Pet Threat Detector: Design Document

ECE 445 Design Document

Brant Bedore, Jason Hackiewicz and Talita Barbosa

Team 45

TA: Madison Hedlund

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1 Introduction

1.1 Problem and Solution

For many households around the world, pets are treated like family members. Many pets need to go outside to get exercise and are left unattended while they roam the yard. This can lead to pets finding themselves in a wide variety of dangerous situations. Some common examples of dangers that pets can encounter include finding a wild animal, becoming injured or wandering far from home. While owners eventually discover the danger their pet was in, this usually happens after the pet has been harmed. Many varieties of global position tracking for pets exist including microchips and Global Position Services (GPS) collars but these only notify the owner of where the pet is located and not of any other existing danger they might have encountered [1].

Rather than use a simple GPS tracker, we propose solving this issue with a comprehensive danger detection system for pets. To monitor the current state of danger that the animal is in, a variety of sensors and a camera will be attached to a harness that the animal will wear when going outside. When these sensors detect a change in the pet's behavior or current state, the owner will receive a notification on their mobile device through a software application. These notifications will include information about the potential type of danger that the pet is experiencing. Applying these sensors along with the traditional GPS tracking and mobile notification system will provide more comprehensive information on the pet and improve an owner's response time for handling the imminent threat to their pet's safety. Our solution can also be safely used with several pets to monitor each of their conditions simultaneously.

1.2 Visual Aid

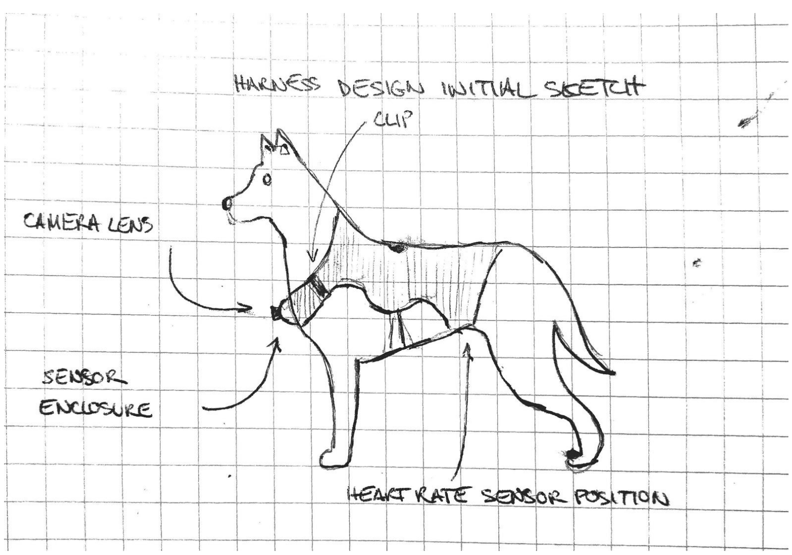

Figure 1 - Initial sketch of the harness design with all sensors and their positions.

1.3 Background

Pet safety technology is a relatively new and unexplored field. The most prominent and commonly used electronic technology for pet safety are microchips using passive integrated transponders (PIT). This development was originally introduced in 1984 to study the migration patterns of fish. PIT devices are injected into the animal and contain a radio frequency identification (RFID) number to track which animal is which. Not very much has changed with this technology since its creation and it has most frequently been used as a method of identifying a lost animal that someone has found [2]. However, PIT microchips do not feature GPS technology and do not track the exact location of a pet. This feature is included for tracking collars. These devices use global positioning and an accelerometer to detect an animal's motion and current position. GPS tracking collars were invented in 2014 by Terrie Williams, Christopher WIlmers and Gabriel Elkaim to track large wild cats [3]. While these devices do monitor the animals' behavior using an accelerometer, the device is not made with the intention of detecting hazards to the animal. These devices have been refined and commercialized for pets as well with some even including cameras to record what the pet does on a day to day basis. Other devices are designed to track the location of hunting dogs so that the owner can locate their dog and game [4].

In the Fall semester of 2019, a solution was developed for this problem by Group 8 for University of Illinois Urbana-Champaign's ECE 445 course under the title "Pet Pest Protector". For this design, the group used a collar equipped with a Passive Infrared (PIR) motion sensor to detect the motion of other animals that may cause the pet harm [5]. As requested for the second half of the ECE 445 Spring semester project, a revised solution was developed based on this initial idea with the intent of improving its principal concepts in the process.

1.4 High-Level Requirements

- HLR-1: The owner shall be notified through the Pet Threat Detector whether or not a pet is in danger in under 10 seconds of the pet encountering a threat with a failure rate of 5% or lower.
- HLR-2: The Pet Threat Detector shall send a notification to the owner's mobile device when the pet is in danger through the Communication Module with failure rate of 5% or lower.
- HLR-3: The Pet Threat Detector shall track the longitudinal and latitudinal coordinates of a pet within a 20 meter radius of its actual location and display these results to the owner as long as communication between the mobile device and harness is maintained.

2 Design

To complete the task of notifying a pet's owner quickly of any possible danger, the design will interface between two physical devices: a modified pet harness, which will be designed specifically for this application, as well as the user's mobile device. Harnesses are commonly used as a training mechanism and should not cause any discomfort during use while still providing a platform to include each of the desired features. The mobile device refers to any smartphone or tablet which can run the student developed software application.

Design organization is subdivided into five modules: a Power Supply Module, a Physical Design Module, a Processing Unit Module, a Communication Module and a Software Module. The primary task of the Power Supply Module is to ensure each component is supplied with the appropriate power required for operation. This includes the battery supply, power wire routing and a small network of linear voltage regulators. Mounting electronics on a pet presents numerous challenges which are diminished through the Physical Design Module. While this module does not include any electrical components, it is still an integral module for keeping the animal safe when the device is in use. All of the sensors for monitoring the pet's physical condition are contained within the Processing Unit Module as well as a microcontroller which collects the data to be sent through the Communication Module. The Processing Unit Module also contains an integrated software component developed on the Arduino integrated development environment (IDE) which will be used to interpret what data to send through the Communication Module. The software that the pet owner will interact with is contained in the Software Module. This includes an application which will be developed for Android devices for the user to calibrate the harness to their pet's needs and receive notifications about the condition of their pet.

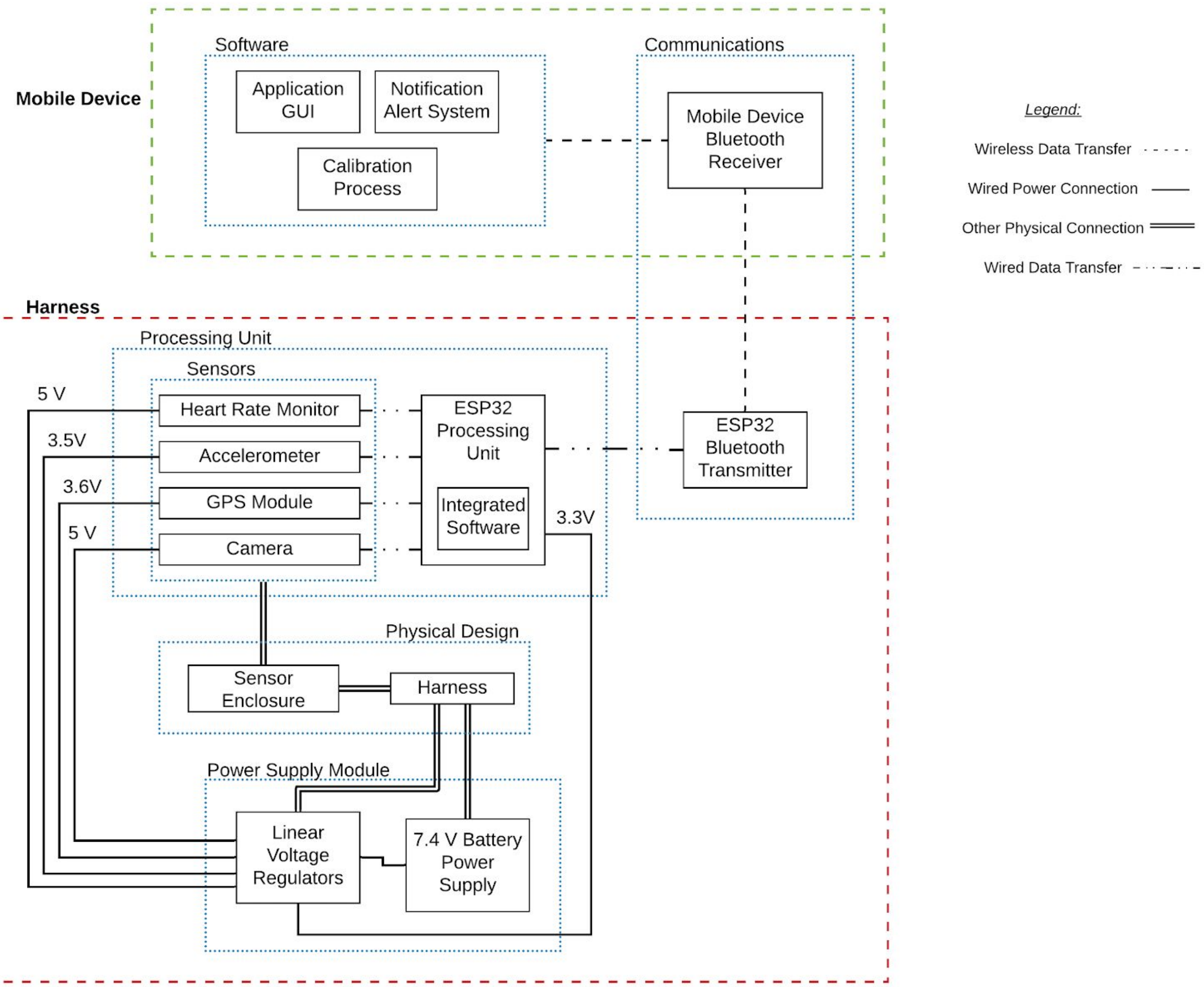

Figure 2 - Block diagram for entire project.

