/Rx pins having a logic level of 3.3V. This breadboard power supply has a 800mA operating current, which is more than enough to power the ESP8266 and also most of the sensors.

VI. User Feedback

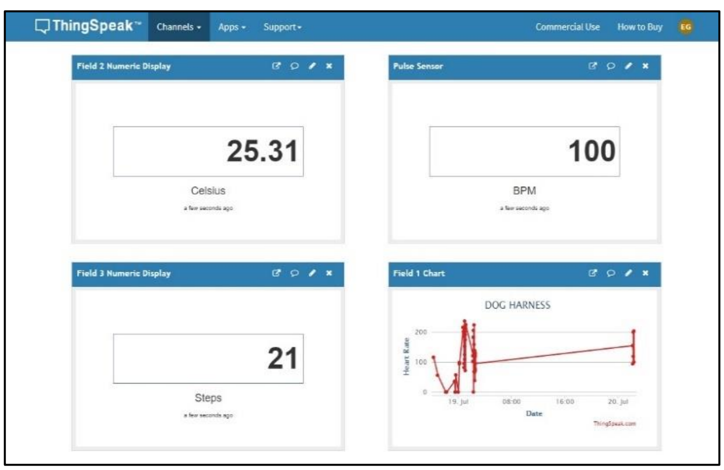


Figure 7. Biometric data presented to the user over ThingSpeak integration

User feedback is essential for the PetAid Harness to accomplish its goal of limiting pet care costs through preventative action. The user of the PetAid harness receives all of their feedback through ThingSpeak by Mathworks. As shown in Figure 7 the user has a neat and practical set of biometric data for their pet. The current data points for the temperature, heartbeat, and daily step count. A log of previous data is easily accessed on the webpage. By providing this feedback the owner can keep vigilant over their dog's physiological condition and provide priceless data to the pet's veterinarian.

V. Software Details

There are multiple ways that we could write code into the microcontroller to get our desired functions, but we decided that the programming of the ATmega328P-PU is best suited to be performed with the Arduino IDE. The Arduino IDE is straightforward and has a large amount of resources online for relatively newer builders to get out of pitfalls that would normally stop all progress. One program is needed per flashed device; the ATmega328P. The code on the Arduino Uno is responsible for the collection of data from the attached peripherals, the functions called to translate the data into something more meaningful to the user, and the transmission of the data to the ESP8266. We were able to flash firmware onto the ESP8266 by using AT commands through the serial monitor of the Arduino IDE.

V. Budget

The total cost of the project must be observed or predicted beforehand, to ensure it meets the maximum budget requirements initially decided as being affordable and reasonable by the whole group. As one of our goals of the project design, the PetAid Harness had to be kept at a budget as low as possible. Cost of the PetAid Harness is an obstacle for our group, since we are college students with no full-time job. This consideration is considered for UCF students which will be a determining factor for overall quality design of the PetAid Harness. Superior quality materials and highest performing component parts should not be decided, since the investment is to be within capstone requirements along with experiencing a short project deadline. A harness is the appropriate fitting and desired classification to be worn by the pet. The choice of selecting to utilize a harness instead of a collar was determined to be not much of a difference in terms of increasing budget cost.

Item	Quantity	Price	Total
PCB	5	12.05	60.25
Pulse Sensor	2	24.95	49.90
ESP8266	2	6.95	13.9
Resistors	6	.50	3.00
Jumper Wires	1	5.95	5.95
9V Alkaline Battery	1	1.95	1.95
Power Supply	1	11.95	11.95
Temp Sensor	2	4.30	8.60
Accelerometer	2	7.95	15.90
Arduino Uno	2	22.00	44.00
PCB Soldering			55.07
Total			270.47

Table 3. Budget Summary

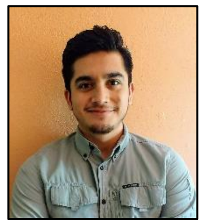
VII. Conclusion

The PetAid harness prototype is a great first step toward accomplishing our product goals and motivations. It successfully logs data on step count, temperature, and heartbeat for the carrier pet. This accomplishes our goal of providing preventative action for pet health discrepancies by giving the product user access to biometric data points for their pets. This combined with vigilant communication between the pet owner and the pet veterinarian allows the product user to reduce the amount of reactive procedures, like surgeries, and decrease their average annual cost of pet care.

Unfortunately, some of our product goals and motivations were not achieved. We were quite short of our desired battery life length. We believe this could lead to customers neglecting to continually replace the battery, and there may be gaps in the important logged biometric data from the device being off for long periods of time. This is our most essential fix for the next iteration of the PetAid harness.

We believe that with the knowledge we learned from the PetAid prototype we can build on the PetAid harness to provide an even greater product. Aside from the previously mentioned longer battery life, other features we would want to include for the next iteration would be GPS capabilities, and a user-controlled LED attachment for finding lost dogs. The LED could easily be incorporated through the Arduino, and with a GPS reliever module the Arduino could keep track of the location of the pet at all times. This would allow us to extend our motivations beyond health care into recovering lost pets.

The Engineers



Pedro Rocha is a 24-year-old graduating Electrical Engineering student. Pedro's career goals are to work for a utility company in electric power system design. Research and Development is a criteria of concentration that keeps him very focused and interested.

Adam Henderson is a 25-year-old graduating Computer Engineering student who is looking to pursue a career in Cybersecurity with L3Harris, working in development of wireless products for first responders.

Pascal Bahms is a 23-year-old graduating Electrical Engineering student who plans to pursue an Electrical Engineering PhD at the University of Central Florida. His interests include signal analysis and control theory.

Edgar Gonzalez is a senior in Electrical Engineering at the University of Central Florida and will be receiving his Bachelors of Science in Electrical Engineering in August 2020. Edgar will pursue a career in electric power distribution after graduation.

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[1] American Pet Products Association, "Pet Industry Market Size & Ownership Statistics," *American Pet Products Association*, January 2020