2.1 Power Supply Module

In order to power the sensors and be paired with a mobile device, the harness will need a power supply. Considering that it will be worn by pets for potentially long periods of time, the power supply cannot add a considerable amount of weight to the harness, nor can it be harmful to the animal, i.e., the battery cannot be prone to be bitten and have its contents exposed. It is also desirable for it to be rechargeable for ease of use.

Lithium-polymer (LiPo) batteries fit these requirements. Its weight ranges from 170 to 250 grams [6], which is ideal for this application and its voltage rating per cell is of 3.7 V [7], which means it is possible to go to 7.4 V with 2 cells, and use voltage regulators to adjust it to each voltage level needed.

Moreover, given that these batteries are widely used in electronics on the market, it would be easy for the user to get it replaced.

When choosing a LiPo battery, it is important to look at the voltage, charge rate, capacity and discharge rate [8]. Given that the biggest voltage drop needed is of 5V, a battery of 7.4 V should suffice, as mentioned before. The charge rate is important in terms of safety, because batteries that overcharge can heat up and explode, so a high rate is better. The capacity is used to determine how much time the battery will last in one charge, with units in milliamp hours, which indicates how many milliamps it can constantly output for an hour. Even though this is not a linear relationship, it is a guideline to follow when choosing a battery. By multiplying the capacity with the discharge rate, which simply indicates how fast a battery discharges, it is possible to determine the maximum load the battery can handle.

All of these characteristics, and also the weight of the battery are important factors to consider when choosing this power supply. Following Table 1, the total maximum current drawn in this project would be 1.4 A if all components are being used to their maximum current rate. This means that, for an hour of use, a battery would need to have at least a capacity of 1400 mAh and a discharge rate that can handle a load of more than 1.4 A. Therefore, the battery chosen has a capacity of 3300 mAh, with a discharge rate of 30 C, which means the harness could function, on its highest ratings, for 2.5 hours, is safe with a load of up to 165 A and weighs 167 grams [9]. 2.5 hours was considered enough for an owner to want to let their pet be in the backyard for with the harness, however, considering that all the components will not always function at their highest rates, the battery will actually last longer than that.

As previously mentioned, a small system of linear voltage regulators will be necessary to ensure that each device receives the appropriate power input. The required voltages for each device, shown in Table 1, are not the same. Therefore, the MIC4576 voltage regulator was chosen, since it can have an adjustable output voltage ranging from 1.23 V to 33 V. Five of those will be needed, one for each component, with adjustable voltage controlled by an additional voltage divider at the output [10]. These would all be mounted to a PCB that will include the ESP32 and the battery, which will also include protection circuits in case of faults that occur in the system.

In terms of safety, the battery will be contained within a lightweight but durable plastic enclosure screwed shut with small and secure screws, such that the pet is not able to open it by biting it, and still being covered by the harness fabric. There will also be a small hole on the side of this enclosure for charging the battery through a cable, with a movable flap that can cover this hole whenever the device is not charging. The charger itself would be obtained through purchasing the battery so designing a charger was deemed outside the scope of this project.

Table 1 - Maximum current and voltage ratings for all components used.

Maximum Ratings	ESP32	Camera	GPS	Accelerometer	Heart Rate Sensor
Current	1.2 A	80 - 100 mA	67 mA	1.95 uA	4 mA
Voltage	3.3 V	5 V	3.6 V	3.5 V	5 V

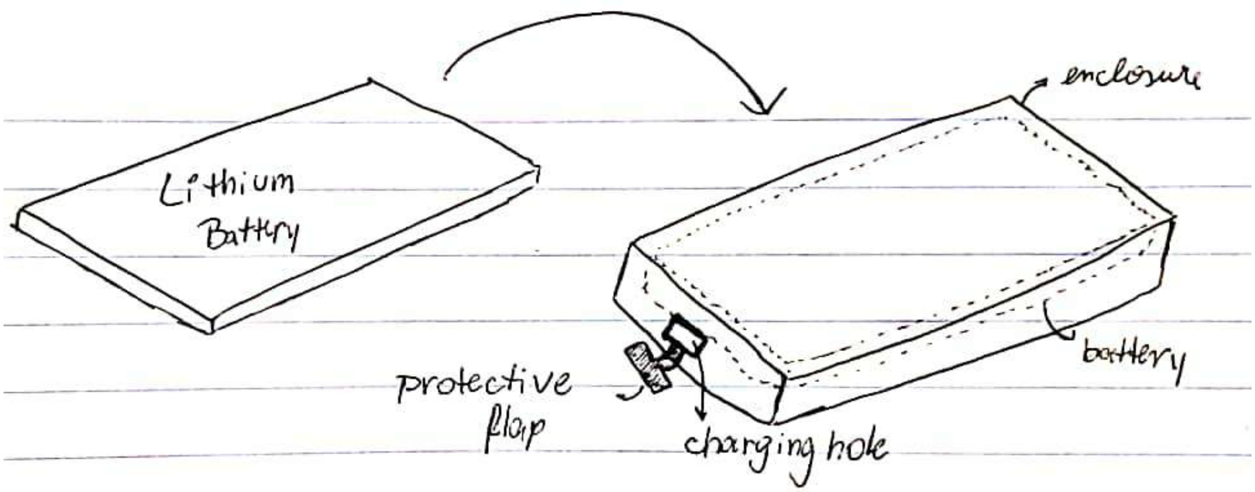

Figure 3 - Sketch of the battery and its enclosure.

Table 2 - Requirements and verification for the Power Supply Module.

Requirements	Verification
PSM-1: The battery shall be safe from biting and rough handling. No contacts should be exposed during use.	A. The battery will be assembled on the harness in the proper position. B. A visual inspection will be conducted to ensure no battery contacts are exposed which might cause an animal harm. C. A staple remover will be clamped on the area of the harness near the electronics. The clamp will be adjusted to supply an amount of force equivalent to the average bite of a large dog. D. The device will then be powered on to determine if the battery is still supplying power. E. The harness will be dropped from a height of 5 feet. F. The device will once again be powered on to determine if the battery is still supplying power.
PSM-2: The power supply shall weigh no more than 300 grams.	A. Before mounting the power supply to the actual device, it will be previously weighed using a scale to ensure that it does not weigh more than 300 grams. B. If this requirement is not met, new components will be considered and steps A and B will be repeated.

2.2 Physical Design Module

While the physical design contains no electrical components, its design contributes important criteria for the focus of the product as a whole and influences choices for other components. Animals can have destructive tendencies, especially when young, so the physical design must be carefully planned to protect electronic devices used. Additionally, pets are living beings that the owner's wish to protect through using this device so its design must minimize discomfort for the animal and maximize safety when in use.

2.2.1 Harness

Despite the original senior design project being based on a collar, it was determined that a harness is the most effective accessory to incorporate the other features of the product. Harnesses are larger in size and cover more of the pets body than a collar does. Unlike a collar based design, this allows room to spread the various devices around the harness to prevent the device from becoming too heavy for the animal in one particular area. In particular, the heart rate of an animal such as a dog or cat is most accurately measured close to the pet's stomach which is more easily accessible through the use of a harness as opposed to a collar. Using a harness also prevents the pet from easily removing the device because it will be secured to the pet in more places than a single clip collar. The harness itself will be composed of a durable but lightweight fabric such that the pet's mobility is not restricted while also being strong enough to avoid being ripped apart by the animal. Materials like polyester and nylon were considered because of these qualities. After comparing both options, polyester became the material of choice because it is slightly stronger than nylon and is everyday waterproof, meaning that the material is completely water resistant unless submerged [11]. This technology can be applied to an animal of any size but for the purposes of this demonstration, the harness and its requirements will be modelled as if the pet is a large dog.

Figure 4 - Image of harness which would be modified for the demonstration. This particular harness is made of Oxford material which is a waterproofed polyester variant [12].

Equally important to this device's success as the pet's safety is its functionality. To take an accurate heart rate measurement, the optical sensor's pad must be positioned close to the animal's hind legs. For this reason, the collar must extend to this area of the animal. Existing harnesses have large areas of fabric which cover the pet's stomach which provides a region close enough to the target area to monitor the pet's heart rate. Additional layers of polyester fabric will be enclosed over any wiring between devices on the harness to avoid interaction between the animal and the electronics. This also means electronics will be inaccessible after being installed in the collar and additional soldering may have to be done to avoid wires from slipping out during use.

Table 3 - Requirements and verification for the Physical Design Module in regards to the harness.

Requirements	Verification
PHD-1: The location of the heart rate monitor shall be positioned to detect an elevated heart rate within the tolerances outlined in [PUM-1].	A. The Champaign County Humane Society will be contacted in regards to testing this device on a healthy and active dog in their shelter. B. Once a dog is selected, the heart rate monitor will be unit tested on the dog in an excited state to determine the areas of the animal in which a heart rate is most easily detected. This will be included in the verification process for [PUM-1] as well. C. The heart rate monitor will be positioned on the harness to correspond to this location on the dog. Then the heart rate sensor will be unit tested with the ESP32 while fastened to the harness. D. Measurements will be taken by moving the heart rate sensor to other nearby locations and repeating this unit test. The location that minimizes the tolerance from the actual elevated heart rate of the dog obtained in step B will be the location chosen.
PHD-2: The harness shall sufficiently cover all electrical components and wires with the exception of the heart rate monitoring pad.	A. All wiring on the harness which would be exposed will be covered by sewing additional layers of polyester over the wiring.
PHD-3: The harness shall safely support all of the electronics while remaining under a weight of 1200 grams.	A. The sum of each individual electrical component will be carefully considered during selection. B. The completely assembled electrical box, battery and harness will be weighed. If the mass limit of 1200 grams is reached, electrical and physical components will be considered for redesign and this verification process will be repeated.

2.2.2 Sensor Enclosure

Along with the ESP32 microcontroller, the most fragile components involved in the physical design are the sensors. These devices must avoid any interference from the pet to function correctly. A small electrical box like enclosure will be fastened near the chest of the pet. Inside of this enclosure will be the ESP32 microcontroller, the accelerometer, the GPS tracker as well as the camera that will be used to capture the image of the potential danger. This position does not restrict the pet's movement anymore than a normal harness and keeps the electronics out of harm's way. To ensure there is no electrical interference and to keep the weight of the device low, the enclosure will be made of a lightweight but durable and waterproof plastic material. Each device will also be secured tightly within the enclosure to prevent the sensors from shifting during use and damaging each other or the microcontroller. The project box chosen for this role is the uxcell Waterproof Plastic Electric Project Case Junction Box which has dimensions 55 by 35 by 15 mm [13]. In order for the camera to be positioned for the most clear image capturing, the ECE machine shop would be asked to modify the project box by cutting a hole for the camera lense. To best protect the electronics, the size of this whole will be very close to the size of the lense itself. The size of this particular project box is quite small and was chosen to be this size to maximize the prevention of discomfort for the pet. While this box is of a small enough size to fit all of the components associated with the ESP32 device and its sensors, if inefficiencies arise in the wiring process for this size box, other project boxes will be considered as replacements.

Table 4 - Requirements and verification for Physical Design Module in regards to the sensor enclosure.

Requirements	**Verification**
PHD-4: The electronics inside the enclosure should not move from their initial positions further than 1 cm after 2 hours of use.	A. During assembly of the sensor enclosure, devices will be securely fastened in place and their initial locations will be measured and recorded in reference to the electrical project box. B. The completed device will be fastened to the dog from the Champaign County Humane Society as described in [PHD-1] and the animal shall wear the device while being outside and active for 2 hours. C. After use, the electrical device will be disassembled and the distance from their initial locations shall be measured and recorded.

2.3 Processing Unit Module

This module takes care of data processing and routing on the harness. Since many signals are being processed and transmitted, a chip such as the ESP32, which includes Bluetooth capability [14], would be needed for the harness processing unit. Any processing and interpretation of data will be accomplished through the integrated software on this microcontroller, while the mobile device application will be mainly utilized for user interaction. This chapter will overview the manner in which the sensors operate followed by a discussion of how the ESP32 processes this data and decides which notification to send to the owner.

2.3.1 Heart Rate Sensor

In order for the ESP32 microcontroller to process the pet's vital conditions, the harness incorporates a variety of sensors. Several other methods of monitoring the pet's current condition were considered before deciding on the heart rate sensor and accelerometer combination. Along with the heart rate monitor, some of the other original ideas for this included measuring the pet's rate of respiration or performing a digital signal processing analysis on the pitch of a bark or other sound to determine if the pet was in pain. Each of these techniques presented its own challenges. Respiratory rate is a difficult parameter to measure with currently available sensors while maintaining a low cost. Using DSP analytical techniques to distinguish between a yelp that indicates discomfort and a normal sound would also be challenging without providing some kind of sample reference sound. Furthermore, a microphone would also detect high frequency noise from other sources in the environment and the software would have to use complex DSP interpretation mechanisms to differentiate these sounds.

Similarly to these two approaches, the heart rate monitor solution provides several concerns. Notably, when a pet becomes excited by anything, its heart rate will rise whether the subject of its excitement is a threat or not. While it is nearly impossible to distinguish exactly why a pet's heart rate might rise from currently available technology, this problem is solved by using an additional camera module and software as discussed in Table 1. Another common issue in regards to heart rate monitoring is accurate detection through pets with thick coats of fur. This is mitigated through two solutions: using an optical heart rate sensor rather than motion or sound based sensor and by positioning the device as close to the heart as possible on the harness [15]. For this application, the SEN-11574 was chosen. The device is priced at a relatively low cost when compared to similar models and is optimized for use with Arduino devices making it easily configurable for use with the ESP32 [15]. At only five eighths of an inch in diameter, the device is small enough to safely and effectively secure onto a harness while only drawing a maximum of 4 mA of current [16]. While the most effective positioning for an accurate reading is not final, the sensor will be located on the harness near the pet's stomach and hind legs to obtain an accurate pulse reading in an area where as little fur blocks the optical detector. This area of the body is commonly used by veterinarians to check an animal's pulse [17]. Other pet based projects have implemented this sensor before in various projects as well making it an effective choice for this design solution [15].

Table 5 - Requirements and verification for Processing Unit Module in regards to heart rate sensor operation.

Requirements	Verification
PUM-1: The heart rate monitor shall identify a heart rate as “elevated” when the pet’s heart rate exceeds the value determined to be elevated through the application setup calibration with a tolerance of ±10% of the pet’s actual elevated heart rate value.	A. The heart rate sensor shall be unit tested on a dog from the Champaign County Humane Society. The pad will be positioned to take readings of the dog’s heart rate at rest. B. A student (or veterinarian if available) shall measure the dog’s resting heart rate by measuring its pulse by hand. Steps A and B will then be repeated for five trials. C. A staff member of the Humane Society will excite the dog without putting it in any danger. The pad will then be positioned to take readings of the dog’s heart rate while excited. D. A student (or veterinarian if available) shall measure the dog’s heart rate while excited by measuring its pulse by hand. Steps C and D will then be repeated for five trials. E. The percent error will be computed for the resting heart rate and excited heart rate. Assuming that this error can occur in the heart rate monitoring process, the software component will be modified such that with this error, the “elevated” heart rate state is triggered within a 10% tolerance of the value measured in step D. F. The harness device shall be tested on the animal after the calibration set up process. If a notification arrives to the app user’s mobile device when the dog becomes excited, this requirement is verified.

2.3.2 Accelerometer

Another issue that arises with using a heart rate monitor is that heart rates are most accurately collected when an animal is standing still. An accelerometer is used to resolve this problem as well as provide additional information about the current state of the pet. Because accelerometers measure proper acceleration a value detected of 1 g (9.81 m/s) indicates no acceleration. This value can also be assumed to be zero velocity because even in the case that a pet moves with a constant forward velocity, the accelerometer will experience values greater than 1 g as the animal has more than a single degree of freedom and the device will bounce up and down while running. This is particularly useful for detecting whether the pet is in motion or not. Therefore this can be encoded as a single bit binary variable representing either very little motion or lots of motion. This will be done by taking the 12 bit serial port output of the accelerometer chip and determining if the acceleration detected is greater than a certain value in the processing unit integrated software [18]. For running humans, about ±2 g is detected while running so this value will be assumed to be relatively similar for animals [19]. Therefore, if the accelerometer detects an acceleration of about 1 g for three consecutive seconds, a heart rate measurement is taken to analyze if the animal has an elevated heart rate.

This result is also applied to enhance the danger identification capabilities of the system. For example, if a pet has an elevated heart rate while moving, it may be in danger of another animal or a moving vehicle. If the pet has an elevated heart rate and is not moving, the pet may have been physically injured and unable to walk or move. Following the detection of an elevated heart rate, the accelerometer will record data three seconds after an elevated heart rate is detected. This data, along with the detected heart rate, will be analyzed in the processing unit's integrated software, where a notification type will be generated and sent back to the owner in the form of a mobile device notification.

For this application, the accelerometer is required to detect typical running acceleration and act as a pedometer of sorts. Because this is a relatively low speed application, there are a variety of accelerometer chips which are capable of being easily programmed with the Arduino IDE. An accelerometer which detects changes in speed in the ±2 g and ± 4 g ranges should be sufficient [20]. The ADXL363 appears to be an accurate fit for this specification, with three detection modes in the ±2 g, ±4 g and ± 8 g ranges with a low current output of about 1.8 μA in normal operation [18].

2.3.3 GPS Tracking Device

Global positioning systems integrate the use of 24 satellites to compute a strong approximation of the latitudinal and longitudinal coordinates of a GPS receiver device anywhere in the world regardless of weather conditions. This technology uses low power radio signals to achieve this communication and represents the ideal way to determine the exact location of a lost pet. GPS receivers collect three important pieces of information: pseudorandom code which corresponds to a device identification number, ephemeris data which give information about the satellite the receiver is communicating with and almanac data which supplies the data necessary to correspond the satellite location with the device location [21].

Locational data from an ESP32 compatible GPS tracking receiver will be used as a supplement to the other sensors used to monitor the danger that the pet is in. The coordinates collected by the GPS receiver will directly be sent back via the Communication Module to the owner's mobile device. Each coordinate (both latitude and longitude) will be represented by a 4 byte float. Through the software application, the user will be able to view the pet's location while they wear the harness at any time as long as communication between the mobile device and harness is maintained. Additionally, the user can set a delimitation radius to receive a notification if the pet's coordinates are outside of the set radius.

To develop a range of values which represent the tolerance for this GPS module, the degrees associated with latitude and longitude were used in reference to the Earth to determine an arc length. While humans are capable of seeing up to 3 miles away (about 4800 m) [22], it would make sense to select a distance such that a human could see their pet easily in environments with unclear conditions. A parking lot was selected as a reference to determine this tolerance as the owner should be able to use the device to find their pet in an area at least that large. Across this parking lot (latitudinally) represented a distance of 0.005 degrees.

$$L = r\theta \quad (1)$$

Converting the angle theta to radians and multiplying the result times the radius of the earth yields a result of approximately 550 m. This is well within the human line of sight and also satisfies the specifications described in [HLR-3].

For this project the NEO-6M was selected due to its popularity in similar applications and simple functionality with Arduino like devices. This device includes two components: the GPS antenna and the module itself. Only four pins are necessary to configure this device and it is rated for a horizontal position accuracy of 2.5 m [23]. Such a high tolerance for accuracy is ideal for this situation since a pet can easily be spotted with the naked eye with 2.5 meters of distance. The voltage requirement is fairly standard at 3.6 V which can be obtained through the use of a voltage regulator and the current drawn from the device is 10mA [23].

Table 6 - Requirements and verification for the GPS Tracking Device.

Requirements	Verification
PUM-2: The GPS receiver shall record and transmit the coordinates of the pet through the Communication Module with a tolerance of ±0.005 degrees in both the latitudinal and longitudinal planes.	A. A GPS module will be selected with a high level of accuracy to obtain results well within the ±0.005 degree tolerance. B. The GPS receiver will be unit tested with the ESP32 and the Arduino IDE to ensure that the correct coordinates are being obtained by the device. The value generated will be compared with the actual latitude and longitude of the location of testing. C. The GPS functionality of the mobile device software application will be tested to ensure that the float values associated with latitude and longitude are visible to the owner. If the device does not produce a coordinate within the outlined tolerance of the requirement, the antenna will be repositioned for better communication with the satellites. If this still fails, research on alternative devices will be conducted and this process will be repeated from step A.

2.3.4 Camera

A small camera device will be positioned on the harness to be able to capture images when an elevated heart rate is detected from the heart rate sensor. Once the image is captured, it is saved on the internal memory of 4 MB of the ESP32, which will then be read and sent via the communication module to the owner's mobile device through a notification, at which point the picture will be deleted from the internal memory. By viewing the contents of the image, the owner will be able to identify the variety of danger the pet is experiencing, or if it is not in any danger at all.

Much like the other sensors used in this design, the camera will require interfacing with the ESP32 module. Unlike the other sensors, associated with this design, the camera presents a much greater demand for power and data transfer when in use. The sheer quantity of data associated with achieving a clear image leads to high amperages during capture and large data transfer between the harness and the mobile device. For this reason, a target resolution of 0.3 Megapixels was desired for this application. Integrated software for the ESP32 microcontroller will collect an image when triggered and transfer the image over Bluetooth via the Communication Module. For each of the three colors associated with the captured image there is a byte of data so by multiplying 3 bytes by 307,200 pixels the total data transfer per picture is 921,600 bytes in an uncompressed form. Fortunately, this data transfer would happen quite infrequently and compressed file formats such as Joint Photographic Experts Group (JPEG) are available through various camera options which limit the size of the data associated with the image.

Limiting the camera to transfer a file in a compressed image format while remaining at the 0.3 Megapixel resolution led to choosing the ZM serial JPEG camera which is built off of the OV7725 color sensor and uses RS232 protocol for device communications [24]. Other devices considered had only some of the stated criteria such as the OV2640 which uses a JPEG output but is 2.0 megapixels [25] and the OV7670 which is a popular 0.3 Megapixel variant but does not support a compressed file output and is designed primarily for video integration [26]. While the ZM serial JPEG camera has the desired data transfer and file size parameters, the device does use slightly more power than the other two devices, drawing about 80 mA to 100 mA when in use [24]. This decision is justified by the fact the camera will rarely need to draw this much current because of the low quantity of images which need to be captured when compared to video.

2.3.5 ESP32 Microcontroller and Integrated Software

The processing unit on the harness will have data coming from the camera, GPS tracking, accelerometer, and heart rate monitor. These would be read and processed by the microcontroller on the ESP32 chip through its integrated software component, which will be coded through the Arduino IDE. Depending on the combination of signals received, different signals will be sent to the mobile device via the Communication Module. The integrated software developed will handle the order in which data is taken in and handle the signal logic associated with the sensors. Some examples of this include the GPS data which should be retrievable anytime the user requests coordinates and the heart rate monitor which should only take readings when the data collected will be accurate.The latter observation means that, when the accelerometer sees near zero motion, the heart rate monitor takes a reading and, if it is elevated, the accelerometer identifies motion for the next 3 seconds, which leads to the identification of the type of danger. The types of notifications sent according to the sensor readings are shown in Table 7. The same Table also shows when a picture will be taken and sent. Once taken, the picture will be stored in the internal memory of the ESP32, which then will be read by the chip and sent via the Communication Module to the user's mobile device.

Table 7 - Simplified notification type truth table based on a combination of different signals

Accelerometer Reading- (before heart rate is captured)	**Heart Rate Captured-**	**Accelerometer Reading-** (3 seconds after heart rate reading)	**Camera -** is a picture taken?	**Notification Type-**
Reading < |1.5 g| (still or small movements)	“Normal”	Not measured	No	No notification sent. Heart rate monitor indicates the pet is safe.
Reading < |1.5 g| (still or small movements)	“Elevated”	Reading > or = |1.5 g| (a lot of movement)	Yes	“Your pet has an elevated heart rate and is moving.” (Notification type 0)
Reading < |1.5 g| (still or small movements)	“Elevated”	Reading > or = |1.5 g| (a lot of movement)	Yes	“Your pet has an elevated heart rate and is not moving.” (Notification type 1)
Reading > or = |1.5 g| (a lot of movement)	Not measured	Not measured	No	No notification sent. No accurate heart rate captured.

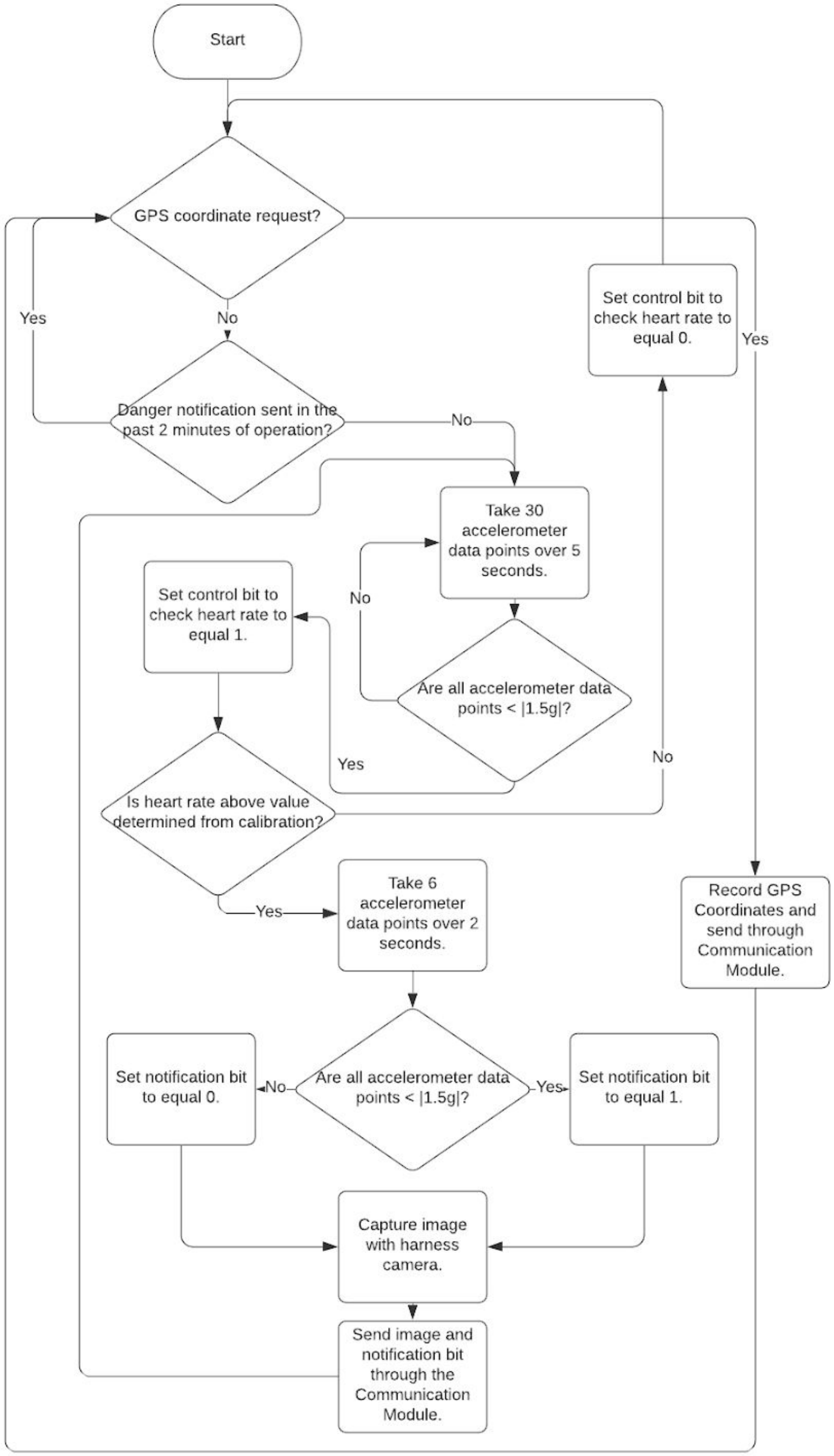

Figure 5 - Flowchart of Integrated Software.

Knowing that these notifications are desired, a binary encoding can be assigned to the variety of notifications and a pseudocode can be created for the ESP32 integrated software. The integrated software will begin by searching if the user has requested for their pet's GPS location. This requires an input control bit from the mobile device software application which will be transferred via the communication module. If the app user is requesting coordinates, the coordinates will be recorded and sent back to the app user by the Communication module.

If the user is not requesting for coordinates the algorithm falls into a conditional statement of whether or not a notification for danger has been sent in the past two minutes. This is done to prevent the mobile device from constantly receiving notifications every few seconds if the pet's heart rate is elevated. If there has not been any notification in the past two minutes, the accelerometer begins taking data points. If each of the data points obtained is under |1.5 g|, then the heart rate data is captured. This heart rate is compared with a value in memory representing the boundary of the pet's elevated heart rate. If the detected heart rate is greater than the value stored in memory the pet is assumed to be in danger. An additional two seconds is taken to observe the data from the accelerometer. If all of the observed data points are less than |1.5 g|, then a bit corresponding to the notification type is set to 0. If the any one of the data points observed is greater than |1.5 g| then the notification bit is set to 1. A notification bit equal to 0 corresponds to sending a notification saying, "your pet has an elevated heart rate and is moving" and a notification bit equal to 1 corresponds to a notification saying, "your pet has an elevated heart rate and is not moving." Next an image is captured and the data for the image and the notification bit are sent by the Communication Module.

It is worth mentioning here about the calibration that will be done when the owner first gets the harness or desires to recalibrate it. The ESP32 will receive a signal to go into calibration mode, which means it will write over previous heart rate values, i.e, global variables in the ESP32 code that describe the pet's resting and elevated heart rate are modified through the calibration process.

Table 8 - Requirements and verification for Processing Unit Module in regards to the ESP32 Microcontroller.

Requirements	**Verification**
PUM-3: The ESP32 integrated software shall process a data packet composed of data collected from the sensors which will produce accurate results to be viewed on the application with a 90% success rate.	A. This requirement will be verified over the course of several days for the health and safety of the test dog. A staff member of the Humane Society will excite the dog without putting it in any danger with the harness attached. Then the dog will be asked to lay down, so that the accelerometer detects little motion, and stays still while its heart rate is still elevated. B. The test mobile device will be monitored for notifications. If a notification with the

	correct message is received, the trial counts as a success. If not, the trial counts as a failure. C. The dog will then be allowed time to calm down to a resting heart rate. D. A staff member of the Humane Society will excite the dog without putting it in any danger with the harness attached. Then the dog will be asked to fetch a ball so that the accelerometer detects motion. E. The test mobile device will be monitored for notifications. If a notification with the correct message is received, the trial counts as a success. If not, the trial counts as a failure. F. The dog will then be allowed time to calm down to a resting heart rate. G. Steps A through F will be repeated 9 other times, if 9 of these 10 attempts are successful, then this requirement is met.
PUM-4: The ESP32 shall take data on the current heart rate when the detected acceleration is less than the absolute value of 1.5 g for 3 seconds.	A. The ESP32 integrated software will be programmed through the Arduino IDE such that if the serial output of the accelerometer is interpreted as a number less than the absolute value of 1.5 g a 2 second timer will start. During this timer 6 accelerometer data points will be taken in evenly spaced time intervals. When this timer is finished, if the six accelerometer data points are all under 1.5 g, the heart rate will be analyzed. B. A single control bit will be assigned to represent whether to analyze the heart rate (1 if the heart rate should be analyzed, 0 if there is no need to analyze because the pet is in motion). Each of the three possible accelerometer outcomes will be tested to determine if the test bit is the correct value: a. The accelerometer reading is above |1.5 g| (0- no need to analyze).

	b. The accelerometer reading is below |1.5g| at the start of the test but contains a data point above |1.5g| at the three second mark (0- no need to analyze). c. The accelerometer reading is below |1.5g| at both the start of the test and for all data points during the three seconds timer (1- analyze heart rate). C. This single bit will be unit tested by being printed onto the serial monitor and ensuring each outcome produces the correct result. D. In the integrated ESP32 software, the single bit output will be replaced with a command to collect data from the heart rate sensor. E. The scenarios from step B will be tested again but instead of analyzing the outcome of a single bit, the heart rate data will be viewed through the serial monitor on the Arduino IDE, ensuring that the heart rate data is captured at the appropriate time.

2.4 Communication Module

In order for the owner to receive the information gathered on their pet's harness, Bluetooth communication will be used. The harness will have its own Bluetooth component that will send information processed on the ESP32 to the user's cellphone. The mobile device will be connected through Bluetooth every time the owner puts the harness on the pet, and a successful connection will be indicated by an LED bright enough to be seen through the harness fabric.

2.4.1 Bluetooth Transmitter

The ESP32 has a built in Bluetooth transceiver, which will be used as a transmitter in this project, and will send all the information gathered from the harness' sensors to the user's mobile device through it. This information, however, will first be processed by the processing unit in the ESP32, which will determine what kind of signal must be sent via Bluetooth to the owner. Therefore, the Bluetooth will transmit the signal received from the processing unit to the software application on the cellphone, and the mobile device application will send the notification accordingly. The Bluetooth transmitter will also send the picture taken from the camera to the phone whenever one is taken.

The range of this Bluetooth connection needs to be large, which means a Class 1 Bluetooth is necessary [27], with around 100 meters of range. Given that a picture needs to be sent to the user's mobile device and the file size will be about 921,600 bytes uncompressed, Classic Bluetooth will be used with a Serial Port Profile, more specifically the RFCOMM protocol. These ensure that there is a "simple reliable data stream to the user" [28]. This protocol emulates the old RS232 cables, which were used for serial data transfer between a Data Terminal Equipment (DTE), which would be the ESP32 on the harness, and a Data Communications Equipment (DCE), which would be the mobile device [29]. The use of RFCOMM can sometimes be slow, especially with big files. If the data is sent to the mobile device and read and written to a file there byte by byte, that can be very slow, and, if the file is sent all at once, there is a big chance for data loss. Therefore, a streamed buffer will be used, in which "packets" of data are sent at once. The optimal size of each packet would be found in testing.

The fact that a modern mobile device can support many Bluetooth connections is used to this project's advantage [30] to be able to support multiple harnesses connected to a single mobile device. A connection through Bluetooth is called point-to-point, which means each Bluetooth device will have an unique connection with a mobile device, but a mobile device can have many of those connections at once, making it possible for a single owner to have multiple pets and multiple harnesses being tracked at the same time [31]. The mobile device application will distinguish the harnesses by knowing each unique connection between them and the mobile device, and, before sending a notification to the user if their pets have elevated heart rates, will check if they are playing together to avoid unnecessary disruption.

Other methods considered for the Communication module were WiFi and Bluetooth Low Energy (BLE). The WiFi would have had simpler ways to transfer data between the ESP32 and a mobile device, but, given that none of the team members have worked with WiFi and its different protocols before, it was safer to go a more familiar route. Bluetooth Low Energy would be useful in its extremely low power consumption, but, given the necessity of transferring a JPEG file, which uses a lot of memory, using Classic Bluetooth is better because of its faster data transfer rate [32] and more resources availability. Moreover, considering that the battery is going to be rechargeable and is able to be big enough to support a few hours of use, the slightly elevated power consumption from the Classic BLuetooth should not be a problem.

The biggest difference between the original project and this version when it comes to Bluetooth communication is the amount of signals being transmitted. Another is the ability to have multiple pets connected to the same network, in the case the owner has more than one pet. A feature that could be implemented in the future is a scatternet, that connects many Bluetooth devices in a big network, which can be used for longer range and to have a more precise analysis of threat detection [33]. With this, it would be possible that, if the pet encounters other pets from the neighbourhood, a notification could be sent to the owner warning them that their pet has encountered another pet. In the latter case, no information about another owner's pet would be shared beyond the picture sent by the harness. It would also allow for an ecosystem to be formed, much like Tile does with its tracking devices, which would use the information of nearby harnesses to precisely track a user's pet, therefore making the range much larger [34]. This feature, however, is not detrimental to the functionality of this project and will only be implemented if there is time.

Table 9 - Requirements and verification for Communication Module in regards to the Bluetooth Transmitter.

Requirements	**Verification**
COM-1: The Bluetooth transmitter shall have a range of 100 meters with a tolerance of ± 10 meters.	A. Group member 1 will first connect a mobile device to the ESP32 through Bluetooth. B. Group member 2 will measure a distance of 100 m from group member 1 using a tape measure, while group member 3 stands at the 100 m mark holding the ESP32. C. From that point, group member 2 will measure both 10 m further and closer to group member 1 and mark those distances using tape. D. Group member 3 will be asked to walk back and forth between the two marked distances. E. Group member 1 will check if the ESP32 has maintained the Bluetooth connection while group member 3 is walking between the two marked distances by seeing if the mobile device is still paired. F. Simultaneously, group member 3 will check that the ESP32 is paired.
COM-2: The Bluetooth transmitter shall establish a connection with the mobile device application with a failure rate of 5%.	A. The ESP32 shall be powered on and ready to be paired. B. The mobile device will then be used to establish a connection with the ESP32 by going into Bluetooth settings and pairing with the ESP32.. C. An LED on the ESP32 should turn on

	ensuring a successful connection between the phone and the Bluetooth device. D. The Bluetooth capabilities on the mobile device will then be turned off, and the LED should turn off accordingly. If these steps are completely successful, this counts as a successful attempt. E. Steps A through D will be repeated 19 more times. Each one of these repetitions will count as an attempt to connect to the Bluetooth. F. Provided that 19 of those 20 attempts succeed, the requirement is met.

2.4.2 Mobile Device Bluetooth Receiver

The mobile device carried by the user, which may be a smartphone or a tablet, will be connected to the harness via the device's internal bluetooth capabilities. As mentioned before, most modern mobile devices are able to have multiple Bluetooth connections, which makes it possible for the user to own many harnesses in case they have more than one pet.

A software application in each device will enable the user to have all the information the harness will provide. More information about this application will be in the Software Module section, in which its functionality and features will be described in detail.

2.5 Software Module

When it comes to software, there are two main components on this project: the integrated software that goes into the processing unit, that will gather and route all the data from the sensors, and the software application for use on a mobile device, which will allow the user to receive all the information needed from the harness, such as the GPS location and the notifications. This module will focus on the latter.

This application will be coded through Android studio, using Java. As mentioned before, a streamed buffer will be used to send packets of data from the harness to the mobile application. The mobile application will receive this information and process its meaning, and display it to the user. For pictures, the mobile application will save the file in the mobile device, and also display it on the application. Each time the user will put the harness on their pet, they need to check the Bluetooth connection with each harness on their mobile device to make sure they did not get disconnected.

When it comes to the application's features, the notifications are one out of the two the most important features of this application, since it is the mechanism through which the user will be warned of their pet's condition. Table 7 describes the type of notifications that will be sent depending on each situation. The notification type will be determined by the processing unit's integrated software and a signal will be sent to the mobile device via Bluetooth to be displayed as a notification on the application for the user to see. The second most important feature is the GPS tracking. The user will be able to view the location of their pet at all times, since, if the pet is unsafe, they know where to go to mitigate the situation.

This application will have a user-friendly graphical user interface (GUI), which will prompt the user for a radius delimitation, a name for the harness, and calibration steps for the heart rate monitor at first use. The radius delimitation, called 'backyard radius', will be a delimitation such that, if the pet leaves it, a notification will be sent, and the harness name is useful for users who have multiple pets and need a way to recognize each harness. The calibration will be done so that the system can recognize the pet's normal and elevated heart rate. At first use of the application, the user will be prompted to put the harness on their pet, and, once done, click on an 'OK' button. After this, the user will be asked to make sure that their pet is calm and still, and, once done, press 'OK' again. Finally, the user will be prompted to make their pet excited or move around, such that their heart rate is elevated, and click 'OK' a final time.

Once the application is initialized, the user will be able to see three tabs: one with all the notifications that were sent, organized by newest, another with the pet's live location from the GPS feature, and another with all the pictures taken by the harness, also organized by newest. On the top right corner, there will be a gear icon, symbolizing the settings of the application, in which the prompted options at the beginning, including the calibration, are available to be modified.

The features highlighted on the last paragraph show a substantial difference from the application made for the original project, which only sent alerts about creatures being detected. Our solution proposes to improve on that idea by adding additional features such as the GPS tracking and pictures, while improving on the alerts, which will be specific to the type of threat the pet might have encountered. As said before, the new solution focuses on the pet's condition rather than finding other creatures that could harm the pet.

Table 10 - Requirements and verification for Software Module.

Requirements	**Verification**
SWM-1: The graphical user interface on the application shall have a notification tab, a GPS tab and a picture tab.	A. When the user opens the mobile application, three tabs with “Notifications”, “GPS” and "Picture" labels will be visible in the application. B. When the user presses one of the tabs, the GUI will display the correct information associated with each tab.
SWM-2: The application shall have an option to change the harness name and the delimitation radius.	A. Once initially set up, the software application should have a gear icon that, when clicked , opens a settings page that has fields available to input the harness name and delimitation radius. B. When the user closes out of the page, the changed information should be visually seen in the app.
SWM-3: The application shall prompt the user for the calibration setup on first use.	A. On first use of the application on a test mobile device, the group members will check if the calibration setup is prompted on the screen while paired to an ESP32 not yet mounted on the harness while paired to an ESP32 not yet mounted on the harness. B. The user will go through the setup steps until they can use the app. C. Given that the ESP32 will not be attached to the harness at this point, the data gathered from the calibration process will be printed on the serial monitor of the Arduino IDE to check if they were saved.

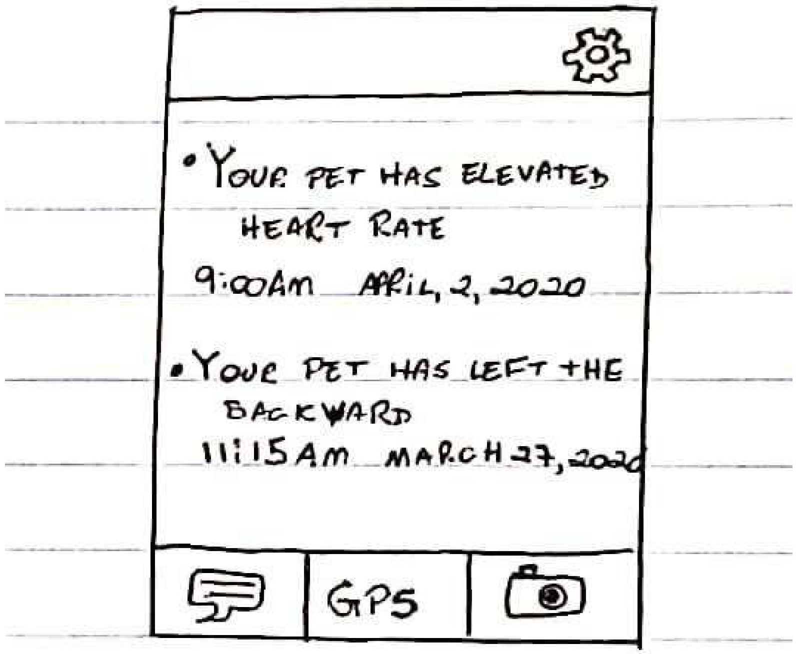

Figure 6 - Sketch of the software application; GUI and example notifications.

2.6 Tolerance Analysis

For devices created with the intent of detecting danger, the time it takes to recognize a threat is imperative to the system's success. Keeping the safety of the pet in mind, this device should be able to respond to an imminent threat within ten seconds of the animal being in danger. Therefore, an analysis was conducted on the timing of the data capture of the devices involved which could affect the timeliness of this response.

To begin this study, the flowchart corresponding to the integrated software in Figure 5 is observed. The heart rate monitor and accelerometer delays have very low amounts of data transferred and the small effect these devices have will be insignificant when compared with the other devices. Additionally, the control bit logic processed by the ESP32 microcontroller should operate very quickly due to the miniscule size of the control logic variables. The ESP32 has an 8 MHz oscillator which is used to process the internal data [35]. Gate delays involved at this stage will be very small when compared to some of the other processes that take a few seconds to complete. To get an accurate measurement for the accelerometer, data is taken over the course of two seconds on two separate occasions in the datapath. This totals to four seconds of accelerometer data capture. The most intensive data transfer operation involves the image obtained from the camera. Even in a compressed file format like a JPEG, the average file size is around 62.7 KB [36]. For this particular camera, the data transfer rate is listed as 14,400 bytes per second. Using the average value for the size of a JPEG image and this data transfer rate, the following results are achieved.

$$\frac{1}{14{,}400}\,\frac{seconds}{bytes} \times 62.7 \times 10^3 = 4.354\ seconds \qquad (2)$$

This same principle can be applied to the data transfer rate associated with Classic Bluetooth communication. Using Classic Bluetooth for ESP32 communications yields a data transfer rate of 235 kilobytes per second.

$$\frac{1}{235}\,\frac{seconds}{kilobytes} \times 62.7 = 0.266\ seconds \qquad (3)$$

The time for the mobile device to display the notification data is also considerably small in comparison to the rest of these times because the only data that needs to be processed are the notification bit and the control bits. The time for the mobile device screen to update with the notification will correspond to the refresh rate of the mobile device which is estimated to be 60 Hz. This would mean it would take about one sixtieth of a second for the user to see the notification which corresponds to 0.017 seconds. By composing the total of these times, the total time it should take for the owner to be alert of potential danger is 8.277 seconds which is less than the original ten second goal. While this time is not particularly fast, the timing can be greatly improved by reducing the image resolution which can be done with the camera selected. This will reduce the amount of image data necessary to transfer and can be implemented if the resulting response time is deemed too slow to detect danger. It is important to note that these calculations were done based on theoretical values found in the datasheets of the components used, and are not necessarily going to be reflected on the actual results during testing.

3 Differences

3.1 Overview

Per request of the ECE 445 professors, this project's problem is based off of a project completed in a previous year. The original solution to this problem was composed by Group 8 from the Fall 2019 semester. The device this group developed was a collar which could protect a pet by detecting the motion of a pest through a PIR sensor which would use temperature detection technology and infrared light to identify if the pet has encountered a threatening animal or person [5]. While the device accomplishes the task of detecting danger from other animals or humans in close proximity to the pet, there are many other forms of danger that would go unnoticed by the PIR sensor. The American Veterinary and Medical Association notes that the average household in the United States has 1.6 dogs indicating that having more than one pet is not an abnormality [37]. However, the device proposed and built by Group 8 does not have a method for distinguishing between a friendly pet and a dangerous pest.

To mitigate the problems present in the prior design, the revised design will focus on tracking the condition of the pet rather than the danger itself. To replace the function of the PIR sensor, the new design will use the heart rate monitor and accelerometer combination in the Processing Unit Module to track the pet's motion and heart rate. The accelerometer performs two functions, the first of which is detecting if the pet's motion is small enough to capture an accurate heart rate measurement. If this is indeed the case, the pet's heart rate will be captured for analysis. If this detected heart rate exceeds the boundary for a resting heart rate which is determined in the device calibration process, the accelerometer will begin performing its second function by analyzing the motion of the pet to achieve a more comprehensive analysis on the pet's condition. After a five second period, the maximum accelerometer data will be analyzed to determine the pet's motion directly after its heart rate has been detected as elevated. Then a notification will be sent to the owner about the potential variety of danger that the pet may be in. This notification will also include a message about whether or not the pet is currently moving based on the measurement detected by the accelerometer. The previous design also featured a notification system but neglected to include any additional information about the potential danger. By providing more knowledge to the owner about the pet's condition, the owner can make an educated decision about whether they need to check on their pet or not.

For the revised design, a picture is taken with a small camera on the harness which will be sent to the owner along with the notification. Similarly to the notification message about the pet's motion, this picture will help the owner indicate if the pet is in danger and, if so, the exact variety of danger the pet is in. Utilizing this photo capability allows this device to be applied to multiple pets because if one pet's heart rate rises because of the other, the other pet will appear in the captured image.

The new solution will also contain a GPS tracking system in which the animal's coordinates can be viewed on the owner's mobile device when requested by the owner. This way, if the pet is in danger, the user can reach their pet as fast as possible, since they will know where to go. Another feature which expands beyond the premise of the original design is a delimitation radius for the pet which can be set through the software application. When the pet moves outside of the radius set by the owner, the owner will get a warning notification that the pet may have run away. This solution can identify more potentially dangerous situations to the owner than the previous design and utilizes different technology for detecting the threat.

3.1 Analysis

While both the previous and revised designs include a danger detection device which would be mounted on the subject, the devices accomplish their goals in very different ways leading to a variety of technical differences between the two devices. A multitude of different components are used between the two systems which lead to differences in power requirements between the two devices. While the previous design uses eight AA batteries in series to produce 12 V, the revised design uses a LiPo battery to produce 7.4 V. Other than the small voltage differences between these two power supplies, the devices also have different weights. For this application, the weight of the device becomes an important factor because the animal should not be in any kind of discomfort while using the device. Unlike the LiPo battery, AA batteries can come in a variety of weights depending on if they are rechargeable or not. Taking Energizer as an example for their battery weights, using disposable batteries for this device would cause the power supply to weigh 113 grams and using rechargeable ones would cause the power supply to weigh 250 grams [38]. The weight of the LiPo battery being used is 167 grams, being right in the middle of the two other presented options. Despite being a little heavier than the 113 grams, it is still not a harmful amount of weight being added, especially when it is not concentrated on the neck of the pet, like the suggested collar from the original design. Using a LiPo battery also makes it possible for it to be rechargeable, which would include a wall outlet charging device if it were to actually be distributed. This choice was made so that the user could avoid purchasing extra sets of batteries for the device. Both devices also use linear voltage regulators to scale down voltages for use with the sensors. The design composed by Group 8 used voltage regulators to step down the voltage from 12 V to 5 V and then 5 V to 3.3 V to operate its associated components. The voltage regulators used by the revised design are all adjustable, which means the output can be adjusted by additional resistors to the exact drop needed, meaning the same regulator model will be used for all components. This circuit will be built on a PCB, that will also have the battery and ESP32 mounted, and will have slots for wires that connect the sensors to it.

The sensors involved also draw different current values. This can be relevant to the pet's safety while using the device because if the preventative measures for protecting the electronics fail, the dog may be put in danger by the current the device is drawing. The current can also have an effect on the power consumption of the device. Note that for this analysis the microcontrollers were not considered as their power consumption and current draw is highly dependent on the process that the microcontroller is handling at a given time. For the previous design, the sensor and electrical device current draw is estimated to be 214 mA and power consumption a little under 3 W [39] [40] [41]. The revised design current draw was estimated to be about 131 mA with a power consumption of during sensor and camera operation [16] [18] [23] [24]. Not using an LED strip in the revised design reduces the power consumption and replaces the LEDs with sensors that add to the danger detection capabilities of the device.

From the perspective of the owner, there are also significant changes made that allow for better tracking of their pet. For example, the software application now features GPS tracking which allows the owner to view the pet's coordinate position. The software application itself includes a variety of features necessary for the new design to operate as intended. A calibration process is needed to accurately measure the heart rate and detect danger. This software must also be able to display the image captured by the harness camera as well as display the coordinates of the animal on a map.

4 Costs

Development costs are $45/hour and each of the three team members is working at an estimated 8 hours/week. The work done for this project is at a reduced 8 weeks compared to the originally scheduled 16 weeks. Thus, the cost reflects this by multiplying a factor of 2 to the amount of time spent per week on the project and doubling the total cost. This yields a total estimated cost of:

$$3 \times \frac{\$45}{hour} \times \frac{16\ hours}{week} \times 8 weeks \times 2.5 \ = \$43,200 \tag{4}$$

In the design, the machine shop will mainly be responsible for modifying the project box by cutting a hole in it such that the different electronic components can be inserted. The precision of this modification should be good enough that the design does not lose its waterproof properties, nor should the modification cause discomfort to the animal. After this, they would then be responsible for ensuring that the design was as covered as possible. Altogether, this would take an estimated 3 hours to complete.

$$3\ hours \times \frac{\$50}{hour} \ = \ \$150 \tag{5}$$

Additionally, the project design uses Android Studio for software development, which is open source and free. Thus, no added costs will come from the software development.

Table 11 - Specific component costs for project’s design.

Description	Manufacturer	Quantity	Cost
Pet Harness	Idepet	1	$15.99
LiPo 7.4 V Battery	Ovonic	1	$18.99
MIC4576 Voltage Regulator	Microchip Technology	6	$26.46
NEO-6 u-blox 6 GPS Module	52Pi Technology	1	$25.99
0.3M Pixel Serial JPEG Camera Module	DFRobot	1	$45.00
ADXL363	Analog Devices	1	$10.29

SEN-11574	Sparkfun	1	$24.95
ESP32 Microprocessor	Espressif Systems	1	$10.99
Waterproof Case	uxcell	1	$7.63

Altogether, the estimated cost of the different components from the table above is estimated $186.29. The estimated cost of machine shop labor is $150 . The estimated cost of the entire project is $43,536.29.

5 Schedule

Table 12 - Schedule of designated tasks for each group member. This is done to ensure the project remains on pace for completion by the time of demonstration.

Week	**Jason** (working on ESP32 integrated software and Android operating system software application)	**Brant** (working on sensors and ESP32 interfacing as well as physical design)	**Talita** (working on ESP32 Bluetooth communications and power system management)
1	Download and install Android Studio IDE. Map out the necessary components of code for the app. This entails the GUI, settings, notifications, picture display, GPS tracking, as well as the software logic for determining the correct program execution.	Order required sensors for the project. Also order other components and physical devices. Discuss with the machine shop how to safely mount items on the harness to protect the animal. Contact Champaign County Humane Society to identify if there are any dogs which can be used to test this product.	Order battery and ESP32. Design PCB with battery circuit and ESP32 integrated.
2	Ensure that the ESP32 microprocessor can effectively use the Arduino IDE for development. Develop data routing and memory storage necessary for design. Continue working on internal logic of Android app.	Conduct unit tests on the sensors and begin the requirement and verification process for the Processing Unit Module.	Design PCB if not done and order it. Test battery and ESP32 connectivity with a mobile device and begin requirement and verification process for the Communication Module.
3	Develop code that has the ability to be used such that the data used can display both notifications and pictures. Begin Development of GUI for the Android app.	Continue the requirement and verification process for the Processing Unit Module.	If the PCB has arrived, start soldering components necessary for battery integration. Finish requirement and verification process for the Communication Module. Continue

			testing ESP32's connectivity and collaborate with Brant to test it with each component at a time.
4	Collaborate with Talita to ensure that the data from the ESP 32 can be read to the mobile device and used accordingly to be used for the app.	Finish the requirement and verification process for the Processing Unit Module. Order new components if necessary and document changes to the design. Assist Jason in finishing the integrated software for the ESP32 microcontroller using knowledge obtained from working with the sensors.	Continue testing ESP32 with each component to make sure they can communicate. Collaborate with Jason to work on sending data from the ESP32 to a mobile device via Bluetooth.
5	Develop GPS Live tracking feature and integrate it into the android app.	Assemble components onto the harness with ESP32 controller. Test the harness on the dog to ensure the sensors take accurate data while the dog is wearing the harness.	Assist Brant on assembling components onto the harness. Continue collaborating with Jason on Bluetooth connectivity and data transfer.
6	Complete full analysis of code and debug the program if necessary. Prepare for use with the software application and if ready perform complete test.	Revise any issues from testing during the previous week and order new components if necessary. Prepare for use with the software application and if ready perform complete test.	Revise any issues from testing during the previous week and order new components if necessary. Prepare for use with the software application and if ready perform complete test.
7	Test device to ensure any issues from the previous week are resolved. Test full integration with use of the software	Test device to ensure any issues from the previous week are resolved. Test full integration with use of the software	Test device to ensure any issues from the previous week are resolved. Test full integration with use of the software

	application.	application.	application.
8	Make any revisions from failures during testing and verify high level requirements during demonstration.	Make any revisions from failures during testing and verify high level requirements during demonstration.	Make any revisions from failures during testing and verify high level requirements during demonstration.

6 Safety and Ethics

The IEEE Code of Ethics was used as a reference to make design decisions for this project. In particular, the nature of the design required the group to heavily focus on policy numbers one, three, seven and nine. The first code referenced in the IEEE Code of Ethics states that this design should “hold paramount the safety, health and welfare of the public, to strive to comply with ethical design and sustainable practices, and promptly disclose any factors that might endanger the public or environment [42].” When working with any electrical or non-electrical device, the safety of the user is a primary concern, especially when the intention of the design is to promote the safety of individuals and their pets. Code number three directly references the honesty and realism of the experiment being conducted [42]. This was an important criteria for developing this design largely due to the importance of receiving accurate data from the sensors and interpreting it correctly. For example, a variety of sensors are used in this design along with the camera to provide the owner with honest measurements of the pet’s condition by attempting to be as comprehensive as possible. As a revision of a previous year’s project, it was also important to consider the effects of IEEE 7.8 Safety and Ethics #7 which covers accepting criticism of technical work, identifying and amend errors and crediting sources which contribute to the work performed [42]. With this design, Group 45 seeks not only to revise the design of Group 8 from the Fall 2019 semester but improve on the concepts it introduced to create technological advancements in the field of animal health and science. Furthermore, any contributions derived from the previous project’s design architecture were carefully cited to ensure the intentions and originality of various components of this design are clear and all parties are credited for their respective work. The ninth code referenced by the IEEE Code of Ethics pertains to avoiding injuring or harming others “by false or malicious action [42].” Similarly to codes one and seven, this incentivises honesty and transparency in development to avoid injuring other parties both physically and in reputation. Due to safety being a primary concern in the development of this technology, this requirement was carefully followed .

All of the other codes were also carefully adhered to but many were followed naturally by the guidelines given for the project and by consequence of other design decisions made. For example, IEEE 7.8 Safety and Ethics Code #4 refers to rejecting bribery in all forms which is irrelevant to this design considering there is no manufacturing that will occur and there are no plans to commercialize the device. Another example of this can be seen in Code #2 which states that conflicts with other parties will be avoided and no conflicts of interest will occur. Because the only other parties involved with this design are the sources used for the development of its architecture there should be no other conflicts of interests that would occur outside of ensuring each source is cited properly. Following this standard is a result of closely following IEEE Codes #7 and #9.

Though for the most part, the pet threat detector is based on providing an added layer of security for pets, there still are some potential hazards that are present. One of the biggest concerns is how the electromagnetic radiation could harm the pets while the device is in use. High frequency electromagnetic radiation can have a harmful effect on biological tissue [43], which could potentially cause more harm than good for the pet wearing the device. This concern pertains to the safety of the public and must be considered in adherence to the first policy of the IEEE Code of Ethics [42]. Despite these concerns, the actual device specifications do not actually call for the use of signals that would be different than that of a cell phone signal. Both humans and animals are frequently exposed to signals of similar magnitude by using electronic devices in close proximity. While the impact from this is non-zero it also has a comparatively insignificant impact on the lifetime of the pet and would provide greater benefits to its safety than detriments. If this product were to be commercialized, the product packaging would include a disclaimer about this impact and its effects on pets.

Another concern is largely related to the use of attaching a battery-using device to a pet in order to operate the device. Different environmental factors such as excessive heat or precipitation could cause the battery to catch on fire, explode, or leak its contents, which would be detrimental to the health of a pet. In accordance with this, different preventative measures mentioned previously on the power supply module and on the risk analysis will be taken such that the risks are as low as possible. One of these measures is to conceal the battery in an enclosure and have that inside the physical harness itself, covered by a high durability fabric such as polyester. Another environmental risk occurs from the electronics becoming exposed to liquids and shorting connections in the process. Everyday waterproof materials were selected for the harness and electrical project box to prevent harm to the animal during use in rainy weather conditions. Despite this, everyday waterproof materials are not designed to be submerged and doing so could risk damaging the device or harming the animal. Therefore, if this product were to be manufactured, a label would be included on the packaging as a disclaimer and warning to not use the system under water. Consequences associated with misusing the product would also be made clear, notifying the owner that incorrect use could cause severe harm to the device or their beloved pet.

The ethics of using various collars and harnesses as a means of restraining animals has been called into question before, especially with dogs. Several varieties of collars cause physical pain, stress and anxiety for dogs when used to restrain them. This would be in violation of the first policy of the IEEE Code of Ethics [42]. For this reason, considerations were taken in the design process to avoid harming pets in use. The non-profit organization People for the Ethical Treatment of Animals (PETA) recommends the use of harnesses to alleviate tension in the neck and to avoid spinal cord injury while in use. For this reason, dogs should be relatively safe when using this device. PETA’s harness and collar safety guidelines were also used as a baseline for determining how devices should be protected to provide the safest environment for the pet [44].

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